DCE 1.2.2 Application Development Guide—Core Components

OSF® DCE Product Documentation

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Preface

The Open Group

The Open Group is the leading vendor-neutral, international consortium for buyers and suppliers of technology. Its mission is to cause the development of a viable global information infrastructure that is ubiquitous, trusted, reliable, and as easy-to-use as the telephone. The essential functionality embedded in this infrastructure is what we term the IT DialTone. The Open Group creates an environment where all elements involved in technology development can cooperate to deliver less costly and more flexible IT solutions.

Formed in 1996 by the merger of the X/Open Company Ltd. (founded in 1984) and the Open Software Foundation (founded in 1988), The Open Group is supported by most of the world's largest user organizations, information systems vendors, and software suppliers. By combining the strengths of open systems specifications and a proven branding scheme with collaborative technology development and advanced research, The Open Group is well positioned to meet its new mission, as well as to assist user organizations, vendors, and suppliers in the development and implementation of products supporting the adoption and proliferation of systems which conform to standard specifications.

With more than 200 member companies, The Open Group helps the IT industry to advance technologically while managing the change caused by innovation. It does this by:

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- managing cost-effective development efforts that accelerate consistent multi-vendor deployment of technology in response to customer requirements
- adopting, integrating, and publishing industry standard specifications that provide an essential set of blueprints for building open information systems and integrating new technology as it becomes available
- licensing and promoting the Open Brand, represented by the “X” mark, that designates vendor products which conform to Open Group Product Standards
- promoting the benefits of IT DialTone to customers, vendors, and the public.

The Open Group operates in all phases of the open systems technology lifecycle including innovation, market adoption, product development, and proliferation. Presently, it focuses on seven strategic areas: open systems application platform development, architecture, distributed systems management, interoperability, distributed computing environment, security, and the information superhighway. The Open Group is also responsible for the management of the UNIX trademark on behalf of the industry.

The Development of Product Standards

This process includes the identification of requirements for open systems and, now, the IT DialTone, development of CAE and Preliminary Specifications through an industry consensus review and adoption procedure (in parallel with formal standards work), and the development of tests and conformance criteria.

This leads to the preparation of a Product Standard which is the name used for the documentation that records the conformance requirements (and other information) to which a vendor may register a product. There are currently two forms of Product

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CAE (Common Applications Environment) Specifications are the stable specifications that form the basis for our Product Standards, which are used to develop X/Open branded systems. These specifications are intended to be used widely within the industry for product development and procurement purposes.

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Preliminary Specifications usually address an emerging area of technology and consequently are not yet supported by multiple sources of stable conformant implementations. They are published for the purpose of validation through implementation of products. A Preliminary Specification is not a draft specification; rather, it is as

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Preliminary Specifications are analogous to the trial-use standards issued by formal standards organizations, and developers are encouraged to develop products on the basis of them. However, experience through implementation work may result in significant (possibly upwardly incompatible) changes before its progression to becoming a CAE Specification. While the intent is to progress Preliminary Specifications to corresponding CAE Specifications, the ability to do so depends on consensus among Open Group members.

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In addition, The Open Group publishes:

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This includes product documentation—programmer's guides, user manuals, and so on—relating to the Prestructured Technology Projects (PSTs), such as DCE and CDE. It also includes the Single UNIX Documentation, designed for use as common product documentation for the whole industry.

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This Book

The *DCE 1.2.2 Application Development Guide* provides information about how to program the application programming interfaces (APIs) provided for each OSF® Distributed Computing Environment (DCE) component.

Audience

This guide is written for application programmers with UNIX operating system and C language experience who want to develop and write applications to run on DCE.

Applicability

This revision applies to the OSF® DCE Release 1.2.2 offering and related updates. See your software license for details.

Purpose

The purpose of this guide is to assist programmers in developing applications that use DCE. After reading this guide, you should be able to program the Application Programming Interfaces provided for each DCE component.

Document Usage

The *DCE 1.2.2 Application Development Guide* consists of three books, as follows:

- *DCE 1.2.2 Application Development—Introduction and Style Guide*
  Document Number F202, ISBN 1–85912– 187–X
- *DCE 1.2.2 Application Development Guide—Core Components*

— Volume 1
Document Number F203A, ISBN 1–85912–192–6

Part 1. DCE Facilities

Part 2. DCE Threads

Part 3. DCE Remote Procedure Call

— Volume 2
Document Number F203B, ISBN 1–85912–154–3

Part 4. DCE Distributed Time Service

Part 5. DCE Security Service

• *DCE 1.2.2 Application Development Guide—Directory Services*
Document Number F204, ISBN 1–85912–197–7

— Part 1. DCE Directory Service

— Part 2. CDS Application Programming

— Part 3. GDS Application Programming

— Part 4. XDS/XOM Supplementary Information

Related Documents

For additional information about the Distributed Computing Environment, refer to the following documents:

• *DCE 1.2.2 Introduction to OSF DCE*
Document Number F201, ISBN 1–85912–182–9

• *DCE 1.2.2 Command Reference*
Document Number F212, ISBN 1–85912–138–1

• *DCE 1.2.2 Application Development Reference*
Document Number F205A, ISBN 1–85912–103–9 (Volume 1)
Document Number F205B, ISBN 1–85912–108–X (Volume 2)
Document Number F205C, ISBN 1–85912–159–4 (Volume 3)

• *DCE 1.2.2 Administration Guide—Introduction*
Document Number F207, ISBN 1–85912–113–6

- *DCE 1.2.2 Administration Guide—Core Components*
  Document Number F208, ISBN 1–85912–118–7
- *DCE 1.2.2 DFS Administration Guide and Reference*
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  Document Number F210, ISBN 1–85912–189–6
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  Document Number F218, ISBN 1–85912–168–3

Typographic and Keying Conventions

This guide uses the following typographic conventions:

Bold — **Bold** words or characters represent system elements that you must use literally, such as commands, options, and pathnames.

Italic — *Italic* words or characters represent variable values that you must supply. *Italic* type is also used to introduce a new DCE term.

`Constant width` — Examples and information that the system displays appear in `constant width` typeface.

[ ] — Brackets enclose optional items in format and syntax descriptions.

{ } Braces enclose a list from which y ou must choose an item in format and syntax descriptions.

| A vertical bar separates items in a list of choices.

<> Angle brackets enclose the name of a key on the keyboard.

... Horizontal ellipsis points indicate that you can repeat the preceding item one or more times.

This guide uses the following keying conventions:

<Ctrl-*x***>** or ^*x*
: The notation **<Ctrl-** *x* **>** or ^*x* followed by the name of a key indicates a control character sequence. For example, **<Ctrl-C>** means that you hold down the control key while pressing **<C>**.

<Return> The notation **<Return>** refers to the key on your terminal or workstation that is labeled with the word Return or Enter, or with a left arrow.

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Pathnames of Directories and Files in DCE Documentation

For a list of the pathnames for directories and files referred to in this guide, see the *DCE 1.2.2 Administration Guide—Introduction* and *DCE 1.2.2 Testing Guide*.

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Part 1

DCE Facilities

Chapter 1

Introduction to DCE Facilities

By now you are aware that DCE consists of a number of major components, each of which addresses some necessary aspect of distributed computing: DCE Threads make programs more efficient by allowing parallel execution of portions of code, remote procedure calls (RPCs) hide network details from applications, the DCE Time Service gives consistent time to widely scattered cells and hosts, the DCE Security Service gives programs assurances that users and other programs are who they say they are and that they are authorized to do what they are supposed to do, and the DCE Directory Service helps clients find servers and other resources. For most applications, a DCE component is not used by itself, but the components all work together to create a very useful and powerful environment.

The more you understand DCE and its components, the more you'll realize that a strict division by component is not always clear. The document set for DCE is organized by component mostly for the convenience of people trying to explain and understand DCE, but applications often contain a blend of aspects of all the components. This is why it often seems like the information you need to do your work is scattered across many chapters or volumes, and why advanced or unusual features seem to be described along-side basic or typical tasks. DCE also has some special facilities that just do not fit neatly into any one discussion of a DCE component, and these are

the facilities we describe in this first part of the *DCE 1.2.2 Application Development Guide—Core Components*.

You should read the *DCE 1.2.2 Application Development—Introduction and Style Guide* prior to using the DCE facilities described here, and you may want to skip to other parts of this guide before learning details about the DCE facilities.

Most DCE facilities are already used by one or more major components of DCE to accomplish some feature they require; others are standalone facilities intended to make developing distributed applications easier. These facilities are described separately here so that you can use them for your own applications too. The DCE facilities include the following:

- Host Services

  Host services give remote access to several kinds of data and functionality with respect to each DCE host and its servers. Each host runs a DCE host daemon (**dced**) as the interface to the host services. In many cases, **dced** automatically maintains the data and performs the functions. Some of the data that you can access (and maintain) remotely includes the host name, the host's cell name, configuration and execution data for all servers on the host, and a database of endpoints (server addresses) through which running servers can be contacted. Some of the functions that you can remotely perform include starting and stopping servers.

- Application Message Service

  This service provides a convenient way to manage readable character strings of information that are usually displayed to application users. The service uses message catalogs to maintain message text and explanations separate from the program so that language, cultural, or other site-specific issues are easily managed for applications. The message text can also be in memory during program execution for more efficient programs.

- Serviceability

  Serviceability is another kind of message text service with functionality beyond just the display of general-purpose text. Serviceability is typically used for message text about a server's activity. Messages can be displayed through standard output or standard error, or they can be routed to log files. The serviceability facility maintains message text in catalogs (or memory) just as the application message service does; but, in addition to the text and its explanation, additional attributes specify subcomponents (program modules), message severity, the action users or programs should take, and the debug level.

- Backing Store Database Service

  You use a backing store to maintain typed data between invocations of applications. For example, you could store application-specific configuration data in a backing store, and then, when the application restarts, it could read the previous configuration from the backing store. Data is stored and retrieved by a Universal Unique Identifier (UUID) or character string key, and each record (or data item) may have a standard header if you wish.

As DCE has developed and improved, useful facilities such as serviceability have been added to make DCE easier and more useful. For example, serviceability makes a distributed application much easier to develop. With it, you can log and distinguish debug messages from complex applications involving multiple clients, servers, and threads. Although the major components are required to make DCE work, this kind of facility is not required.

Some solutions developed to implement a major component's feature can also prove useful to your applications. For example, the security component must have a way to maintain access control lists (ACLs). While the backing store was developed to handle this kind of task, you can use this facility to store your own application-specific data across invocations.

This first part of the *DCE 1.2.2 Application Development Guide—Core Components* describes how you might put these useful facilities to work in your applications.

Chapter 2

DCE Host Services

Every DCE host must maintain certain kinds of data about itself and the servers it provides. For example, each host stores configuration data about its DCE environment, and it also stores data about servers registered and running on the host. In addition, each host needs some services to not only manage this data but also to administer the host and DCE servers. For example, a service that can start and stop specific servers has obvious value. The DCE host services consist of the following:

- Endpoint Mapper

  The endpoint mapper service enables a client to find servers on a particular host and the services and objects provided by those services. This service maintains on each host an endpoint map that contains a mapping of port addresses (endpoints) to servers, the services servers provide, and the objects servers manage.

- Hostdata Management

  The hostdata management service stores and controls access to such data as the host's cell name, the host name, and the cell alias names, among other things.

- Server Management

The server management service can start and stop specified servers on a host, enable or disable specific services provided by a server, and manage configuration and execution data about these servers.

- Security Validation

  The security validation service maintains a login context for the host's identity of itself, maintains the host principal's keys, and ensures applications (especially login programs) that the DCE security daemon (**secd**) is genuine.

- Key Table Management

  A server uses private keys for its security instead of human-entered passwords. The key table management service can be used to manage the keys stored in key tables on a server's host.

Of course, in a distributed environment, these data and services must be easily yet securely accessible from other hosts. The DCE host daemon (**dced**) is a continuously running program on each host that provides access to the host services either locally on that host or remotely from another host.

2.1 Types of Applications

Although applications may need some aspect of these host services (control over which services are enabled for a particular server, for example), typical servers do not have to do any special coding for them. This reduces the size and complexity of server code and keeps the details of administration out of applications. It also removes the burden of server administration so you can concentrate on the application's business functionality.

System administrators will appreciate this development model too because it is unlikely that many servers implementing their own administrative mechanisms will all behave in the same manner. Administrators commonly use the DCE control program, **dcecp**, to access the host services (via **dced**) of any host in their distributed environment (provided the user has the appropriate permissions). The DCE control program also uses a script language for more sophisticated administration. See the *DCE 1.2.2 Administration Guide—Core Components* for more on using **dcecp** to access the host services.

Although **dcecp** commands offer an administrator a great deal of control over DCE hosts and servers, a set of APIs are also supplied for application developers who need to access the DCE host services from an application rather than from scripts or the operating system's command line.

Typical business applications do not use the APIs of these services, but a *management application* might. A management application is a client or server that manages other servers or some aspect of the distributed environment. (The **dced** program is itself a management application that is built into DCE.) Some other types of applications that might use these API include

- Applications that control other servers for load balancing or server redundancy.
- An application that uses a graphical user interface (GUI) instead of the command-line interface provided by **dcecp**.
- An application that needs to monitor a server's current state. For example, an application may need to make sure a particular server or one of its services is available.

2.2 Issues of Distributed Applications

The most important aspect of **dced** is that it gives system administrators the ability to remotely manage services, servers, endpoints, and even objects on any host in DCE. This eliminates the frustrating and tedious task of logging into many different hosts to manage them. This also allows for scalability because it is impractical to manage a large system by logging into all its hosts.

The features of **dced** are greatly enhanced when used remotely. Of course, an administrator can use **dced** to locally manage a host's services, but **dced**'s real power is in remotely managing system and application server configurations, key tables, server startup, login configurations, and cell information.

Security becomes a major issue when it comes to remote services. With the power of **dced**'s services and **dcecp**, it is important that only authorized principals can use them. The **dced** program controls access to its various objects by using ACLs. Server keys are security-sensitive data that must be seldom transmitted over the network. All key table data is encrypted when it is transmitted for secure remote key table management.

Finally, the remote capabilities of **dced** give you real-time status of processes and services in DCE.

2.3 Managing a Host's Endpoint Map

Each DCE host has an endpoint map that contains a mapping of servers to endpoints. Each endpoint map server entry is associated with an array of services (interfaces) provided by the server, and each service is associated with an array of objects supported by the service.

When a typical server calls the **dce_server_register()** routine, the RPC runtime generates the endpoints on which the server will listen for calls and then uses **dced**'s endpoint mapper service of the local host to register the endpoints. Later, when a typical client makes a remote procedure call, its RPC runtime uses the server host's endpoint mapper service to find the server. When the typical server shuts down, it calls the **dce_server_unregister()** routine to remove its endpoints from the endpoint map so that clients do not later try to bind to it.

Applications can also use the lower-level **rpc_ep_register()** and associated RPC routines. Because the endpoint map is essential for RPCs to work, endpoints are fully described in Chapter 12 and the endpoint map structure is described with respect to routing of RPCs in Chapter 16.

The endpoint map is for the most part maintained automatically by **dced**. For example, it periodically removes stale endpoints so that the RPC runtime will not try to complete a binding for a client to a server that is no longer running. However, administrative applications may find it necessary to peruse a remote endpoint map and even remove specific endpoints from a local host's endpoint map.

To read the elements of a remote endpoint map, applications use a loop with the set of routines **rpc_mgmt_ep_elt_inq_begin()**, **rpc_mgmt_ep_elt_inq_next()**, and **rpc_mgmt_ep_elt_inq_done()**. The inquiry can return all elements until the list is exhausted, or the inquiry can be restricted to return elements for the following:

- Elements matching an interface identifier (UUID and version number)
- Elements matching an object UUID
- Elements matching both an interface identifier and object UUID

Administrators can manage the endpoint map by using **dcecp** with the **endpoint** object.

You can use the **dced_server_disable_if()** routine to mark as disabled all the endpoints for a specific interface. This will prevent any new RPCs with partial bindings from binding to the server for this interface, but not prevent clients from using the interface if they already have a full binding with these endpoints. You can use the **dced_server_enable_if()** routine to reenable previously disabled interfaces. In an extreme situation, you could permanently remove endpoints directly from the local endpoint map by calling the **rpc_mgmt_ep_unregister()** routine. This function cannot be done remotely for security reasons.

2.4 Binding to dced's Services

When you write a program that uses a host service, you begin by creating a **dced** binding to the service on a particular host. Bindings are relationships between clients and servers that allow them to communicate. A **dced** binding is a specific kind of binding that not only gives your application a binding to the **dced**[1] server but also associates the binding with a specific host service on that server.

In general, an application follows these basic steps to use a host service:

1. Establish a binding to the service on the desired host. For example, your application can establish a binding to the host data management service on another host.
2. Obtain one or more **dced** entries for that service. For example, your application can obtain the **hostdata** entry that identifies the host's cell name, among other things. This step is valid for the following services:
   - hostdata management
   - server management
   - key table management

1. Applications must establish a binding to each host service used. However, the endpoint mapper service uses a different binding mechanism and API from the other host services. This is due to the fact that the endpoint mapper service already existed within the very large RPC API in earlier versions of DCE, prior to the development of **dced**.

Depending on the service and function desired, this step may or may not be necessary. For example, the security validation service does not store data, so **dced** maintains no entries for this service.

3. Access (read or write) the actual data for the entries obtained or perform other functions appropriate for the service. For example, if your application reads the hostdata management service's cell name entry, the API accesses **dced** which may actually read the data from a file. For another example, if your application established a binding to the security validation service, it could validate the security daemon.

4. Release the resources obtained in step 2.

5. Free the binding established in step 1.

Applications bind to a host service by using the **dced_binding_create()** or **dced_binding_from_rpc_binding()** routine. The first routine establishes a **dced** binding to a service on a host specified in a service name, and the second routine establishes a **dced** binding to a service on a host for which the application already has a binding. Both of the routines return a **dced** binding handle of type **dced_binding_handle_t**, which is used as an input parameter to all other **dced** API routines.

2.4.1 Host Service Naming in Applications

Applications include a host service name as input to the **dced** binding routine **dced_binding_create()**. A host service name is a string that may include a host name, or a cell and host name. The following key words in the host service name refer to a specific DCE host service:

hostdata Refers to configuration data of the hostdata management service.

srvrconf Refers to the static server configuration portion of the server management service. This refers to the management of a DCE-installed server.

srvrexec Refers to the dynamic server execution portion of the server management service. This refers to the management of a running DCE-installed server.

secval Refers to the security validation service.

keytab Refers to the private key data of the key table management service.

The following examples show service names and the locations of the hosts in the namespace:

service The host is local, the same as the application's.

service@**hosts/***host*
The host is in the local namespace.

/.:/hosts/*host***/config/** *service*
The complete specification for *service*@**hosts/** *host* where the host is in the local namespace.

/.../*cell***/hosts/** *host***/config/** *service*
The host is in the global namespace.

Because the **dced_binding_from_rpc_binding()** routine already knows which host to bind to from an RPC binding input parameter, it uses one of the global variables defined for each service (instead of a string) to specify which **dced** service to use.

2.4.2 The dced Program Maintains Entry Lists

One **dced** service's data is very different from another's (for example, server configuration data versus key table data), but you manipulate the data in a similar way. This is because it is a simpler and more efficient design to implement a few API routines that can handle more than one kind of data rather than many routines that do essentially the same thing but on a different service's data. An added benefit is a flexible API that can handle your own application's data and new kinds of DCE data in the future.

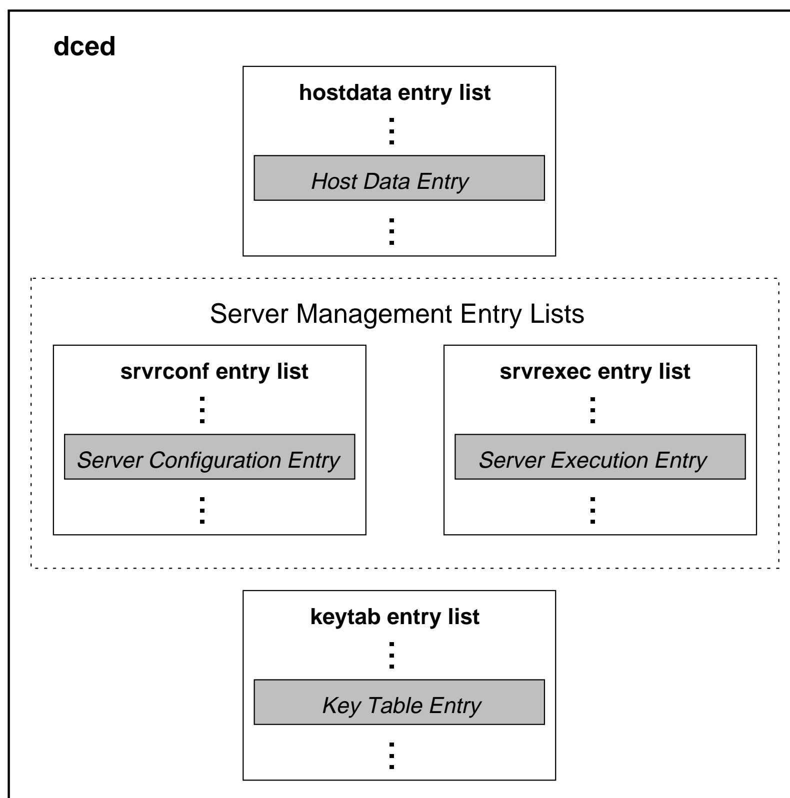
To separate the actual data from the API implementation, a **dced** service maintains a list of all data items in an *entry list*. Entry lists contain *entries* that describe the name and location of each item of data, but they do not contain the actual data. With this mechanism, **dced** can obtain and manipulate data very efficiently, without concern for the implementation and location of the actual data. It also supports well the model that administrators commonly need when accessing data: scan a list, select an item, and use the data.

The **dced** program maintains entry lists for the **hostdata**, **srvrconf**, **srvrexec**, and **keytab** services. The **secval** service does not need an entry list because it does not maintain any data, but functions are performed to set its state.

There is a special relationship between **srvrconf** and **srvrexec** entries. In order for **dced** to control the start of a server, the server must have a **srvrconf** entry associated with server configuration data. When **dced** starts a server, it generates from the **srvrconf** entry and data a **srvrexec** entry and associates the new entry with the running server's state.

Figure 2-1 shows the entry lists maintained by **dced**.

Figure 2–1. The dced Entry Lists



Although an entry can be associated with many different kinds of data items, all entries have the same structure, shown in Figure 2-2.

Figure 2–2. Structure of an Entry

Entry UUID, Name, Description, Storage Tag

Each entry is a **dced_entry_t** data structure. Each member of this data structure is described as follows:

id An entry UUID is necessary to uniquely identify the data item. Some data items have well-known UUIDs (the same UUID for the particular item on all hosts). The data type is **uuid_t**.

name Each data item is identified with a name, to which applications refer. The name need only be unique within an entry list because the entry UUID guarantees the entry's uniqueness. Some item names are well-known and defined in header files. The data type is **dced_string_t**.

description This is a human-readable description of the data item. Its data type is **dced_string_t**.

storage_tag The storage tag locates the actual data. Each service *knows* how to interpret this tag to find the data. For example, some data is stored in a file, the name of which is contained in the storage tag. Other data is stored in memory and the storage tag contains a pointer to the memory location. The data type is **dced_string_t**.

2.4.3 Reading All of a Host Service's Data

Suppose you want to display host service data in an application that has a graphical user interface. The **dcecp** commands may not be adequate to display data for this application. The following example shows how to obtain the entire set of data for each host service:

```
dced_binding_handle_t   dced_bh;
dced_string_t           host_service;
```

```
void                    *data_list;
unsigned32              count;
dced_service_type_t     service_type;
error_status_t          status;
 .
 .
 .
while(user_selects(&host_service, &service_type)){ /*application*/
                                                         /*specific*/
    dced_binding_create(host_service,
          dced_c_binding_syntax_default,
                 &dced_bh,
          &status);
    if(status == error_status_ok) {
        dced_object_read_all(dced_bh, &count, &data_list, &status);
        if(status == error_status_ok) {
            display(service_type, count, data_list);    /* application*/
                                                        /* specific*/
            dced_objects_release(dced_bh, count, data_list, &status);
        }
        dced_binding_free( dced_bh, &status);
    }
}
```

user_selects()

This is an example of an application-specific routine that constructs the complete service name from host and service name information. Data is stored and retrievable for the **hostdata**, **srvrconf**, **srvrexecD**, and **keytab** services. No data is stored for the **secval** service.

dced_binding_create()

Output from the **dced_binding_create** routine includes a **dced** binding handle whose data type is **dced_binding_handle_t**. If an application already has an RPC binding handle to a server on the host desired, it can use the **dced_binding_from_rpc_binding()** routine to bind to **dced** and one of its host services on that host. (Applications also use these routines to bind to the **secval** service to perform other functions.)

dced_object_read_all()
Applications use the **dced_object_read_all()** routine to read data for all the objects in an entry list. The output includes the address of an allocated buffer of data and a count of the number of objects the buffer contains. The data type in the buffer depends on the service used.

display() This is an application-specific routine that displays the data. Before the data is displayed, it must be interpreted depending on the service. The **hostdata** data is an array of **sec_attr_t** data structures, the **srvrconf** and **srvrexec** data are arrays of **server_t** structures, and the **keytab** data is an array of **dced_key_list_t** structures. The following code fragments show the data type for each service:

```
void display(
dced_service_type_t service_type, /* dced service type */
int                 count,   /* count of the number of data items */
void                *data)   /* obtained from dced_object_read{_all}()*/
{
    sec_attr_t               *host_data;
    server_t       *servers;
    dced_key_list_t          *keytab_data;
    .
    .
    .
    switch(service_type) {
    case dced_e_service_type_hostdata:
        host_data = (sec_attr_t *)data;
        . . .
    case dced_e_service_type_srvrconf:
        servers = (server_t *)data;
        . . .
    case dced_e_service_type_srvrexec:
        servers = (server_t *)data;
        . . .
    case dced_e_service_type_keytab:
        keytab_data = (dced_key_list_t *)data;
        . . .
    default:
        /* No other dced service types have data to read. */
```

```
        break;
    }
    return;
}
```

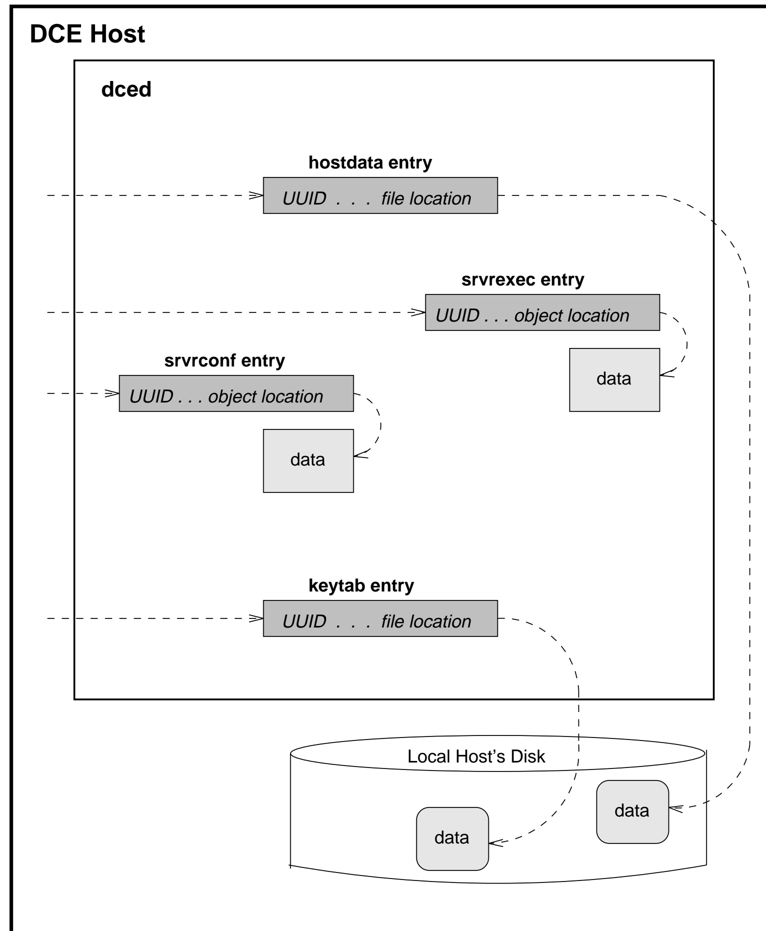
dced_objects_release()
Each call to the **dced_object_read_all()** routine requires a corresponding call to **dced_objects_release()** to release the resources allocated.

dced_binding_free()
Each call to the **dced_binding_create()** routine requires a corresponding call to **dced_binding_free()** to release the resources for the binding allocated.

2.4.4 Managing Individual dced Entries

Figure 2-3 shows examples of individual **dced** entries and the locations of associated data. The data item name or its UUID is used to find an entry, and then the storage tag is used to find the data.

Figure 2–3. Accessing Hostdata



The data for each **hostdata** item is stored in a file on disk. The **dced** program uses the UUID to find the entry in the **hostdata** entry list. The entry's storage tag is then used to find the data. For **hostdata**, the tag contains a filename in OSF's reference implementation. The data returned for one entry is an array of strings in a **sec_attr_t** structure.

The server management data is stored in memory. The **dced** program uses UUIDs (maintained in the entry lists by **dced**) to find an entry. The location of the data in

memory is indicated by the storage tag. The data returned for one entry is a structure of server data (**server_t**). All data for the **srvrconf** and **srvrexec** entries are accessed from memory for fast retrieval, but the **srvrconf** data is also stored on disk for use when a host needs to reboot.

Each **keytab** entry stores its data in a file on disk. However, like the server management entries, the **keytab** entries use server names and corresponding UUIDs (maintained by **dced**) to identify each entry. The storage tag contains the name of the key table file. The data returned for one entry is a list of keys of type **dced_key_list_t**.

The following example shows how to obtain and manage individual entries for the **hostdata**, **srvrconf**, **srvrexec**, or **keytab** services:

```
handle_t                rpc_bh;
dced_binding_handle_t   dced_bh;
dced_entry_list_t       entries;
unsigned32              i;
dced_service_type_t     service_type;
void                    *data;
error_status_t          status;
 .
 .
 .
dced_binding_from_rpc_binding(service_type, rpc_bh, &dced_bh, &status);
if(status != error_status_ok)
    return;
dced_list_get(dced_bh, &entries, &status);
if(status == error_status_ok) {
  for(i=0; i<entries.count; i++) {
    if( select_entry(entries.list[i].name) ) {/* application specific */
        dced_object_read(dced_bh, &(entries.list[i].id), &data, &status);
        if(status == error_status_ok) {
            display(service_type, 1, &data);  /* application specific */
            dced_objects_release(dced_bh, 1, data, &status);
            }
        }
    }
    dced_list_release(dced_bh, &entries, &status);
}
```

```
dced_binding_free(dced_bh, &status);
```

Each routine is described as follows:

dced_binding_from_rpc_binding()
The **dced_binding_from_rpc_binding()** routine returns a **dced** binding handle whose data type is **dced_binding_handle_t**. This binding handle is used in all subsequent **dced** API routines to access the service. The host is determined from the RPC binding handle, *rpc_bh*, and the *service_type* is selected from the following list:

- **dced_e_service_type_hostdata**
- **dced_e_service_type_srvrconf**
- **dced_e_service_type_srvrexec**
- **dced_e_service_type_keytab**

dced_list_get()
Applications use the **dced_list_get()** routine to get a service's entire list of names. Using the **dced_list_get()** routine gives your application great flexibility when manipulating entries in an entry list. If you prefer, your application can use the **dced_entry_cursor_initialize()**, **dced_entry_get_next()**, and **dced_entry_cursor_release()** set of routines to obtain individual entries, one at a time.

select_entry()
This is an application-specific routine that selects which entry to use based on the entry name.

dced_object_read()
The default attribute for **dced_object_read()** is to return an array of strings. The **hostdata** and **keytab** services have other read routines that allow you to specify binary data.

display() This is an example of an application-specific routine that simply displays the server configuration data read. Depending on the service, a different data structure is used. For the **hostdata** service, a **sec_attr_t** is used. For the **srvrconf** and **srvrexec** services **server_t** structures are used. For the **keytab** service, a **dced_key_list_t** structure is used.

dced_objects_release()
After your application is finished with the data read with the **dced_object_read()** routine, free the buffer of allocated data by using the **dced_objects_release()** routine.

dced_list_release()
Each call to the **dced_list_get()** routine requires a corresponding call to **dced_list_release()** to release the resources allocated for the entry list.

dced_binding_free()
Each call to the **dced_binding_from_rpc_binding()** routine requires a corresponding call to **dced_binding_free()** to release the resources of the allocated binding.

2.5 Managing Hostdata on a Remote Host

Administrators typically use the **dcecp hostdata** object to remotely manage the data of the **hostdata** service. However, application developers can use the **dced** API for their own management applications or if **dcecp** does not handle a task in the desired way, such as for a browser of hostdata that uses a graphical user interface.

2.5.1 Kinds of Hostdata Stored

Each **hostdata** item is stored in a file, and **dced** has a UUID associated with each. The standard data items include the following well-known names:

cell_name The name of the cell to which your host belongs is stored.

cell_aliases When the cell name changes, the old names are designated as cell aliases.

dce_cf.db The DCE configuration data file is stored.

host_name The host name is stored.

pe_site The location of the security server is stored.

post_processors
The **post_processors** file contains UUID-program pairs for which the UUIDs represent other **hostdata** items. If changes occur to an associated **hostdata** item, the system runs the program.

svc_routing The default routing file for serviceability messages is stored.

Depending on your DCE provider, additional items may exist. In addition to the well-known **hostdata** items, applications can also add their own. The well-known **hostdata** items have well-known UUIDs defined in the file **/usr/include/dce/dced_data.h**, but you can use the **dced_inq_uuid()** routine to obtain any UUID associated with any name known to **dced**.

2.5.2 Adding New Hostdata

In addition to modifying existing hostdata, you can add your own data by using the hostdata API. For example, suppose you want to add a printer to a host and make the configuration file part of that host's **dced** data. The following example shows how to do this:

```
dced_binding_handle_t    dced_bh;
error_status_t           status;
dced_entry_t             entry;
dced_attr_list_t         data;
int                      num_attr, str_size;
sec_attr_enc_str_array_t *attr_array;
 .
 .
 .
dced_binding_create(dced_c_service_hostdata,
             dced_c_binding_syntax_default,
             &dced_bh,
      &status);
/*Create Entry Data */
uuid_create(&(entry.id), &status);
entry.name = (dced_string_t)("NEWERprinter");
entry.description = (dced_string_t)("Configuration for a new printer.");
entry.storage_tag = (dced_string_t)("/etc/NEWprinter");

/* Create the Attributes, one for this example */
data.count = 1;
num_attr = 1;
```

```
data.list  = (sec_attr_t *)malloc( data.count * sizeof(sec_attr_t) );
(data.list)->attr_id = dced_g_uuid_fileattr;
(data.list)->attr_value.attr_encoding = sec_attr_enc_printstring_array;
str_size = sizeof(sec_attr_enc_str_array_t) +
                    num_attr * sizeof(sec_attr_enc_printstring_p_t);
attr_array = (sec_attr_enc_str_array_t *)malloc(str_size);
(data.list)->attr_value.tagged_union.string_array = attr_array;
attr_array->num_strings = num_attr;
attr_array->strings[0] =
                  (dced_string_t)("New printer configuration data");

dced_hostdata_create(dced_bh, &entry, &data, &status);
dced_binding_free( dced_bh, &status);
```

The description of this example is as follows:

dced_binding_create()
: This routine creates a **dced** binding to a **dced** service. The binding handle created is used in all subsequent calls to appropriate **dced** API routines. By using the **dced_c_server_hostdata** value for the first parameter, we are using the **hostdata** service on the local host.

Create Entry Data
: Prior to creating a **hostdata** entry, we have to set its values. These include the name and UUID that **dced** will use to identify the new data, a description of the entry, and a filename with the full pathname of where the actual data will reside.

Create the Attributes
: The data stored is of type **sec_attr_t**. This data type is a very flexible one that can store many different kinds of data. In this example, we set the file to have one attribute, printable string information. This example has only one string of data. You can also establish binary data for the file.

dced_hostdata_create()
: This routine takes the binding handle, entry, and new data as input; it creates the file with the new data and returns a status code.

If the printer configuration file already exists on the host, but you want to now make it accessible to **dced**, use the **dce_entry_add()** routine instead of **dced_hostdata_create()**.

dced_binding_free()
Each call to the **dced_binding_create()** routine requires a corresponding call to **dced_binding_free()** to release the binding resources allocated.

Use the **dced_hostdata_delete()** routine to delete application-specific **hostdata** items and their entries. For example, the printer installed in the example is easily removed with this routine. If you are only taking the printer out of service for a short time, use the **dced_entry_remove()** routine to remove the **dced** entry but not the data file itself. When the printer is later ready again, use the **dced_entry_add()** routine to reinstall it.

Do not delete the well-known **hostdata** items or remove their entries.

2.5.3 Modifying Hostdata

Changing hostdata cannot only change the way the host works but it also affects other files and processes on the host. Therefore, care should be taken when changing hostdata. Deleting the well-known **hostdata** entries can cause even more serious operational problems for the host.

The current as well as earlier versions of DCE provide configuration routines that use a **dce_cf.db** file for data. When hostdata changes, **dced** also makes the appropriate changes to this file so that the **dce_cf*** routines continue to work correctly. This is one reason the **hostdata** items are established as well-known names with well-known UUIDs so that **dced** knows which values to monitor.

Management applications use the **dced_hostdata_read()** routine to obtain the data for an entry referred to by an entry UUID. To modify an entry's actual data, applications use the **dced_hostdata_write()** routine. This routine replaces the old data with the new data for the **hostdata** entry represented by the entry UUID. The **hostdata** entry must already exist because this routine will not create it. Use the **dced_hostdata_create()** routine to create new **hostdata** entries.

2.5.4 Running Programs Automatically When Hostdata Changes

The following example shows how to use the **post_processors** feature of the well-known hostdata to cause **dced** to automatically run a program if another **hostdata** entry changes. In this example, the **post_processors** file is read, and data is added for the **NEWERprinterhostdata** entry created in an earlier example. The data is placed in a **dced_attr_list_t** structure and written back to the **post_processors hostdata** entry.

```
dced_binding_handle_t dced_bh;
uuid_t                entry_uuid;
sec_attr_t            *data_ptr;
error_status_t        status;
int                   i, num_strings, str_size;
sec_attr_enc_str_array_t *attr_array;
unsigned_char_t       *string_uuid, temp_string[200];
dced_attr_list_t      attr_list;

dced_binding_create(dced_c_service_hostdata,
             dced_c_binding_syntax_default,
             &dced_bh,
      &status);
dced_hostdata_read(dced_bh,
                   &dced_g_uuid_hostdata_post_proc,
                   &dced_g_uuid_fileattr,
                   &data_ptr,
                   &status);

/* Create New Array and Copy Old Data into it */
num_strings =
         data_ptr->attr_value.tagged_union.string_array->num_strings + 1;
str_size = sizeof(sec_attr_enc_str_array_t) +
                      num_strings * sizeof(sec_attr_enc_printstring_p_t);
attr_array = (sec_attr_enc_str_array_t *)malloc(str_size);
attr_array->num_strings = num_strings;
for(i=0; i<(num_strings-1); i++) {
    attr_array->strings[i] =
        data_ptr->attr_value.tagged_union.string_array->strings[i];
}
```

```
dced_inq_id(dced_bh, "NEWERprinter", &entry_uuid, &status);

uuid_to_string(&entry_uuid, &string_uuid, &status);
sprintf(temp_string, "%s %s", string_uuid, "/path/and/program/to/run");
attr_array->strings[num_strings-1] = (dced_string_t)(temp_string);
data_ptr->attr_value.tagged_union.string_array = attr_array;

attr_list.count = 1;
attr_list.list =
              (sec_attr_t *)malloc(attr_list.count * sizeof(sec_attr_t));
attr_list.list = data_ptr;
dced_hostdata_write(dced_bh,
                    &dced_g_uuid_hostdata_post_proc,
                    &attr_list,
                    &status);

dced_objects_release(dced_bh, 1, (void*)(data_ptr), &status);
dced_binding_free(dced_bh, &status);
```

The description of this example is as follows:

dced_binding_create()
: This routine creates a **dced** binding to the **hostdata** service on a specified host. The binding handle created is used in all subsequent calls to appropriate **dced** API routines. The **dced_c_service_hostdata** argument is a constant string that is the well-known name of the **hostdata** service. When this string is used by itself, it refers to the service on the local host.

dced_hostdata_read()
: This routine reads the **hostdata** item referred to by the entry UUID. In this example, the global variable **dced_g_uuid_hostdata_post_proc** represents the UUID for the well-known **post_processors** file. The second parameter specifies an attribute for the data. Attributes describe how the data is to be interpreted. In this example, we know the data to be read is plain text, so we use the global variable **dced_g_uuid_fileattr** to specify plain text rather than binary data (**dced_g_uuid_binfileattr**).

Create a New Array

The next few lines copy the existing array of print strings into a new array that has additional space allocated for the new data.

dced_inq_id()

This routine acquires the UUID **dced** that maintains for a known entry name. In this example, we need the UUID for the **NEWERprinter hostdata** entry so that it can be included in the data stored back in the **post_processors** file.

uuid_to_string()

This routine returns the string representation of a UUID. Each line in the **post_processors** file contains a string UUID and a program name for **dced** to run if the **hostdata** entry referred to by the UUID changes. The next few lines create a new string containing the string UUID and a program name, adds the new string to the new array, and reassigns the new array to the old data pointer.

dced_hostdata_write()

Since hostdata could have more than one attribute associated with each entry, the data must be inserted in an attribute list data structure before the **dced_hostdata_write()** routine is called. In the case of the well-known **post_processorshostdata** object, the attribute is for a plain text file. The **dced_hostdata_write()** routine replaces the old data with the new data for the **hostdata** entry represented by the entry UUID.

dced_objects_release()

Each call to the **dced_hostdata_read()** routine requires a corresponding call to **dced_objects_release()** to release the resources allocated.

dced_binding_free()

Each call to the **dced_binding_create()** routine requires a corresponding call to **dced_binding_free()** to release the resources allocated.

The **post_processors** data for this **dced** now contains an additional string with a UUID and program name. If the **hostdata** item represented by the UUID for **NEWERprinter** is changed, **dced** automatically runs the program.

2.6 Controlling Servers Remotely

Both applications developers and system administrators may want servers to have certain support services and control functionality. For example, servers may need mechanisms to store operational data, and they may need to start or stop in various ways. The **dced** program provides these support and control mechanisms for servers.

Servers are typically configured by an administrator using the **dcecp server** object in a script after the server is installed on the host. In addition to configuring the server, this script would commonly include other tasks like create an account and assign a principal name for the server, modify the ACLs and key table files (keytabs) to control access to the server and its resources, and export the server binding information to the Cell Directory Service (CDS) so that clients can find a server that will start dynamically later.

After a server is configured, whether it runs as a persistent daemon or an on-demand (dynamic) process, administrators would again use **dcecp** if they need to control or modify its behavior. Although server management is typically an administrator's task, you may want a management application to perform these tasks, including the following:

- Configure a server to describe how it can be invoked
- Start a server based on configuration data
- Stop a running server
- Disable a specific service provided by a running server
- Enable a specific service for a running server
- Modify a server's configuration
- Delete a server's configuration, effectively removing the server from **dced**'s control

2.6.1 Two States of Server Management: Configuration and Execution

If all servers ran as persistent processes, **dced** could maintain data about each server in a single (albeit complex) data structure. However, due to the fact that some servers

may run on demand, it is a more flexible design to have two sets of data: one that describes the default configuration to start the server, and one that describes the executing (running) server. Earlier in this chapter when we described **dced** service naming, we defined **srvrconf** and **srvrexec** objects to name the two portions of the server management service.

Table 2-1 lists the routines that applications can use to control servers. It also shows the valid object names to use when establishing a **dced** binding prior to using the routine.

Table 2–1. API Routines for Remote Server Management

API Routine	**Service Name for Binding**
dced_server_create()	**srvrconf**
dced_server_start()	**srvrconf**
dced_server_disable_if()	**srvrexec**
dced_server_enable_if()	**srvrexec**
dced_server_stop()	**srvrexec**
dced_object_read()	**srvrexec** or **srvrconf**
dced_object_read_all()	**srvrexec** or **srvrconf**
dced_server_modify_attributes()	**srvrconf**
dced_server_delete()	**srvrconf**

2.6.2 Configuring Servers

Although administrators commonly use **dcecp** to configure servers remotely, management applications can use **dced** API routines to configure a new server remotely by creating server configuration data, changing a remote server's configuration, and deleting a server's configuration data.

2.6.2.1 Configuring a New DCE Server

Management applications use the **dced_server_create()** routine to add a new server to a host. After a server is configured, it can be remotely controlled by modifying its configuration attributes, starting and stopping it, enabling or disabling the RPC interfaces it supports, and deleting its configuration.

Configuring the server involves describing the server for DCE by allocating and filling in a **server_t** data structure, as shown in the following example. Note that not all **server_t** fields are assigned values in this example.

```
int                   i;
dced_binding_handle_t dced_bh;
server_t              conf, exec;
dced_string_t         server_name;
uuid_t                srvrconf_id, srvrexec_id;
dced_attr_list_t      attr_list;
error_status_t        status;
static service_t      nil_service;
 .
 .
 .
dced_binding_create("srvrconf@hosts/somehost",
                    dced_c_binding_syntax_default,
                    &dced_bh,
                    &status);
dced_inq_id(dced_bh, server_name, &srvrconf_id, &status);
if(status == error_status_ok) {
    puts("Configuration already exists for this server.");
    dced_binding_free(dced_bh, &status);
    return;
}
/* ___________setup a server_t structure ________________*/
uuid_create(&(conf.id), &status);
conf.name           = server_name;
conf.entryname      = (dced_string_t)"/.:/greeter";
conf.services.count = 1;
```

```
/* ___service_t structures represent each interface supported ___*/
conf.services.list =
    (service_t *)malloc(conf.services.count * sizeof(service_t));
for(i=0; i<conf.services.count; i++) {
    rpc_if_inq_id(greetif_v1_0_c_ifspec,
                  &(conf.services.list[i].ifspec),
                  &status);
    conf.services.list[i] = nil_service;
    conf.services.list[i].ifname     = (dced_string_t)"greet";
    conf.services.list[i].annotation =
                               (dced_string_t)"The greet application";
    conf.services.list[i].flags      = 0;
}

/* ______________server_fixedattr_t structure _______________*/
conf.fixed.startupflags =
    server_c_startup_explicit | server_c_startup_on_failure;
conf.fixed.flags = 0;
conf.fixed.program = (dced_string_t)"/server/path/and/program/name";

dced_server_create(dced_bh, &conf, &status);
dced_binding_free(dced_bh, &status);
```

dced_binding_create()

To configure a server, the application must first create a **dced** binding to the **srvrconf** portion of the server management service on a specified host. The binding handle created is used in all subsequent calls to appropriate dced API routines.

dced_inq_id()

This routine returns the UUID that **dced** associates with the name input. Each configured server has an associated UUID used by **dced** to identify it. In this example, we won't try to create a configuration for a server that already exists.

Set Up a **server_t** Structure for the Server

The **server_t** structure contains all the information DCE uses to specify a server.

Set Up **service_t** Structures for Each Interface
Each service that the server supports is represented by a **service_t** data structure that contains the interface specification, among other things. In this example the client stub for the interface was compiled with the program so that the interface specification (**greetif_v1_0_c_ifspec**) could be obtained without building the structure from scratch.

Set Up a **server_fixedattr_t** Structure
Other fixed attributes required for all servers describe how the server can start, the program name and pathname for the server so that **dced** knows which program to start, and the program's arguments, among other things.

dced_server_create()
This routine uses the filled-in **server_t** structure to create a **srvrconf** entry for **dced**. The data is stored in memory for quick access whenever the server is started.

dced_binding_free()
Each call to the **dced_binding_create()** routine requires a corresponding call to **dced_binding_free()** to release the binding resources allocated.

2.6.2.2 Modifying a Server's Configuration Attributes

The data for configuring servers includes arrays of attributes. For flexibility, **dced** is implemented using the extensible and dynamic data structures developed for the DCE security registry attributes. This extended registry attribute (ERA) schema gives vendors the flexibility to modify the attributes appropriate for configuring servers on various systems. The use and modification of these data structures are described in Chapter 28.

Applications commonly use **dced_server_modify_attributes()** after the **dced_server_create()** routine to change the default configuration attributes (the **attributes** field of a **server_t** structure) for a remote server. A **dced_attr_list_t** data structure is input that contains an array of **sec_attr_t** data structures and a count of the number in the array.

2.6.2.3 Deleting a DCE Server

Management applications use **dced_server_delete()** to delete a server's configuration data and entry in its hosts **dced**. Although this does not delete the actual server program from the host, it removes it from DCE control.

2.6.3 Starting and Stopping Servers

A server typically runs as persistent process or is started on demand when a client makes a remote procedure call to it. Management applications can start remote servers by using the **dced_server_start()** routine. This is a **srvrconf** routine that takes as input server configuration data in the form of an attribute list.

Once a server has started, it tends to remain running until an administrator or management application stops it, but some applications may stop themselves if, for example, they do not detect activity within a specified time. To stop remote servers, applications can use the **dced_server_stop()** routine.

The following example shows how an application starts or stops a server:

```
dced_binding_handle_t dced_bh, conf_bh, exec_bh;
server_t              conf, exec;
dced_string_t         server_name;
uuid_t                srvrconf_id, srvrexec_id;
error_status_t        status;
 .
 .
 .
/* Toggle the Starting or Stopping of a Server */
dced_binding_create("srvrconf@hosts/somehost",
                    dced_c_binding_syntax_default,
                    &conf_bh,
                    &status);
dced_binding_create("srvrexec@hosts/somehost",
                    dced_c_binding_syntax_default,
                    &exec_bh,
```

```
                    &status);
dced_inq_id(exec_bh, server_name, &srvrexec_id, &status);
if(status != error_status_ok) {
  puts("Server is NOT running.");
  dced_inq_id(conf_bh, server_name, &srvrconf_id, &status);
  dced_server_start(conf_bh, &srvrconf_id, NULL, &srvrexec_id, &status);
}
else {
    puts("Server is RUNNING.");
    dced_server_stop(exec_bh, &srvrexec_id, srvrexec_stop_rpc, &status);
}
dced_binding_free(conf_bh, &status);
dced_binding_free(exec_bh, &status);
```

dced_binding_create()

These routines create **dced** bindings to the **srvrconf** and **srvrexec** portions of the server management service on a specified host. The binding handles created are used in all subsequent calls to appropriate **dced** API routines.

dced_inq_id()

This routine returns the UUID that **dced** associates with the name input. Each name used to identify an object of each service has a UUID. If **dced** maintains a UUID for a **srvrexec** object, the server is running. However, it is possible that the server is in an in-between state as it is starting up or shutting down. For a more robust check as to whether the server is running, use the **dced_object_read()** routine to read the **server_t** structure for the **srvrexec** object. If the *exec_data.tagged_union.running_data.instance* UUID is the same as the **srvrconf** UUID (*srvrconf_id*), the server is running.

dced_server_start()

This routine starts the server via **dced**. The **srvrconf** binding handle and UUID are input. For special server configurations, you can start a server with a specific list of attributes, but a value of NULL in the third parameter uses the attributes of the server configuration data. You can input a **srvrexec** UUID for **dced** to use, or allow it to generate one for you.

dced_server_stop()
: This routine stops a running server identified by its **srvrexec** UUID. The cleanest stop method is to cause **dced** to use the **rpc_mgmt_server_stop_listening()** routine so that all outstanding remote procedure calls complete before the server stops.

dced_binding_free()
: Each call to the **dced_binding_create()** routine requires a corresponding call to **dced_binding_free()** to release the binding resources allocated.

2.6.4 Enabling and Disabling Services of a Server

Most servers have all their services enabled to process all requests. However, a server may need to enable or disable services to synchronize them, for example. For another example, an administrator (or management application) may need to disable or enable services to perform orderly startup or shutdown of a server.

Each service provided by a server is implemented as a set of procedures. DCE uses an interface definition to define a service and its procedures, and application code refers to the interface when controlling the service.

When a server starts, it initializes itself by registering with the RPC runtime and the **dced** process on its host by using the **dce_server_register()** routine. This enables all services (interfaces) that the server can support. The server can then disable and reenable services (in whatever order it requires) by using the **dce_server_disable_if()** and **dce_server_enable_if()** routines.

To control the services of remote servers, management applications use the **dced_server_disable_if()** and **dced_server_enable_if()** routines. These routines work on the **srvrexec** object. When a service (interface) is disabled, a client that already knows about the service (through a binding handle to this interface and server) will no longer work because the interface is unregistered with the RPC runtime. If you wish to have clients that already know about the server and service work, but wish to prohibit any new clients from finding the server and service, you can use **rpc_mgmt_ep_unregister()** to remove from the endpoint map the server address information with respect to the service. This routine does not affect the RPC runtime.

2.7 Validating the Security Server

The security validation service (**secval**) has the following major functions:

- It maintains a login context for the host's self-identity which includes periodic changes to the host's key (password).
- It validates and certifies to applications, usually login programs, that the DCE security daemon (**secd**) is legitimate.

Clients (including remote clients, local servers, host logins, and administrators) all need the security validation service to make sure that the **secd**) process being used by the host is legitimate. The security validation service establishes the link in a trust chain between applications and **secd** so that applications can trust the DCE security mechanism.

An application can trust its host's security validation service because they are on the same host, but an application has no way to convince itself that **secd**, presumably on another host, is genuine. However, if the application trusts another principal (in this case, the security validation service), which in turn trusts **secd**, then the trust chain now extends from the application to **secd**.

Typically, a login program accesses the security validation service when it uses the DCE Security Service's login API, described in Chapter 29. Administrators access the **secval** service by using the **dcecp secval** object. However, suppose you are writing a security monitoring application to watch for and respond to security attacks. After the application binds to the **secval** service, it can call the **dced_secval_validate()** routine to verify that the **secd** process is legitimate.

Applications can also use the **dced_secval_start()** and **dced_secval_stop()** routines to start and stop the security validation service on a given host.

For example, during configuration of a host, the **dced** program can start with or without the security validation service. Later when security is configured, a management application can start **secval** by using the **dced_secval_start()** routine. For another example, suppose our security monitoring application mentioned earlier suspects an attack. The application can call **dced_secval_stop()** to stop the security validation service without stopping the entire **dced**. This makes the login environment more restrictive.

2.8 Managing Server Key Tables

Keys for servers are analogous to passwords for human users. Keys also play a major role in authenticated remote procedure calls. Keys have some similarities with passwords. For example, server keys and user passwords have to follow the same change policy (or a more stringent one) for a given host or cell. This means that, just as a user has to periodically come up with a new password, a server has to periodically generate a new key. It is easy to see that a human user protects a password by memorizing it. But a server memorizes a key by storing it in a file called a *key table*.

It is more complex for a server to change keys than it is for a human user to change a password. For example, a human user needs to only remember the latest password, but a server may need to maintain a history of its keys by using version numbers so that currently active clients do not have difficulty completing a remote procedure call. When a client prepares to make authenticated remote procedure calls, it obtains a ticket to talk with the server. (The security registry of the authentication service encrypts this ticket by using the server's key, and later the server decrypts the ticket when it receives the remote procedure call.)

Timing can become an issue when a client makes a remote procedure call because tickets have a limited lifetime before they expire, and servers must also change their keys on a regular basis. Assuming the client possesses a valid ticket, suppose that, by the time the client makes the call, the server has generated a new key. If a server maintains versions of its keys, the client can still complete the call. Authentication is described in detail in Chapter 23.

A key table usually contains keys stored by one server, and it must be located on the same host as that server. However, a key table can hold keys for a set of related servers, as long as all the servers reside on the same host. Servers usually maintain their own keys, and Chapter 30 describes the API they use. Administrators can remotely manage key tables and the keys in the tables by using the **dcecpkeytab** object. This section describes the API routines that management applications can use to manage the key tables and keys of other servers on the network.

Suppose you discover that a server or an entire host's security has been compromised. Applications can use the **dced_keytab_change_key()** routine to change a key table's key. The following example shows how to reset the key for all key tables on a specified host:

```
dced_binding_handle_t   dced_bh;
dced_entry_list_t       entries;
unsigned32              i;
error_status_t          status;
dced_key_t              key;

dced_binding_create("keytab@hosts/somehost",
                     dced_c_binding_syntax_default,
                     &dced_bh,
                     &status);

dced_binding_set_auth_info(dced_bh,
                           rpc_c_protect_level_default,
                           rpc_c_authn_default,
                           NULL,
                           rpc_c_authz_dce,
                           &status);

dced_list_get(dced_bh, &entries, &status);

for(i=0; i<entries.count; i++) {
    generate_new_key(&key); /* application specific */
    dced_keytab_change_key(dced_bh, &entries.list[i].id, &key, &status);
}
dced_list_release(dced_bh, &entries, &status);
dced_binding_free( dced_bh, &status);
```

dced_binding_create()

This routine creates a **dced** binding to a **dced** service on a specified host. The binding handle created is used in all subsequent calls to appropriate **dced** API routines. The **keytab** portion of the first argument represents the well-known name of the keytab service. When this string is used by itself, it refers to the service on the local host.

dced_binding_set_auth_info()
Accessing keytab data requires authenticated remote procedure calls. The **dced_binding_set_auth_info()** routine sets authentication for the **dced** binding handle, *dced_bh*.

dced_list_get()
Applications use the **dced_list_get()** routine to get a service's entire list of names.

generate_new_key()
This application-specific routine generates the new key and fills in a **dced_key_t** data structure. This routine could use the **sec_key_mgmt_gen_rand_key()** routine to randomly generate a new key.

dced_keytab_change_key()
The **dced_keytab_change_key()** routine tries to change the principal's key in the security service's registry first. If that is successful, it changes the key in the key table.

dced_list_release()
Each call to the **dced_list_get()** routine requires a corresponding call to **dced_list_release()** to release the resources allocated for the entry list.

dced_binding_free()
Each call to the **dced_binding_create()** routine requires a corresponding call to **dced_binding_free()** to release the resources allocated for a **dced** binding handle.

For more detailed key table management, applications can peruse a key table's list of keys by using the **dced_keytab_initialize_cursor()**, **dced_keytab_get_next_key()**, and **dced_keytab_release_cursor()** routines. Reading key table data remotely presents a greater security risk because data is sent over the network. For remote access, these routines actually get all the keys during one remote procedure call to be more efficient and to minimize the time keys are being sent over the network.

Earlier in this section we described how to change the key of a key table with the **dced_keytab_change_key()** routine. The key table management service also provides the routines **dced_keytab_add_key()** and **dced_keytab_remove_key()** to control key modification in even greater detail.

Finally, you can create a new key table by using **dced_keytab_create()**, or you can delete an existing key table by using **dced_keytab_delete()**.

2.9 Sample dced Application

The following sections contain the complete source code, Makefile, and **dcecp** installation scripts for a simple DCE application that uses some of the **dced** server management facilities.

The **greet_dced** application is an adaptation of the **greet** application described in Section 3.10.1 of the *DCE 1.2.2 Introduction to OSF DCE*. The **greet_dced** server is registered and executed via **dced**.

Once started, **greet_dced**'s behavior is identical to that of **greet**. The client side of the application sends a greeting to the server side of the application. The server prints the client's greeting and sends a return greeting back to the client. The client prints the server's reply and terminates. (Note that the server does not catch signals, so when it is stopped it does not clean up its namespace or registry entries; this must be done manually.)

2.9.1 Running the Program

To run **greet_dced**, do the following:

1. Build the program by invoking the **make** command.
2. Change the **uid** and **gid** values in **greet_dced.install** according to your preferences. If you do change them, make sure that you chown the **keytab** file to the same **uid** in Step 4 below.
3. As **cell_admin**, do:

   dcecp greet_dced.install

   This creates a server principal and account with the password ‘‘secret’’, creates a CDS directory and changes permissions on it (so that the server principal has rights to create its server entry), creates a **keytab** entry and creates a **srvrconf**

entry. It handles errors, so if something fails (e.g. if the user already exists) the program will still run to completion.

4. As root, do:

   chown*your_user_name***greet_dced.ktab**

   This is necessary because the form of the **chown** command in **greet_dced.install** will fail—it is present there only as a reminder. If you use a different **uid** in the script, change it here as well.

5. As **cell_admin**, do:

   dcecp -c server start greeter_dced

6. Wait a few moments and check **/tmp/srv.out** to make sure the server has started.

7. Start the client as follows:

   ./greet_dced_client /.:/subsys/my_company/greet_dced/greeter_dced_entry

After you are done, you can get rid of everything as follows:

1. As **cell_admin**, stop the server:

   dcecp -c server stop greeter_dced -method soft

2. As **cell_admin**, run the delete script:

   dcecp greet_dced.delete

The program has the following limitations:

- The server does not catch signals, so when it is stopped it does not clean up anything.

- The dce_server_sec_begin() routine logs in using the server principal and keytab specified in the **srvrconf** file. It also starts a thread to manage the server's key. However, it does *not* start a thread to refresh the server's login context. That still needs to be done by the application writer, using the same method that was used in DCE 1.0.x:

```
create a thread to run the following:

loop
 find out when the login context expires
 do a pthread_delay_np for
  (expiration time - current time - 10 minutes)
 sec_login_refresh_identity();
 sec_key_mgmt_get_key();
 sec_login_validate_identity();
 sec_key_mgmt_free_key();
end loop
```

2.9.2 greet_dced.idl

Following are the contents of the **greet_dced.idl** file.

```
/*
 * greet_dced.idl
 *
 * The "greet_dced" interface.
 */

[uuid(3d6ead56-06e3-11ca-8dd1-826901beabcd),
version(1.0)]

interface greet_dcedif
{
    const long int REPLY_SIZE = 100;

    void greet_dced(
        [in]            handle_t h,
        [in, string]    char client_greeting[],
        [out, string]   char server_reply[REPLY_SIZE]
    );
}
```

2.9.3 greet_dced_server.c

Following are the contents of the **greet_dced_server.c** file, which contains the **greet_dced** server setup and cleanup routines. This is where the server's interaction with **dced** takes place.

```
/* greet_dced_server_dce.c
 * Main program (initialization) for "greet_dced" server.
 * NEW SERVER for DCE 1.1.
 */

#include <stdio.h>
#include <dce/dced.h>
#include "greet_dced.h"
#include "util.h"

char invocation_instructions[] = "Usage:\n\
1. Invoke the dcecp program: dcecp\n\
   dcecp>\n\
2. Start the server:\n\
   dcecp> server start greeter_dced\n\
3. If dced cannot find a matching server object,
   create server configuration:\n\
   dcecp> source greet_dced.install\n\
   dcecp> server start greeter_dced\n\
4. exit dcecp.\n\
   dcecp> exit";

FILE * out = NULL;

boolean32 rpc_mgmt_authorize (rpc_binding_handle_t client_bn,
         unsigned32 op_no,
         unsigned32 *st);

int main(
    int  argc,
    char *argv[]
)
```

```
{
    server_t                     *server_conf;
    dce_server_register_data_t  register_data[1];
    dce_server_handle_t         server_handle;
    error_status_t              status;

    /* if we are a daemon stderr is missing */
    out = fopen ("/tmp/srv.out" , "w");

    /* otherwise just use
    out = stderr;
    */

    fprintf(out, "Server start\n");    fflush(out);

    /******** Get the server's configuration from the local dced ******/
    fprintf(out, "dce_server_inq_server() call\n");
    fflush(out);
    dce_server_inq_server(&server_conf, &status);
    fprintf(out, "dce_server_inq_server() return\n");
    fflush(out);
    if(status != error_status_ok) { /* Describe startup via dcecp */
                                    /*  and dced */
        fprintf(out, "%s\n", invocation_instructions);
        fflush(out);
        ERROR_CHECK(status, "Cannot get server configuration structure");
    }

    /********* login and manage key ******************************/
    fprintf(out, "dce_server_sec_begin() call\n");
    fflush(out);
    dce_server_sec_begin
              (dce_server_c_login|dce_server_c_manage_key, &status);
    fprintf(out, "dce_server_sec_begin() return\n");
    fflush(out);
    if ( status != error_status_ok) {
        fprintf(out, "Failed in dce_server_sec_begin()\n");
        fflush(out);
        ERROR_CHECK(status, "Cannot sec_begin");
    }
```

```
/********** Only the protocol sequences we want ****************/
fprintf(out, "dce_server_use_protseq() call\n");
fflush(out);
dce_server_use_protseq( NULL, (idl_char *)"ncadg_ip_udp", &status);
fprintf(out, "dce_server_use_protseq() return\n");
fflush(out);
if ( status != error_status_ok) {
    fprintf(out, "Failed to specify protocol sequence\n");
    fflush(out);
    ERROR_CHECK(status, "Cannot specify protocol sequence");
}

/******* Fill in rest of registration data structures ***********/
register_data[0].ifhandle = greet_dcedif_v1_0_s_ifspec;
register_data[0].epv = NULL; /* use default entry point vector */
register_data[0].num_types = 0;
register_data[0].types = NULL;

/************************** Register the Server *****************/
fprintf(out, "dce_server_register() call\n");
fflush(out);
dce_server_register(
    dce_server_c_ns_export,/*flag says register server with CDS */
    server_conf,
    register_data,
    &server_handle,
    &status
);
fprintf(out, "dce_server_register() return\n");
fflush(out);
if ( status != error_status_ok) {
    fprintf(out, "Failed dce_server_register. Error %d\n", status);
    fflush(out);
ERROR_CHECK(status, "Can’t register server with DCE");
}

/******************* Listen for remote procedure calls **********/
fprintf(out, "Listening...\n");    fflush(out);
rpc_server_listen(rpc_c_listen_max_calls_default, &status);
```

```
    fprintf(out, "Returned from listening...\n");
    fflush(out);
    if ( status != rpc_s_ok) {
        fprintf(out, "Failed rpc_server_listen\n");
        fflush(out);
 ERROR_CHECK(status, "Can't start listening for calls");
    }

    /*********************** Unregister from DCE ******************/
    fprintf(out, "dce_server_unregister call\n");
    fflush(out);
    dce_server_unregister(&server_handle, &status);
    fprintf(out, "dce_server_unregister return\n");
    fflush(out);
    if ( status != error_status_ok) {
        fprintf(out, "Failed dce_server_unregister\n");
        fflush(out);
 ERROR_CHECK(status, "Can't unregister server from DCE");
    }

    fprintf(out, "dce_server_sec_done call\n");
    fflush(out);
    dce_server_sec_done(&status);
    fprintf(out, "dce_server_sec_done return\n");
    fflush(out);
    if ( status != error_status_ok) {
        fprintf(out, "Failed dce_server_sec_done\n");
        fflush(out);
 ERROR_CHECK(status, "Can't do sec_done");
    }

}
```

2.9.4 greet_dced_manager.c

Following are the contents of the **greet_dced_manager.c** file, which contains the implementation of the **greet_dced** interface.

```
/*
 * greet_dced_manager.c
 *
 * Implementation of "greet_dced" interface.
 */

#include <stdio.h>
#include "greet_dced.h"

void
greet_dced(
    handle_t h,
    idl_char *client_greeting,
    idl_char *server_reply
)
{
    printf("The client says: %s\n", client_greeting);

    strcpy(server_reply, "Hi, client!");
}
```

2.9.5 greet_dced_client.c

Following are the contents of the **greet_dced_client.c** file.

```
/*
 * greet_dced_client.c
 *
 * Client of "greet_dced" interface.
 */

#include <stdio.h>
#include <dce/nbase.h>
#include <dce/rpc.h>

#include "greet_dced.h"
#include "util.h"
```

```
int
main(
    int argc,
    char *argv[]
)
{
    rpc_ns_handle_t import_context;
    handle_t binding_h;
    error_status_t status;
    idl_char reply[REPLY_SIZE];

    if (argc < 2) {
        fprintf(stderr, "usage: greet_dced_client <CDS pathname>\n");
        exit(1);
    }

    /*
     * Start importing servers using the name specified
     * on the command line.
     */
    rpc_ns_binding_import_begin(
        rpc_c_ns_syntax_default, (unsigned_char_p_t) argv[1],
            greet_dcedif_v1_0_c_ifspec, NULL, &import_context, &status);
    ERROR_CHECK(status, "Can't begin import");

    /*
     * Import the first server (we could interate here,
     * but we'll just take the first one).
     */
    rpc_ns_binding_import_next(import_context, &binding_h, &status);
    ERROR_CHECK(status, "Can't import");

    /*
     * Make the remote call.
     */
    greet_dced(binding_h, (idl_char *) "hello, server", reply);

    printf("The Greet Server said: %s\n", reply);
}
```

2.9.6 util.c

Following are the contents of the **util.c** file, which contains the error message handling routines for the **greet_dced** server and client.

```
/*
 * util.c
 *
 * Utility routine(s) shared by "greet_dced" client
 * and server programs.
 */

#include <stdio.h>
#include <dce/nbase.h>
#include <dce/dce_error.h>

void
error_exit(
    error_status_t status,
    char *text
)
{
    unsigned char error_text[100];
    int dummy;

    dce_error_inq_text(status, error_text, &dummy);
    fprintf(stderr, "Error: %s - %s\n", text, error_text);
    exit(1);
}
```

2.9.7 util.h

Following are the contents of the **util.h** file, which contains declarations used in the **util.c** file.

```
/*
 * util.h
 *
 * Declarations of utility routine(s) shared by "greet_dced" client
 * and server programs.
 */

#define ERROR_CHECK(status, text) if (status != error_status_ok) \
           error_exit(status, text)

void
error_exit(
    error_status_t status,
    char *text
);
```

2.9.8 greet_dced.install

Following are the contents of the **greet_dced.install** file, which is the **dcecp** install script for the **greet_dced** server.

```
set dir /users/your_user_name/src/dce/greet_dced/greet_dced
set cds_dir /.:/subsys/my_company/greet_dced

# Unix and group id of the server process owner
# has to own the keytab file as well
set uid 1265
set gid 1000

# add a PGO for the server
set cmd "user create greet_dced_server -group servers \
        -o osf -password secret -mypwd -dce-"
if {[catch $cmd msg] != 0} {
 echo "user create:" $msg
}

# create a directory in CDS and give access to the server
```

```
# this will fail if any directory in the chain is not already there
set cmd "directory create $cds_dir"
if {[catch $cmd msg] != 0} {
 echo "directory create: " $msg
}

set cmd "acl modify $cds_dir -add {user greet_dced_server rwdit}"
if {[catch $cmd msg] != 0} {
 echo "acl modify: " $msg
}

# create a keytab for the server
set cmd "keytab create greet_dced.ktab \
 -storage $dir/greet_dced.ktab \
 -data {greet_dced_server plain 1 secret}"
if {[catch $cmd msg] != 0} {
 echo "keytab create: " $msg
}

# dced create the keytab file with root as its owner
# so we have to chown it, but
# this may require root permission, so it's likely to fail.
set cmd "exec chown $uid $dir/greet_dced.ktab"
if {[catch $cmd msg] != 0} {
 echo "chown: " $msg
}

# create the srvrconf object
set cmd "server create greeter_dced \
 -program $dir/greet_dced_server \
 -entryname $cds_dir/greeter_dced_entry \
 -keytabs [attrlist getvalues [keytab show greet_dced.ktab]\
        -type uuid]\
 -principals {greet_dced_server} \
 -starton explicit \
 -directory $dir/exec_dir \
 -services { {ifname greet_dced} \
             {interface {3d6ead56-06e3-11ca-8dd1-826901beabcd 1.0}}} \
 -uid $uid -gid $gid"
if {[catch  $cmd msg] != 0} {
```

```
 echo "server create: " $msg
}
```

2.9.9 greet_dced.delete

Following are the contents of **greet_dced.delete**, which contains the **dcecp** cleanup script for the **greet_dced** server.

```
set dir /users/your_user_name/src/dce/greet_dced/greet_dced
set cds_dir /.:/subsys/my_company/greet_dced

catch "server delete greeter_dced"
catch "keytab delete greet_dced.ktab"
catch "directory delete $cds_dir -tree"
catch "user delete greet_dced_server"
```

2.9.10 Makefile

Following are the contents of the **greet_dced** Makefile.

```
######################################################################
#
# Makefile: A generic makefile suitable for building the greet_dced
#           application.
#
#                               -77 cols-
#####################################################################

DCEROOT  = /opt/dcelocal
CC  = /bin/c89
IDL  = idl
LIBDIRS  = -L${DCEROOT}/usr/lib
LIBS  = -ldce -lc_r
```

```
LIBALL  = ${LIBDIRS} ${LIBS}
INCDIRS  = -I. -I${DCEROOT}/share/include
CFLAGS  = -g ${INCDIRS} -D_SHARED_LIBRARIES -D__hppa -Dhp9000s800 \
  -Dhp9000s700 -D__hp9000s800 -D__hp9000s700 -DHPUX -D__hpux \
  -Dunix +DA1.1 -D_HPUX_SOURCE
IDLFLAGS = -v ${INCDIRS} -cc_cmd "${CC} ${CFLAGS} -c"

all: greet_dced_client greet_dced_server

greet_dced.h greet_dced_cstub.o greet_dced_sstub.o: greet_dced.idl
 ${IDL} ${IDLFLAGS} greet_dced.idl

greet_dced_client:  greet_dced.h greet_dced_client.o util.o \
   greet_dced_cstub.o
 ${CC} -o greet_dced_client greet_dced_client.o \
   greet_dced_cstub.o util.o ${LIBALL}

greet_dced_server:  greet_dced.h greet_dced_server.o \
  greet_dced_manager.o util.o greet_dced_sstub.o
 ${CC} -o greet_dced_server greet_dced_server.o \
  greet_dced_manager.o greet_dced_sstub.o util.o ${LIBALL}

greet_dced_client.c greet_dced_server.c util.c: util.h
greet_dced_manager.c greet_dced_client.c greet_dced_server.c:
                                                        greet_dced.h

clobber:
 rm -f greet_dced.h greet_dced_client greet_dced_client.o \
  greet_dced_cstub.o greet_dced_manager.o greet_dced_server \
  greet_dced_server.o greet_dced_server_dce.o \
  greet_dced_sstub.o server_struct.o greet_dced_server_dce util.o
```

Chapter 3
DCE Application Messaging

Message generation by distributed programs can be divided into two broad kinds:

- Normal (often user-prompted, client-generated) messages
- Server event messages, containing information about server activity, either normal or extraordinary

Similarly, DCE makes available to applications two messaging APIs:

- The DCE messaging interface
- The DCE serviceability interface

The DCE serviceability interface is designed specifically to route messages of the second type; it is described in Chapter 4. Messages in the first category are output using the DCE general-purpose application messaging routines, which are the subjects of this chapter.

Although the two interfaces, broadly speaking, do the same general thing (that is, write messages), their functionality was designed to serve different needs, both of which

occur in most distributed applications. Nevertheless, either interface can be used more or less exclusively of the other, if desired.

3.1 DCE and Messages

A *message* is a readable character string conveying information about some aspect of a program's state or activity to a human audience. Messages may be purely informational or they may be intended to be responded to (that is, be interactive). Prompts, error displays, warnings, logs, announcements and program responses are all various kinds of message.

DCE applications can simply use the standard output routines (such as **printf()**, **sprintf()**, and so on) for messaging. However, DCE provides two message interfaces that automatically and transparently take care of many of the special problems that distributed application messaging can give rise to. These interfaces are used by the DCE components themselves to implement their messaging.

Both of the DCE message facilities use XPG4 message catalog files (see the *X/Open Portability Guide*) to hold message text. The message catalogs are generated by a DCE utility (called **sams**) during the application development process, and must be installed in the correct platform-dependent location in order for the DCE messaging library routines to be able to find them (and, consequently, the messages) at runtime.

The main purpose of message catalogs is to allow programs' message text to be stored and organized (separately from the programs themselves) in a culture- or nationality-specific way. This enables programs to switch their I/O styles and contents to the form appropriate to the geographical location (*locale*) they are running in, simply by using the appropriate catalog. Thus, it is essential to compose catalogs in such a way that each one contains message text appropriate only to a single (same) locale.

Questions such as the proper use of locales, proper language style for messages, where catalogs should be installed, and so on, all fall under the broad topic of *internationalization*, and are not discussed in this chapter. The other important aspect of internationalization, namely character and code set compatibility, is discussed in detail in Chapter 16.

3.2 DCE Messaging Interface Usage

Use of the DCE messaging API is very straightforward. In the application code itself, all that is usually required is simply to call one of the output routines, passing it the ID of the message to be output. The messages themselves must first be defined in a text file which must then be processed by the DCE **sams** (symbols and message strings) utility, which generates the message catalog file along with other C source files that contain code necessary to facilitate the additional layer of functionality that DCE has added to the XPG4 message catalog mechanism.

3.2.1 A Simple DCE Messaging Example

The following subsections describe all the steps and code necessary to compile an application that uses the DCE messaging API to print the familiar ''Hello World'' message.

3.2.1.1 Defining the Message

For our example, we will define a **sams** file with the minimum contents necessary to print the one brief message we want to display. (Additional information on the use of **sams** can be found in the **sams(1dce)** reference page, which contains comprehensive descriptions of all aspects of the utility.)

Each line in a **sams** file consists of a simple *header* and *value* combination. The *header* indicates the meaning of the value being specified, and *value* is the value itself. A **sams** file for messaging use is normally made up of three parts (although only two parts are needed for the short example in this chapter). The first part consists of a minimum of one line that specifies the name of the *component* (that is, the application) that is to use the messages that will be generated from the file.

Each invocation of **sams** to process a separate **.sams** input file produces a complete set of output files that can be used by the DCE messaging routines to print or log messages as required. These sets of output files are organized by DCE *component*. (In DCE itself, these components are identical to the DCE components: RPC, DTS, and so on; for applications, the categorization of components is determined by the

developer.) Each set of output files will have names in which the component name (also determined by the developer) appears.

The component name that you specify at the top of a **sams** file must consist of a three-character (no more, no less) string. For the ‘‘Hello World’’ program we will use the component name **hel**:

```
# Part I of simple sams message file...
component           hel
```

The **hel** string will be used to identify all the files and data structures that **sams** will generate from the file.

The second (and final) part of a **sams** file for DCE messaging consists of a series of records that specify the messages themselves. Each record is delimited by the **start** and **end** keywords. Within each record, a series of keywords identifies the various information that each message consists of or has associated with it.

Our file will contain only one message, the text of which is to be ‘‘Hello World’’. The record that specifies it is as follows:

```
start
code          hello_msg
text          "Hello World"
action        "None required"
explanation   "Greeting message for sample messaging program"
end
```

The keywords specified have the following meanings:

code Identifies the message.

text Specifies the text of the message itself.

explanation Describes the meaning of the message. The text following this keyword is used to generate the documentation of the component’s messages.

action Describes any action(s) that should be taken in response to the message. The text following this keyword is used to generate the documentation of the component's messages.

3.2.1.2 Processing the **.sams** File

The entire **sams** file for the **hello** program is as follows:

```
# Part I
component     hel

# Part II
start
code          hello_msg
text          "Hello World"
action        "None required"
explanation   "Greeting message for sample messaging program"
end
```

We create the file with these contents and name it **hel.sams** .

A **sams** file containing DCE messaging API message definitions (in other words, a sams file not containing definitions for DCE serviceability API messages) should be compiled by invoking **sams** as follows:

sams -o thmc *sams_filename*

where:

-o Introduces output flags as follows:

- **t** Specifies that a file containing source code to generate an in-memory message table be output by **sams**.
- **h** Specifies that a header file defining codes for the message numbers be output by **sams**.

m Specifies that a **.msg** file be output by **sams**.

c Specifies that **sams** call **gencat** (with the **.msg** file as input) to produce a message catalog.

Running the command as shown will result in four files being output:

dcehel.cat XPG4 message catalog file created by **gencat**. If you wish to use the message catalog, you must install it yourself.

dcehel.msg Message input file for **gencat**.

dcehelmsg.c Code defining the in-memory table of message texts. By using this table you can avoid depending on extracting message texts from the message catalog.

dcehelmsg.h Header file containing definitions for **dcehelmsg.c**.

The header file should be included in the program source code. The **dcehelmsg.c** module should be compiled and linked with the program object module. The message catalog should be installed in the correct platform-dependent location.

All that remains now is to create a simple C program that calls a DCE messaging routine to output the ‘‘Hello World’’ message.

3.2.1.3 Program Source

The complete source code for **hello.c** is as follows:

```
#include <dce/dce_svc.h>
#include "dcehelmsg.h"

int
main(
    int     argc,
    char    *argv[])
{

    dce_printf(hello_msg);
```

```
}
```

To build the application, you simply

- Process the **hel.sams** file with the **sams** command.
- Build and link **hello** from the following modules:
  - **dcehelmsg.c**
  - **hello.c**

When executed, the program will print the following:

```
Hello World
```

This is the text of the **hello_msg** message as defined in the **hel.sams** file.

3.2.1.4 DCE Messaging and Message Catalogs

The reader may be wondering why, in the previous example, it was not necessary to explicitly open the message catalog before making the call to retrieve and print the message itself. The answer is that **dce_printf()** takes care of this step implicitly. It is able to find the message catalog because the catalog's name is generated from the **component** field in the first part of the **sams** file. Of course, for this to work, the message catalog must be installed in the correct system-defined location before the application is run.

An application may even dispense with the use of installed message catalogs altogether, and use in-memory message tables instead. The necessary code to declare the **sams** file messages as arrays in program memory is contained in the **dce***cmp***msg.c** file generated with the **sams -o t** option. To initialize the table before using it the application must also call the **dce_msg_define_msg_table()** routine, described in Section 3.3.3. The message routines will, when called, attempt to use the application's message catalog; but if it cannot be found, the in-memory table will be used instead.

3.2.2 The DCE Message Interface and sams Input and Output Files

Figure 3-1 shows the relationship of the various files, both source and **sams** output, that go to make up DCE application code that uses the DCE messaging API.

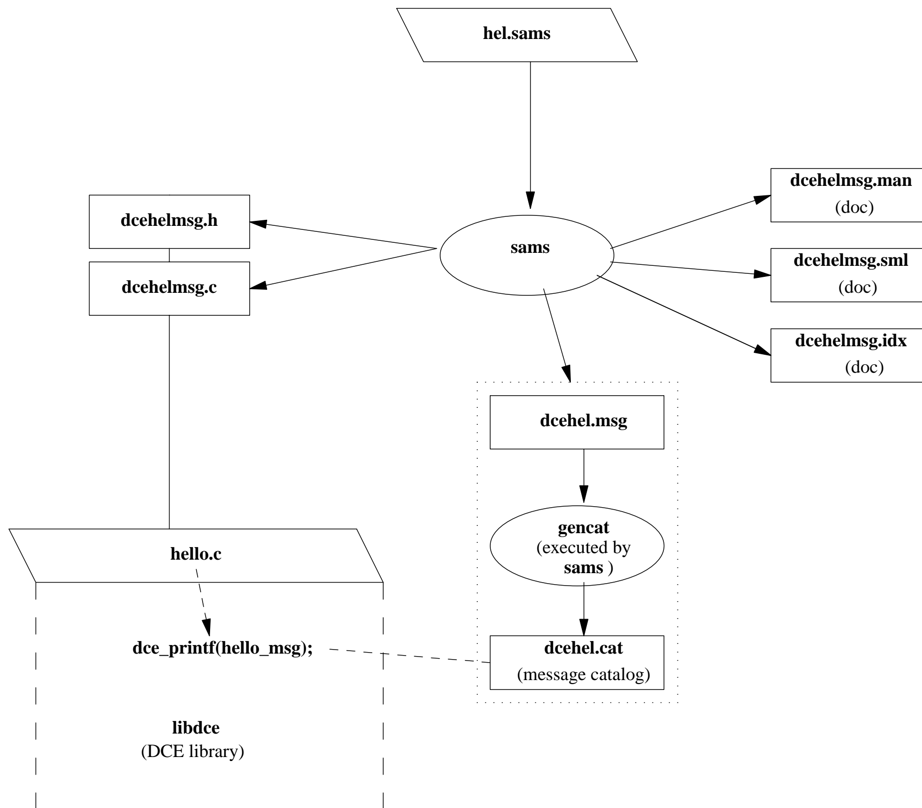
The two parallelogram-shaped objects represent the files that must be created by the developer (you).

Rectangular objects with solid lines represent files that are generated by **sams**; the two ovals represent executable utilities: one is **sams**, the other **gencat** (which is implicitly run by **sams** when message catalogs are generated).

The large rectangular object in dashed lines represents **libdce** , which contains the DCE message API library.

This illustration makes no attempt to show how a DCE application that uses DCE messaging should be compiled and linked, nor how it runs. It is merely a static map of the general place of DCE application messaging in DCE development.

Figure 3–1. sams and DCE Messages



The **sams** output filenames are made up of the following pieces:

tech_name + *comp_name* + *part_name* + *extension*

where:

tech_name Is the technology name (optionally specified at the top of the **hel.sams** file); by default **dce**.

comp_name Is the component name (specified at the top of the **hel.sams** file); in this case, **hel**.

part_name Is a substring identifying the particular file; for example, **svc** or **msg**, and so on. This piece of the name is omitted from the message catalog filenames (in our example, **dcehel.msg** and **dcehel.cat**).

extension Is the file extension (preceded by a **.** (dot) character).

The files **dcehelmsg.man** (generated by **sams -p d hel.sams**)and **dcehelmsg.sml** (generated by **sams -p p hel.sams**), which are shown in Figure 3-1, were not generated by the following command:

```
sams -o thmc hel.sams
```

They could have been generated by executing this command:

```
sams -o dp hel.sams
```

These are automatically generated documentation files (their nature and purpose were previously described) that have nothing to do with the operation of the interface itself.

A definitive description of **sams** and the contents of **sams** files can be found in the **sams(1dce)** reference page.

3.3 DCE Messaging Routines

There are several different DCE messaging routines. It is possible for an application to accomplish all of its messaging tasks with only one or two of these routines (**dce_printf()** and **dce_error_inq_text()**); additional routines allow applications to perform manipulations on message tables, open and close message catalogs explicitly, retrieve messages without printing them, and so on. The complete list of routines is as follows:

- Message output routines

  These routines retrieve and output a specified message. If necessary, the message catalog is opened.

  — **dce_printf()**

  - **dce_fprintf()**
  - **dce_sprintf()**
  - **dce_pgm_printf()**
  - **dce_pgm_sprintf()**
  - **dce_pgm_fprintf()**

- Message retrieval routines

  These routines retrieve a specified message. If necessary, the message catalog is opened.

  - **dce_msg_get_msg()**
  - **dce_msg_get()**
  - **dce_msg_get_default_msg()**
  - **dce_error_inq_text()**

- Message table routines

  Miscellaneous routines for manipulating in-memory message tables.

  - **dce_msg_define_msg_table()**
  - **dce_msg_translate_table()**

- DCE XPG4 routines

  DCE versions of the XPG messaging routines **catopen()**, **catgets()**, and **catclose()**.

  - **dce_msg_cat_open()**
  - **dce_msg_cat_get_msg()**
  - **dce_msg_get_cat_msg()**
  - **dce_msg_cat_close()**

Generally speaking, routines that retrieve or print messages will first try to get a message from the message catalog file (the routines deduce the correct message catalog from the message ID that is passed to them). Routines will look for the catalog in the current locale's system-specific location for correctly installed message catalogs.

If the message catalog cannot be found, and an in-memory message table has been defined, the message will be retrieved from there.

The only exception to this message-finding algorithm occurs with **dce_msg_get_default_msg()**, which always attempts to retrieve the in-memory message only.

The following sections describe each of the DCE messaging routines in detail. Complete reference pages for the routines can be found in the *DCE 1.2.2 Application Development Reference*.

3.3.1 Message Output Routines

The six message output routines in this group essentially reproduce the functionality of **printf()**, **fprintf()**, and **sprintf()**, with the difference being that they operate on a specified message rather than on a string variable. The routines can be called without any special preparation (but see the descriptions of the three **dce_pgm_** routines).

dce_fprintf()

Retrieves the message text associated with the specified message ID, and prints the message and its arguments on the specified stream. The message is printed *without* a concluding newline; if a newline is desired at the end of the message, then it should be coded (as **\n**) in the message definition in the **sams** file.

The routine determines the correct message catalog and, if necessary, opens it. If the message catalog is inaccessible, and the message exists in an in-memory table, then this message (the default message) is printed. If for any reason the message cannot be retrieved, an error message is printed.

dce_printf() Performs a **dce_fprintf()** of the specified message to standard output.

dce_sprintf()

Retrieves the message text associated with the specified message ID, and writes the message and its arguments into an allocated string (which should be freed by the caller). The routine determines the correct message catalog and, if necessary, opens it. If the message catalog is inaccessible, and the message exists in an in-memory table, then this message (the default message) is printed. If for any reason the message cannot be retrieved, an error message is printed.

For example, assume that the following message is defined in an application's **sams** file:

```
start
code         arg_msg
text         "This message has exactly %d not %d argument(s)"
action       "None required"
explanation  "Test message with format arguments"
end
```

The following code fragment shows how **dce_sprintf()** might be called to write the message (with some argument values) into a string:

```
unsigned char     *my_msg;

my_msg = dce_sprintf(arg_msg, 2, 8);

/* Process my_msg as appropriate...    */

free(my_msg);
```

Of course, **dce_printf()** could also be called to print the message and arguments:

```
dce_printf(arg_msg, 2, 8);
```

dce_pgm_printf()

Equivalent to **dce_printf()**, except that it prefixes the program name to the message (in the standard style of DCE error messages), whereas **dce_printf()** does not. This allows clients (which do not usually use the serviceability interface) to produce error (or other) messages that automatically include the originating application's name. The message is printed with a concluding newline.

Note that the client should call **dce_svc_set_progname()** first to set the desired application name. Otherwise, the default program name will be

PID#*nnnn*

where *nnnn* is the process ID of the application making the call.

dce_pgm_sprintf()

Equivalent to **dce_sprintf()**, except that it prefixes the program name to the string (in the standard style of DCE error messages), whereas **dce_sprintf()** does not. Note that the client must call **dce_svc_set_progname()** first to set the desired application name.

Otherwise, the default name is

PID#*nnnn*

where *nnnn* is the process ID of the application making the call.

dce_pgm_fprintf()

Equivalent to **dce_fprintf()**, except that it prefixes the program name to the string (in the standard style of DCE error messages), whereas **dce_fprintf()** does not. The message is printed with a concluding newline.

Note that the client must call **dce_svc_set_progname()** first to set the desired application name. Otherwise, the default name is

PID#*nnnn*

where *nnnn* is the process ID of the application making the call.

dce_error_inq_text()

Opens a message catalog, extracts a message identified by a message ID, and places the message in the space pointed to by the *text* parameter. If the message catalog is inaccessible, and there is a default message in memory, the default message is copied into the space passed. If neither the catalog nor the default message is available, a status code is placed in the status output parameter and the message is returned as a hexadecimal number; the routine always returns a printable message.

This routine existed in prior releases of DCE and has been modified for DCE Version 1.1 to use the default message arrays. Programs prior to Version 1.1 that use the routine do not need to be modified.

For example, assume that the following message is defined in an application's **sams** file:

```
start
code          error_msg
text          "Error: %s"
action        ""
explanation   "DCE error status message"
end
```

The following code fragment shows how **dce_error_inq_text()** could be used to retrieve the error status received from a DCE routine:

```
dce_error_string_t  error_string;
unsigned32          status;
int                 error_inq_status;
uuid_t              type_uuid, obj_uuid;

             <. . .>

rpc_object_set_type(&obj_uuid, &type_uuid, &status);
if (status != rpc_s_ok)
{
  dce_error_inq_text(status, error_string, \
                     &error_inq_status);
  dce_printf(error_msg, error_string);
}
```

3.3.2 Message Retrieval Routines

The following three routines retrieve messages, but do not print them.

dce_msg_get_msg()
Retrieves a message (identified by a global message ID) from a message catalog, and returns a pointer to a **malloc()**'d space containing the

message. The routine determines the correct message catalog and opens it. If the message catalog is inaccessible, and the message exists in an in-memory table, then this message (the default message) is returned in the allocated space. If neither the catalog nor the default message is available, an error status code is placed in the status output parameter.

The following code fragment shows how **dce_msg_get_msg()** might be called to retrieve the ‘‘Hello World’’ message defined in the example program earlier in this chapter:

```
#include <dce/dce.h>
#include <dce/dce_msg.h>
#include "dcehelmsg.h"

unsigned char       *my_msg;
unsigned32          status;

             <. . .>

my_msg = dce_msg_get_msg(hello_msg, &status);
printf("Message is: %s\n", my_msg);
free(my_msg);
```

dce_msg_get()

This is a convenience form of **dce_msg_get_msg()**. If it fails, it does not pass back or return a status code, but instead fails with an assertion error, that is, aborts the calling process.

The following code fragment shows how the routine might be called to retrieve the ‘‘Hello World’’ message defined in the example program earlier in this chapter:

```
#include <dce/dce.h>
#include <dce/dce_msg.h>
#include "dcehelmsg.h"

unsigned char       *my_msg;
```

```
            <. . .>

my_msg = dce_msg_get(hello_msg);
printf("Message is: %s\n", my_msg);
free(my_msg);
```

dce_msg_get_default_msg()

Retrieves a message (identified by a global message ID) from an in-memory message table and returns a pointer to static space containing the message retrieved. If the default message is not available, an error status code is placed in the status output parameter.

The following code fragment shows how **dce_msg_get_default_msg()** might be called to retrieve the in-memory copy of the ‘‘Hello World’’ message defined in the example program earlier in this chapter:

```
#include <dce/dce.h>
#include <dce/dce_msg.h>
#include "dcehelmsg.h"

unsigned char       *my_msg;
unsigned32          status;

            <. . .>

my_msg = dce_msg_get_default_msg(hello_msg, &status);
printf("Message is: %s\n", my_msg);
```

Note that, in order for this call to be successful, **dce_msg_define_msg_table()** must first have been called to set the table up in memory. For an example of how this is done, see the following section.

3.3.3 Message Table Routines

The two routines in this group are intended to be used to perform manipulations on the in-memory message table.

The in-memory table is implemented with code generated by **sams** and contained in the **dce** *cmp* **msg.c** module (where *cmp* is the component name of the application, as specified in the **component** field in part I of the **sams** file). This file must then be compiled and linked with the application, and **dce_msg_define_msg_table()** is called at runtime to set up the table.

Note that, even if an in-memory table is defined, the DCE messaging routines still will always attempt first to extract the specified message from the message catalog, and only if unsuccessful will they revert to the in-memory table. The exception to this rule is **dce_msg_get_default_msg()**, which always attempts to retrieve the in-memory message only.

dce_msg_define_msg_table()

Installs a default in-memory message table accessible to DCE messaging routines. This routine is intended to be used by programs that load all messages from a catalog into memory in order to avoid file access overhead on message retrieval.

The following code fragment shows how **dce_msg_define_msg_table()** might be called to set up an in-memory message table consisting of the contents of the messages defined in **hel.sams** earlier in this chapter:

```
#include <dce/dce.h>
#include <dce/dce_msg.h>
#include "dcehelmsg.h"

unsigned32          status;

             <. . .>

dce_msg_define_msg_table(hel_msg_table,
 sizeof(hel_msg_table) / sizeof(hel_msg_table[0]),
                         &status);
```

dce_msg_translate_table()

Makes a new copy of the specified in-memory message table (that is, updates the table with the contents of a message table, which has changed because of a change in locale).

Note that this routine will fail if the message catalog is not installed or if **LANG** is not properly set, since the update depends on accessing the contents of the message catalog (unlike the initial table setup, which is done from the code in the **dce***cmp***msg.c** file).

The following code fragment shows how **dce_msg_translate_table()** might be called to translate the in-memory table that was set up by the call to **dce_msg_define_msg_table()** in the previous example:

```
#include <dce/dce.h>
#include <dce/dce_msg.h>
#include <locale.h>
#include "dcehelmsg.h"

char                *loc_return;
unsigned32          status;

             <. . .>

loc_return = setlocale(LC_MESSAGES, "C");
dce_msg_translate_table(hel_msg_table,
 sizeof(hel_msg_table) / sizeof(hel_msg_table[0]),
                        &status);
```

3.3.4 DCE XPG4 Routines

The four routines in this group provide DCE versions of functionality of the XPG messaging routines **catopen**(), **catgets()** , and **catclose**().

dce_msg_cat_open()

(DCE abstraction over **catopen**()) Opens a message catalog identified by a message ID. The routine returns a handle to the open catalog from which messages will be extracted. This routine is intended for use by applications (such as user interface programs) that display many messages from a particular catalog.

The routine will fail if the message catalog is not installed or if **LANG** is not properly set.

The following code fragment shows how **dce_msg_cat_open()** might be called to open the message catalog containing the ‘‘Hello World’’ message defined for the example application earlier in this chapter:

```
#include <dce/dce.h>
#include <dce/dce_msg.h>
#include "dcehelmsg.h"

dce_msg_cat_handle_t    hel_msg_handle;
unsigned32              status;

             <. . .>

hel_msg_handle = dce_msg_cat_open(hello_msg, &status);
```

dce_msg_cat_get_msg()

(DCE abstraction over **catgets()**) Retrieves a message from an open catalog. If the message is not available, returns NULL.

The routine will fail if the message catalog is not installed or if **LANG** is not properly set.

The following code fragment shows how **dce_msg_cat_get_msg()** might be called to retrieve the ‘‘Hello World’’ message. Note that the message catalog must first be opened.

```
#include <dce/dce.h>
#include <dce/dce_msg.h>
#include "dcehelmsg.h"

dce_msg_cat_handle_t    hel_msg_handle;
unsigned32              status;
unsigned_char_t         *msg;

             <. . .>

hel_msg_handle = dce_msg_cat_open(hello_msg, &status);
```

```
msg = (unsigned_char_t *)dce_msg_cat_get_msg(hel_msg_handle,
                                             hello_msg,
                                             &status);
printf("Message from dce_msg_cat_get_msg == %s\n", msg);
```

dce_msg_get_cat_msg()

Convenience form of previous routine. Opens a message catalog, extracts a message identified by a global message ID, and returns a pointer to **malloc()**'d space containing the message. If the message catalog is inaccessible, returns an error.

The routine will fail if the message catalog is not installed or if **LANG** is not properly set.

The following code fragment shows how **dce_msg_get_cat_msg()** might be called to retrieve the ''Hello World'' message:

```
#include <dce/dce.h>
#include <dce/dce_msg.h>
#include "dcehelmsg.h"

unsigned32              status;
unsigned_char_t         *msg;

             <. . .>

msg = dce_msg_get_cat_msg(hello_msg, &status);
printf("Message from dce_msg_get_cat_msg == %s\n", msg);
```

dce_msg_cat_close()

(DCE abstraction over **catclose()**) Closes the catalog specified by *handle*.

The following code fragment shows how **dce_msg_cat_close()** might be called to close the message catalog containing the ''Hello World'' message:

```
#include <dce/dce.h>
#include <dce/dce_msg.h>
#include "dcehelmsg.h"

dce_msg_cat_handle_t    hel_msg_handle;
unsigned32              status;

             <. . .>

dce_msg_cat_close(hel_msg_handle, &status);
```

Chapter 4

Using the DCE Serviceability Application Interface

DCE serviceability was originally developed simply as a way of standardizing server messages. The goal of its design was to make sure that all situations requiring human intervention that can be encountered by a server are documented and identified (both by the server when reporting them, and by the documentation when explaining them) in a standard coordinated way so that system administrators can easily determine the proper corrective action to take in response. Both the server message text and the relevant documentation are derived from the same source (that is, a **.sams** input file), which minimizes the possibility of any discrepancies appearing between the two.

The serviceability component is used by the DCE components (RPC, DTS, Security, and so on) for their server messaging, and it is made available as an API for use by DCE application programmers who wish to standardize their applications' server messaging. (The DCE components are required to use the serviceability routines, but applications are not.)

4.1 Overview

Serviceability uses XPG4 message catalogs to hold message text, but it adds an additional layer to the XPG4 functionality. The message catalogs and other required data (and documentation) files are generated by a utility called **sams** (symbols and message strings). Its input is a text file that establishes some organizational information about the program that is to use the messages, followed by a series of specifications of the messages themselves.

Each message specification contains, along with the message text itself, a detailed explanation of the situation in which the message will be displayed, together with a description of the action required, where applicable, to correct the situation. Part of the output of **sams** thus consists of automatic documentation of all the messages writable via the serviceability API. This output was used as the basis of the contents of the *DCE 1.2.2 Problem Determination Guide* for the DCE component server messages.

Messages also have one or more *attributes* specified in the **sams** input file. The attributes fall into three broad categories: those that indicate message *severity*, those that specify message *routing*, and those that specify some *action* (usually some form of program exit) that should be taken immediately after the message is written. The effect of the presence of a severity attribute is to cause the message text to contain a severity-identifying string when displayed or written. The effect of the presence of a routing attribute is to cause the message to be routed by default to one of a couple of standard destinations (more flexible routing is available dynamically). The effect of the presence of an action attribute is to cause the program to terminate execution in one of three ways as soon as the message has been written or displayed, or to cause a special short form of the message to be generated.

The serviceability API can also be used by DCE applications. The advantage in using it consists mainly in the following:

- It allows all application messaging to be routed uniformly, on the basis of the severity of the message and the functional part of the program originating the message.
- It allows application messages to be made self-documenting.

Serviceability also contains facilities for debug messaging, which can be compiled in or out of executables and which can be activated and routed by component at nine different levels.

4.1.1 How Programs Use Serviceability

The DCE serviceability mechanism uses XPG4 message catalogs to hold message text. Additional files contain the messages' associated documentation and other extra information used by the mechanism. All of these files, including the message catalog, are generated in a single step by running the DCE **sams** utility. The input to **sams** is a single **sams** file that is written by the developer, and which contains all the necessary information (text, documentation, additional information) for each message. The message catalogs and associated information generated by **sams** are then accessed whenever **dce_svc_printf()** or one of the other serviceability routines is called to print or log a message.

Thus, the result of converting a program to use serviceability will essentially be that all **printf()**, **fprintf()**, and other such routines will be replaced by calls to **dce_svc_printf()** or one of the related serviceability routines. For example, a line of code such as the first one that follows would be replaced by the second:

```
fprintf(stderr, "File %s not found\n", filename);

dce_svc_printf(DCE_SVC(cmp_svc_handle, ""), cmp_s_server, \
  svc_c_sev_error, cmp_s_file_not_found, filename);
```

where the constants *cmp*_**s_server** and *cmp*_**s_file_not_found** were generated by **sams**, and identify the server subcomponent of the application and the message to be written, respectively. The *cmp*_**svc_handle** constant is the application's handle to its serviceability message tables and other necessary data; *cmp*_**s_server** is actually an index to a subtable within this dynamically generated area, and *cmp*_**s_file_not_found** is the index of the message text within the subtable.

By convention, *cmp* is a three-character code identifying the application as a whole; serviceability uses it to group all of an application's message and table data together. Specifying **svc_c_sev_error** gives the message the severity of error; the significance of severity in serviceability will be explained in the following sections. **DCE_SVC()** is a macro that helps simplify the coding of **dce_svc_printf()** calls; as will be seen, another macro mechanism can be used to make the calls much simpler still.

4.1.2 Simple Serviceability Interface Tutorial

In this section, we'll see how to go about creating a simple C program that uses the serviceability interface to print the familiar ''Hello World'' message.

All that is necessary to do this is to replace the first call that follows with something like the second:

```
printf("Hello World\n");

dce_svc_printf(hello_world_message);
```

However, making the **dce_svc_printf()** call requires the following preliminary steps:

1. Defining the message in a **sams** file.
2. Processing the **sams** file to obtain a set of files that contain code used by the serviceability routines.
3. Coding some serviceability initialization calls into the C program itself.
4. Coding the **dce_svc_printf()** call.

The next several sections describe each of these steps.

4.1.2.1 Defining the Message

In order to print any message through the serviceability interface, we must first define the message in a **sams** file and process the file with the **sams** utility. For the **hello_svc** program, we will define a **sams** file with the bare minimum contents necessary. Additional information on the use of **sams** can be found in the **sams(1dce)** reference page.

Each line in a **sams** file consists of a simple *header* and *value* combination. The *header* indicates the meaning of the value being specified, and *value* is the value itself. A **sams** file for serviceability use is made up of three parts. The first part consists of a minimum of one line that specifies the name of the *component* (that is, the application) that is to use the messages that will be generated from the file.

The component name that you specify at the top of a **sams** file must consist of a three-character (no more, no less) string. For the ‘‘Hello World’’ program, we will use the component name **hel**:

```
# Part I of simple sams file ...
component           hel
```

The **hel** string will be used to identify all the files and data structures that **sams** will generate from the file.

The second part of the **sams** file contains some additional serviceability-specific information about the message data structures that will be generated. (This information is necessary if the **sams** file is intended for serviceability use because **sams** is also used to generate message files for general, nonserviceability use.)

This part of the file specifies the names of the serviceability *table* and the serviceability *handle*. It also contains a list of the component’s *subcomponents*. A subcomponent consists of a distinct functional module of executing code. For example, most distributed applications would have a basic server subcomponent, a reference monitor subcomponent that would handle authorization decisions, and one or more subcomponents that would contain the application’s particular functionality.

The serviceability interface finds a component’s messages in one or more subtables, each one associated with a subcomponent. When the message is displayed or written, the associated subcomponent name is written in a field of the message. This allows messages to be distinguished during routing or other processing on the basis of the subcomponent with which they are associated.

Following is what the second part of our simplified sample **sams** file looks like. We call the serviceability table **hel_svc_table**, and we call the serviceability handle **hel_svc_handle**. Although we have used the three-letter component code **hel** in these names, we were under no obligation to do so; we could have named the table and the handle anything we wanted. (We will need to know both of these names when we make the call in the application to initialize the interface in preparation for displaying messages.)

A component must have at least one subcomponent specified in its **sams** file. Subcomponents are specified in this part simply by supplying their *table index*, their *name*, and their *descriptive id* in a series of separate lines, one per subcomponent and

each one beginning with the **sub-component** keyword, between a set of **start** and **end** keywords:

```
# Part II
serviceability table hel_svc_table handle hel_svc_handle
start
subcomponent   hel_s_main      "main"  hel_i_svc_main
end
```

In our example,

hel_s_main is the table index name for the subcomponent. Serviceability routines need this name in order to locate and print any of the subcomponent's messages.

main is the name of the subcomponent, specified in quotes.

hel_i_svc_main
is a name that will be used (later on in the file) to identify a message that describes the subcomponent.

(Note that **sams** assigns values to all of these indexes automatically.)

The third (and final) part of the **sams** file consists of a series of records that specify the messages themselves. Each record is delimited by the **start** and **end** keywords. Within each record, a series of keywords identifies the various information that each message consists of or has associated with it.

Our file will contain only one message, the text of which is to be ‘‘Hello World’’. The record that specifies it is as follows:

```
# Part III
start
code                hel_s_hello
subcomponent       hel_s_main
attributes          "svc_c_sev_notice | svc_c_route_stderr"
text                "Hello World"
explanation         "A short informational greeting"
action              "None required."
```

```
end
```

The keywords specified have the following meanings:

start Marks the beginning of a message definition. This keyword can optionally be followed by various values.

- A *number* following the keyword specifies that the ID that is generated by **sams** for the message should be based on (*number* multiplied by 100). This allows the ID numbers of messages that belong to the same subcomponent of an application to be in the same numerical subseries (**collection**), even if additional messages for subcomponents have to be added later on. If each subcomponent's first message is **start**ed with a **collection** number that allows for enough extra ID space in the previous subcomponent to accommodate a reasonable number of future additional definitions, then each subcomponent's ID series will be able to maintain its unbroken series.

  As mentioned, the default size of a **collection** number is 100. Thus, the following **collection** specification is interpreted as ''200'':

  ```
  start             2
  ```

  To change the default **collection** size, specify

  ```
  collection size dddd
  ```

  (where *dddd* is the **collection** size you desire) in a separate line in Part 1 of the **sams** file.

code Identifies the message.

sub-component
Identifies the subcomponent that will use the message. (This must also have been defined in Part II of the **sams** file.)

attributes Specifies various things about the message: what kind of message it is, how it is to be routed, and so on. Multiple attributes are specified by ORing their values together. In the example shown, the message

has the *severity* attribute **svc_c_sev_notice**, and the *routing* attribute **svc_c_route_stderr** ; the latter forces the message to be routed to **stderr** whenever it is written by a serviceability routine.

text Specifies the text of the message itself.

explanation Describes the meaning of the message. The text following this keyword is used to generate the documentation of the component's messages.

action Describes any action(s) that should be taken in response to the message. The text following this keyword is used to generate the documentation of the component's messages.

Not all the possible keywords are illustrated in our example, and, of those illustrated, only **code** and **text** are required in all circumstances. In the example, **explanation** and **action** have been specified because it is simpler at this point to do so than to leave them out, and **attributes** and **sub-component** have been specified for reasons that will be made clear later on.

This final part of the **sams** file also contains a series of one or more records that specify messages identifying each of the subcomponents themselves. Since our application has only one subcomponent, it contains only one such subcomponent-identifying message:

```
# Part IIIa
# Messages for serviceability table

start               !intable undocumented
code                hel_i_svc_main
text                "hello_svc main"
end
```

The keywords have the same meanings as they did in the ‘‘Hello World’’ message. A couple of flags have been specified after the **start** keyword. The first will cause the message to *not* be generated in the message table, and the second means that the message does not need any **explanation** or **action** text associated with it. By specifying **undocumented** (with **intable**, to cause the message to actually be generated even though it was to be undocumented) for the ‘‘Hello’’ message, we could have eliminated the **explanation** and **action** keywords there also.

4.1.2.2 Processing the **sams** File

The entire **sams** file for the **hello_svc** program is as follows:

```
# Part I
component           hel
table               hel_msg_table

# Part II
serviceability  table hel_svc_table handle hel_svc_handle
start
subcomponent   hel_s_main      "main"  hel_i_svc_main
end

# Part III
start
code                hel_s_hello
subcomponent       hel_s_main
attributes          "svc_c_sev_notice | svc_c_route_stderr"
text                "Hello World"
explanation         "?"
action              "None required."
end

# Part IIIa
start               !intable undocumented
code                hel_i_svc_main
text                "hello_svc main"
end
```

We create the file with these contents and name it **hel.sams** . It can be processed with the simple command that follows:

sams hel.sams

Running the command as shown will result in ten files being created:

dcehel.cat XPG4 message catalog file created by **gencat**. If you wish to use the message catalog, you must install it yourself. Its proper location is platform dependent.

dcehel.msg Message input file for **gencat**.

dcehelmac.h
Defines *convenience macros* for use with the serviceability interface to write serviceability messages.

dcehelmsg.c Code defining the in-memory table of message texts. By using this table, you can avoid depending on extracting message texts from the message catalog.

dcehelmsg.h Header file containing definitions for **dcehelmsg.c**.

dcehelmsg.sml
Code for a *DCE 1.2.2 Problem Determination Guide* subsection documenting the messages.

dcehelmsg.man
Code for a reference page subsection documenting the messages.

dcehelmsg.idx
Code for building an index for the *DCE 1.2.2 Problem Determination Guide* subsection.

dcehelsvc.c Code defining the serviceability table. (This is a separate table containing the serviceability subcomponent identifying messages specified at the end of the **sams** file.)

dcehelsvc.h Header file containing definitions for **dcehelsvc.c**.

Of these files, only the following are needed for the **hello_svc** program:

dcehelmac.h
Contains convenience macro code.

dcehelmsg.c Contains in-memory message table code.

dcehelmsg.h Contains definitions for in-memory message table code.

dcehelsvc.c Contains serviceability message table code.

dcehelsvc.h Contains definitions for serviceability message table code.

The three header files should be included into the program source code. The **dcehelmsg.c** and **dcehelsvc.c** modules should be compiled and linked with the program object module.

All that remains now is to create a simple C program that calls the necessary serviceability routines to output the ‘‘Hello World’’ message.

4.1.2.3 Coding the Serviceability Calls

The bare minimum required to initialize the serviceability interface and use it to display our message is

- Call **dce_svc_register()** to get a serviceability handle that we can pass to serviceability message routines.
- Call **dce_msg_define_msg_table()** to set up the in-memory message table.
- Call **dce_svc_printf()** to print the message.

To call **dce_svc_register()**, you must declare the serviceability handle that you defined in **hel.sams**:

```
#include "dcehelsvc.h"

             <. . .>

dce_svc_handle_t  hel_svc_handle;
unsigned32        status;

             <. . .>

hel_svc_handle = dce_svc_register(hel_svc_table, \
  (idl_char*)"hel", &status);
if (status != svc_s_ok)
{
    printf("dce_svc_register failed\n");
    exit(1);
}
```

This call is the only initialization we need if we have installed our message catalog and are willing to depend on the message(s) being extracted from there. However, if we wish to have the messages available in program memory (and thus not depend on the catalog's being correctly installed), then we have to call **dce_msg_define_msg_table()** to initialize the in-memory table, as follows:

```
#include <dce/dce_msg.h>
#include "dcehelmsg.h"

             <. . .>

dce_msg_define_msg_table(hel_msg_table,
     sizeof(hel_msg_table) / sizeof(hel_msg_table[0]),
                         &status);
if (status != svc_s_ok)
{
    printf("dce_svc_define_msg_table failed\n");
    exit(1);
}
```

Now we can call **dce_svc_printf()** to print the message, as follows:

```
#include "dcehelmac.h"

             <. . .>

dce_svc_printf(HEL_S_HELLO_MSG);
```

Note the argument **HEL_S_HELLO_MSG**, which we did not define in the **hel.sams** file. **HEL_S_HELLO_MSG** is, in fact, a macro that was generated by **sams** from our definition for the **hel_s_hello** message, as you can see from the following code:

```
start
code                 hel_s_hello
subcomponent        hel_s_main
attributes           "svc_c_sev_notice | svc_c_route_stderr"
```

```
text                "Hello World"
explanation         "?"
action              "None required."
end
```

The macro automatically generates the long argument list that must be passed to **dce_svc_printf()** to get it to print the message. The code for this convenience macro is contained in **dcehelmac.h** .

A convenience macro is generated for every message in a **sams** file that has both **sub-component** and **attributes** specified. The macro's name is formed from the uppercase version of its **code** value (as specified in the **sams** file), with the string **_MSG** appended.

The complete source code for **hello_svc.c** is as follows:

```
#include <dce/dce.h>
#include <stdio.h>
#include <stdlib.h>
#include <stddef.h>
#include <dce/utctypes.h>
#include <pthread.h>
#include <dce/dce_msg.h>

#include "hel_svc.h"
#include <dce/dcesvcmsg.h>
#include "dcehelmsg.h"
#include "dcehelsvc.h"
#include "dcehelmac.h"

int main( int  argc,
          char *argv[] )
{

    dce_svc_handle_t    hel_svc_handle;
    unsigned32          status;

    hel_svc_handle = dce_svc_register(hel_svc_table, \
      (idl_char*)"hel", &status);
```

```
    if (status != svc_s_ok)
    {
            printf("dce_svc_register failed\n");
            exit(1);
    }

    dce_msg_define_msg_table(hel_msg_table,
          sizeof(hel_msg_table) / sizeof(hel_msg_table[0]),
                             &status);
    if (status != svc_s_ok)
            printf("dce_svc_define_msg_table failed \
                  -- will use catalogs\n");

    dce_svc_printf(HEL_S_HELLO_MSG);

}
```

4.1.2.4 Building and Running the Program

To build the application, you simply perform these steps:

1. Process the **hel.sams** file with the **sams** command
2. Build and link **hello_svc** from the following modules:
   - **dcehelmsg.c**
   - **dcehelsvc.c**
   - **hello_svc.c**

4.1.2.5 Fields of a Serviceability Message

When executed, the program will print a message similar to the following:

```
1994-04-05-20:13:34.500+00:00I----- PID#9467 \
         NOTICE hel main hello_svc.c 47 0xa444e208
```

```
Hello World
```

This message is made up of the following fields:

time inaccuracy process_ID severity component subcomponent src_file src_line thread_ID text

Where the field names have the following meanings:

time The time that the message was written, in ISO format:

CCYY-MM-DD-hh:mm:ss.fff[+|−]II:ii

Where the digit groups represent:

CCYY	Century and year
MM	Month
DD	Day
hh	Hour
mm	Minutes
ss	Seconds
fff	Fractions of second
II:ii	Time inaccuracy expressed in hours and minutes

The final groups represent a time differential factor (expressed in hours and minutes), followed by an inaccuracy component. For further information on time format, see Chapter 20.

process_ID The process ID of the program that wrote the message (**PID#9467** in the example). If **dce_svc_set_progname()** had been called to establish the application's program name, that name would appear in this field instead of the process ID. See Section 4.3.1 for further information.

severity The severity level of the message (**NOTICE** in the example).

component The component name of the program that wrote the message (**hel** in the example).

subcomponent
The subcomponent that wrote the message (**main** in the example; note that this program has only one subcomponent).

src_file The name of the C source file in which the **dce_svc_printf()** call was executed.

src_line The line number, in the source file, at which the **dce_svc_printf()** call is located.

thread_ID The thread ID of the thread that wrote the message, expressed as a hexadecimal number (**0xa444e208** in the example).

text The text of the message (**Hello World** in the example).

4.1.3 Serviceability Input and Output Files

Figure 4-1 shows the relationship of the various files, both source and **sams** output, that go to make up the **hello_svc** application.

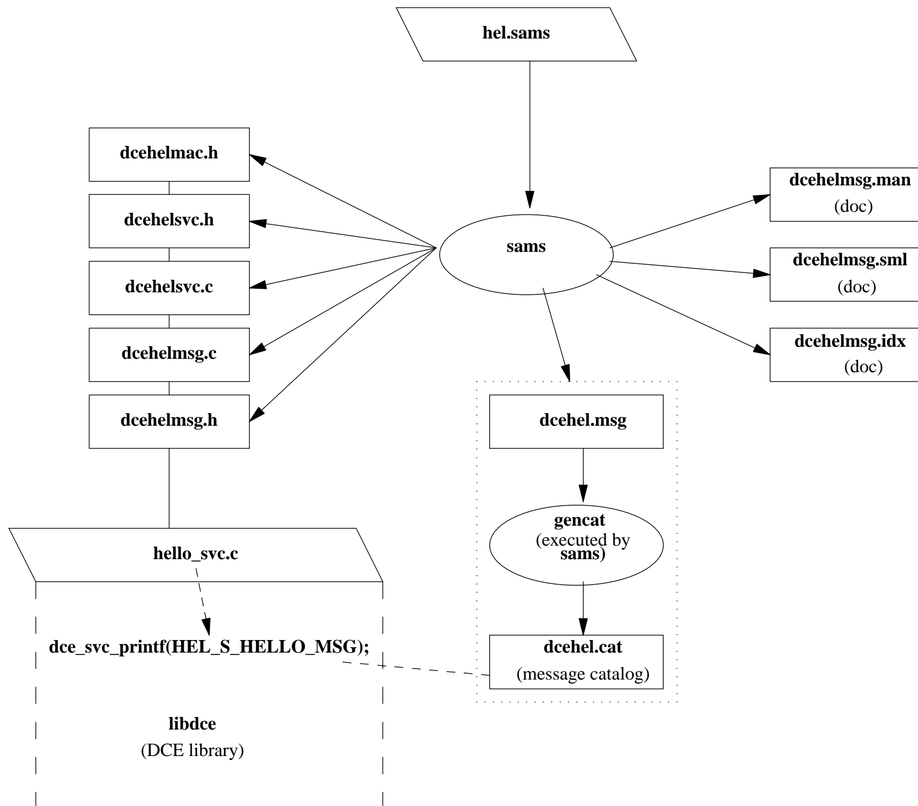
The two parallelogram-shaped objects represent the files that must be created by the developer (you).

Rectangular objects with solid lines represent files that are generated by **sams**; the two ovals represent programs: one is **sams**, the other **gencat** (which is implicitly run by **sams** when message catalogs are generated).

The large rectangular object in dashed lines represents **libdce** , which contains the serviceability library.

The diagram makes no attempt to show how **hello_svc.c** itself is compiled and linked, nor how it runs. It is just a static map of the general place of serviceability in DCE development.

Figure 4–1. Serviceability and DCE Applications



The **sams** output filenames are constructed as follows:

*tech_name***.***comp_name***.***part_name***.***extension*

where:

tech_name Is the technology name (optionally specified at the top of the **hel.sams** file); by default it is **dce**.

comp_name Is the component name (specified at the top of the **hel.sams** file); in this case, **hel**.

part_name Is a substring identifying the particular file; for example, **svc** or **msg**, and so on. This piece of the name is omitted from the message catalog filenames (in our example, **dcehel.msg** and **dcehel.cat**).

extension Is the file extension (preceded by a **.** (dot) character).

Because we executed the simplest form of the **sams** command (that is, without specifying any output flags), the full repertory of **sams** output files was created, even though the following files were not needed for our application:

- **dcehel.msg** and **dcehel.cat**

  The file **dcehel.msg** is input to **gencat** when it is invoked by **sams** to create **dcehel.cat**, the message catalog. (Although our example application used in-memory tables, the serviceability routines always attempt to use the message catalog first.)

- **dcehelmsg.man** and **dcehelmsg.sgm**

  These are automatically generated documentation files (their nature and purpose were previously described) that have nothing to do with the operation of the interface itself.

The many additional features of serviceability will be described in the following sections. A definitive description of **sams** and the contents of **sams** files can be found on the **sams(1dce)** reference page.

4.2 Integrating Serviceability into a Server

The purpose of the preceding tutorial was simply to give a brief taste of what it feels like to use the interface. The main task involved in using serviceability does not, however, lie in mastering the mechanics of the interface, but rather in understanding the purpose of handling server messages in this way, and then applying this understanding in order to develop an effective and serviceable messaging strategy for one's own application.

4.2.1 Serviceability Strategy

The serviceability mechanism is designed to be used mainly for server informational and error messaging—that is, for messages that are of interest to those who are concerned with server maintenance and administration (in the broadest sense of these terms). The essential idea of the mechanism is that all server events that are significant for maintaining or restoring normal operation should be reported in messages that are made to be self-documenting so that (provided all significant events have been correctly identified and reported) users and administrators will by definition always be able to learn what action they should take whenever anything out of the ordinary occurs. User-prompted, interactive, client-generated messaging should be handled through the DCE messaging interface, which is described in Chapter 3.

It follows that serviceability is not just an interface; it is partly a state of mind. The first thing that a developer who wishes to use serviceability should do is examine his or her server code with a view to identifying all the *event points* that should be covered by serviceability calls. Once these have been determined, the **sams** file (containing the message definitions) should be written; the last step will be to insert the messaging calls into the code.

4.2.2 Components and Subcomponents

The very first step in incorporating serviceability into a server is to analyze it into functionally discrete modules (called *subcomponents*), each of which will usually be associated with a separate set of messages.

The program itself is regarded as the component. The main significance of subcomponents is that each one uses a separate part of the message table generated by **sams**, and every message is identified both by component and by subcomponent; message routing and the level of debug messaging can be specified separately by subcomponent.

4.2.3 Identifying Event Points

Once you have established the subcomponent organization of the server application, you can begin the work of identifying all the points in the server code at which events occur or can occur that require serviceability messaging.

Following is a list of the events and kinds of events that should be reported through the serviceability interface:

- Server startup

  Servers should report when they are started, when they have completed their initialization, and when they are ready to perform work. They should also indicate when they are going offline.

- Server exit

  All fatal exits should be reported as fatal errors, using the **svc_c_sev_fatal** severity attribute in a call to **dce_svc_printf()**. In other words, **exit()** or **abort()** should not be called directly; this ensures that all such fatal errors will be logged. For an explanation of severity level attributes, see Section 4.3.1.

- Other fatal errors

  Errors that make it impossible to proceed should be detected as close as possible to the point where the actual failure occurred. This class of error includes such impossible conditions as failure to successfully allocate memory, failure to open a configuration file for reading, failure to open a log file for writing, and so on.

- Impaired efficiency

  Conditions that may indicate system-level malfunction or poor performance should be reported as warnings. An example of such a situation (from one of the DCE components) would be the RPC runtime detecting that it is having to make an excessive number of retransmits.

- Significant routine activity

  Routine administrative actions should be reported as informational (**svc_c_sev_notice**) messages. Such activity includes creation, modification and deletion of tickets, threads, files, sockets, RPC endpoints, or other objects; message transfer, including name lookup, binding, and forwarding; directory maintenance (including caching, advertising, skulking, and replication); and database maintenance (including replication or synchronization).

- Data input syntax errors

  Routines that process data that could have been entered from a keyboard should fail gracefully (and not core dump, for example) if the data is syntactically incorrect. Serviceability can be used to report this kind of failure.

Once you have identified the points in your code that should be reported with serviceability messaging, the next step is to define the messages themselves (in the **sams** file) and code the serviceability calls. The serviceability features of **sams** files were described previously; the following sections describe the various parts of the serviceability interface itself.

Using the serviceability interface to report errors ensures that the error codes used will be unique within DCE.

4.3 Application Use of Serviceability

The following subsections describe in detail the various elements of the serviceability API and what you can do with them.

Complete reference pages for all the serviceability routines can be found in the *DCE 1.2.2 Application Development Reference*.

4.3.1 Basic Server Calls

The basic serviceability routines are the following:

- **DCE_SVC_DEFINE_HANDLE()**

  This is a macro that can be used instead of **dce_svc_register()** to register a table (it does this by means of a global variable created at compile time). It could have been used in the **hello_svc.c** code as follows, with exactly the same results as from using **dce_svc_register()**:

```
DCE_SVC_DEFINE_HANDLE(hel_svc_handle, hel_svc_table, "hel");
/*                        handle            |          |   */
```

```
/*                                           table          |    */
/*                                              component name  */
```

Note that either **DCE_SVC_DEFINE_HANDLE()** or **dce_svc_register()***must* be called before the interface can be used.

- **dce_svc_register()**

  This is the function call for registering a serviceability message table. Either it or **DCE_SVC_DEFINE_HANDLE()** must be called before any routines can be called to display or log messages. An example of its use can be seen in the illustrated **hello_svc.c** code.

- **dce_svc_unregister()**

  This is the function call for destroying a serviceability handle. Calling it closes any open message routes and frees all allocated resources associated with the handle. However, it is not usually necessary to call this routine since the normal process exit will perform the required cleanup.

  The routine could have been called at the end of the **hello_svc.c** application as follows:

```
dce_svc_unregister(hel_svc_handle, &status);
```

  where **hel_svc_handle** is the serviceability handle that was originally returned by the call to **dce_svc_register()**, or filled in by the **DCE_SVC_DEFINE_HANDLE()** call.

- **dce_svc_set_progname()**

  This function sets the application's *program name*, which is included in all messages. In this way, multiple programs can write messages to the same file and the messages will remain distinguishable.

  For example, this routine could have been called in the **hello_svc.c** code, as follows:

```
dce_svc_set_progname("hello_program", &status);
```

The message printed by the program would, as a result, have looked like the following:

```
1994-04-05-20:13:34.500+00:00I----- hello_program \
        NOTICE hel main ...
Hello World
```

instead of looking like this:

```
1994-04-05-20:13:34.500+00:00I----- PID#9467 NOTICE hel main ...
Hello World
```

where the default process ID information has been replaced by the string **hello_program** in the first example. The second example shows what the message looks like if the routine is not called. The **PID#** *nnnn* value is the value returned by **getpid()**.

This call is *optional*.

- **dce_svc_printf()**

  This is the normal call for writing or displaying serviceability messages. It cannot be called with a literal text argument; instead, the message text and other necessary information must be pre-specified in a file that is processed by the **sams** utility, which in turn outputs sets of tables from which the messages are extracted for output. The tutorial in Section 4.1.2 provides a brief example of how this is done.

  There are two main ways in which to call the routine. If a message has been defined in the **sams** file with both **sub-component** and **attributes** specified, then the **sams** output will include a convenience macro for the message that can be passed as the single argument to **dce_svc_printf()**, for example:

```
dce_svc_printf(HEL_S_HELLO_MSG);
```

The convenience macro's name will be generated from the uppercase version of the message's **code** value (as specified in the **sams** file), with the string **_MSG** appended.

If a convenience macro is not generated, or if you want to override some of the message's attributes at the time of output, then you must call the routine in its long form. For the **hel_s_hello** message, such a form of the call might look as follows:

```
dce_svc_printf(DCE_SVC(hel_svc_handle, ""), hel_s_main,\
  svc_c_sev_error | svc_c_route_stderr, hel_s_hello);
```

DCE_SVC() is a macro that *must* be passed as the first argument to **dce_svc_printf()** if a convenience macro is not being used. It takes two arguments:

— The caller's serviceability handle

— A format string for the message that is to be output

The format string is for use with messages that have been coded with argument specifiers. The **hel_s_hello** message had no argument specifiers, so an empty string is passed here to **DCE_SVC**. For an example of printing a message with arguments, see the end of this subsection.

The remaining arguments passed to **dce_svc_printf()** are as follows:

— Subcomponent table index

This symbol was declared in the **sub-component** list coded in Part II of the **sams** file; its value is used to index into the subtable of messages in which the desired message is located.

— Message attribute(s)

This argument consists of one or more attributes to be applied to the message that is to be printed. Note that you *must* specify at least a severity here (for a list of message severity values, see Section 4.3.3). Multiple attributes are ORed together, as shown in the example.

There are four categories of message attributes:

routing The available routing attribute constants are

- **svc_c_route_stderr**

- **svc_c_route_nolog**

However, most routing is done either by passing specially formatted strings to **dce_svc_routing()** or by environment variable values. See Section 4.3.4 for more detailed information.

severity — The available severity attribute constants are

- **svc_c_sev_fatal**
- **svc_c_sev_error**
- **svc_c_sev_warning**
- **svc_c_sev_notice**
- **svc_c_sev_notice_verbose**

For more detailed information, see Section 4.3.3.

action — The available message action attribute constants are

- **svc_c_action_abort**
- **svc_c_action_exit_bad**
- **svc_c_action_exit_ok**
- **svc_c_action_brief**

For more detailed information, see Section 4.3.7.

debug level — Nine different debug levels can be specified. For more detailed information, see Section 4.3.12.

— message ID

This argument consists of the message's **code**, as declared in the **sams** file.

As an example of how to use format specifiers in messages, consider the following **sams** file fragment, in which we define a second message for the **hello_svc.c** application:

```
start
code                hel_s_testmessage
text                "This message has exactly %d not %d argument(s)"
explanation         "This message is to show how to pass arguments"
action              "None required."
```

```
end
```

The message could be printed by a call like the following:

```
dce_svc_printf(DCE_SVC(hel_svc_handle, "%d%d"), hel_s_main,\
               svc_c_sev_notice | svc_c_route_stderr,\
               hel_s_testmessage, 2, 7);
```

Note the format specifiers passed in the format string to **DCE_SVC**, and the argument values passed at the end of the argument list. This call would cause the following message to be printed:

```
1994-04-06-20:06:33.113+00:00I----- hello \
          NOTICE hel main hello_svc.c line_nr 0xa444e208
This message has exactly 2 not 7 argument(s)
```

4.3.2 Extended Format Notation for Message Text

A slightly extended notation allows you to define message texts in the **sams** file that will (if desired) have format specifiers in their application code forms (that is, in the **.c** and **.msg** files output by **sams**), but which will be replaced by some specified string constant in the message texts that are generated for documentation use (that is, in the **.sml** and **.man** files).

The notation consists in surrounding the format specifier and alternative constant with < and > (angle bracket) characters, and separating the two with a | (vertical bar). (You can use a preceding \ (backslash) to escape these symbols.) For example, the following message text field:

```
text          Can't open input file %s for reading
```

would become something like the following:

```
text          Can't open input file <%s|filename> for reading
```

This message text definition, when processed by **sams**, would generate a format string with **%s** in the **.c** and message files, but this format specifier would be replaced by the string *filename* in the **.sml** and **.man** file versions.

4.3.3 Specifying Message Severity

Production (that is, nondebug) serviceability messages are categorized by their *severity level*, which implies various important things about the kind of situation that causes the message to be printed. Every message's severity is stated in the text of the message itself (for example, **NOTICE** in the examples given previously shows that the messages are informational notices), and the serviceability routines can route and process messages differently on the basis of their severity levels.

Severity levels are attached to messages either when the messages are defined (in the **sams** file) or when the messages are written (by specifying an argument to the routine writing the message). These severity levels can then be used at runtime as the basis on which to route the messages (the way this is done will be explained in the next section).

Thus, each severity level is represented by a *constant* by which it is specified in program code, and a *name* by which it is referred to in routing files and environment variables. Each level's name and constant is shown, together with an explanation, in Table 4-1.

Table 4–1. Serviceability Message Severities

Name	**Specifier**	**Meaning**
FATAL	**svc_c_sev_fatal**	A fatal error has occurred; the program is about to exit.
ERROR	**svc_c_sev_error**	An error has occurred.

WARNING	svc_c_sec_warning	An error has been detected; the program is continuing execution.
NOTICE	svc_c_sev_notice	A nonerror event has occurred; this message is an informational notice of it.
NOTICE_VERBOSE	svc_c_sev_notice_verbose	A nonerror event has occurred; this message is a verbose informational notice of it.

Detailed explanations of the levels are as follows:

FATAL Fatal error exit: An unrecoverable error (such as database corruption) has occurred which will probably require manual intervention to be corrected. The program usually terminates immediately after such an error.

ERROR Error detected: An unexpected event that is nonterminal (such as a timeout), or is correctable by human intervention, has occurred. The program will continue operation, although some functions or services may no longer be available. This severity level may also be used to indicate that a particular request or action could not be completed.

WARNING Correctible error: An error occurred that was automatically corrected (for example, a configuration file was not found, and default values were used instead). This severity level may also be used to indicate a condition that *may* be an error if the effects are undesirable (for example, removing all files as a side effect of removing a nonempty directory), or to indicate a condition which, if not corrected, will eventually result in an error (for example, a printer's running low on paper).

NOTICE Informational notice: A significant routine major event has occurred; for example, a server has started.

NOTICE_VERBOSE
Verbose information notice: A significant routine event has occurred; for example, a directory entry was removed.

Note that debug messages are identified as such by their own set of levels; see Section 4.3.12 for more information.

4.3.4 How to Route Messages

Serviceability messages can be written to any of the normal output destinations. Routing for serviceability messages can be specified in any of three different ways (in ascending order of precedence):

1. By the contents of a routing file
2. By the contents of a routing environment variable
3. By calling the **dce_svc_routing()** routine (often as part of processing an application's command-line arguments)

Additional routing (that is, in addition to whatever routing has been specified by the means described) of a message to standard error can be performed in either of the following two ways:

- By specifying the routing as one of the message's **attributes** (in the **sams** file definition of the message)
- By specifying the attribute in the call to **dce_svc_printf()** (or other serviceability output routine) to generate the message

Routing a message actually consists of specifying two things:

- How the message should be processed (the form it should be put in)
- Where the message should be sent (its destination)

The two specifications are sometimes closely interrelated, and sometimes specifying a certain destination implies that the message must be put into a certain form. This fact allows certain combinations of processing and destination to be abbreviated.

In the following sections, each of the ways to route serviceability messages is described.

Note that debug messages are routed by a similar, but slightly different, technique. For a full description, see Section 4.3.12.

4.3.4.1 Using a Routing File

If a file called *dce-local-path***/svc/routing** exists, the contents of the file (if in the proper format) will be used to determine the routing of messages written via serviceability routines.

The value of *dce-local-path* is usually **/opt/dcelocal**; the default location of the serviceability routing file is usually **/opt/dcelocal/svc/routing**. However, a different location for the file can be specified by setting the value of the environment variable **DCE_SVC_ROUTING_FILE** to the complete desired pathname.

The routing file consists of formatted strings specifying the routing desired for the various kinds of messages (based on message severity). Each string consists of three fields as follows:

*sev***:***out_form***:***dest***[;***out_form***:***dest* **. . .] [GOESTO:{***sev* | *comp***}]**

where:

sev
: Specifies the severity level of the message, and must be one of the following:

- **FATAL**
- **ERROR**
- **WARNING**
- **NOTICE**
- **NOTICE_VERBOSE**

The meanings of these severity levels are explained in detail in Section 4.3.3.

out_form
: (output form) Specifies how the messages of a given severity level should be processed, and must be one of the following:

BINFILE Write these messages as binary log entries.

TEXTFILE Write these messages as human-readable text.

FILE Equivalent to **TEXTFILE**.

DISCARD Do not record messages of this severity level.

STDOUT Write these messages as human-readable text to standard output.

STDERR Write these messages as human-readable text to standard error.

Files written as **BINFILE**s can be read and manipulated with a set of log file functions, or with the **svcdumplog** command. For further information, see Section 4.3.6.

The *out_form* specifier may be followed by a two-number specifier of the form:

.*gens***.***count*

where:

gens Is an integer that specifies the number of files (that is, generations) that should be kept.

count Is an integer specifying how many entries (that is, messages) should be written to each file.

The multiple files are named by appending a dot to the simple specified name, followed by the current generation number. When the number of entries in a file reaches the maximum specified by *count*, the file is closed, the generation number is incremented, and the next file is opened. When the maximum generation number files have been created and filled, the generation number is reset to 1, and a new file with that number is created and written to (thus overwriting the already-existing file with the same name), and so on, as long as messages are being written. Thus the files wrap around to their beginning, and the total number of log files never exceeds *gens*, although messages continue to be written as long as the program continues writing them.

dest (destination) Specifies where the message should be sent and is a pathname. The field can be left blank if the *out_form* specified is **DISCARD**, **STDOUT**, or **STDERR**. The field can also contain a **%ld** string in the filename which, when the file is written, will be replaced by the process ID of the program that wrote the message(s). Filenames may *not* contain colons, semicolons, or periods.

Multiple routings for the same severity level can be specified by simply adding the additional desired routings as semicolon-separated strings in the following format:

*out_form***:***dest*

For example, consider the following:

```
FATAL:TEXTFILE:/dev/console
WARNING:DISCARD:--
NOTICE:BINFILE.50.100:/tmp/log%ld;STDERR:-
```

These strings specify that

- Fatal error messages should be sent to the console.
- Warnings should be discarded.
- Notices should be written both to standard error and as binary entries in files located in the **/tmp** directory. No more than 50 files should be written, and there should be no more than 100 messages written to each file. The files will have names of the form

  /tmp/log*process_id***.***nn*

  where *process_id* is the process ID of the program originating the messages, and *nn* is the generation number of the file.

The **GOESTO** specifier allows messages for the severity whose routing specification it appears in to be routed to the same destination (and in the same output form) as those for the other, specified, severity level (or component name). For example, the following specification:

```
WARNING:STDERR:;GOESTO:FATAL
FATAL:STDERR:;FILE:/tmp/foo
```

means that **WARNING** messages should show up in three places: twice to **stderr**, and then once to the file **/tmp/foo**.

Note that a **GOESTO** specification should be the last element in a multidestination route specification.

4.3.4.2 Routing by Environment Variable

Serviceability message routing can also be specified by the contents of certain environment variables. If environment variables are used, the routes they specify will override any conflicting routings specified by a routing file.

The routings are specified (on the basis of severity level) by putting the desired routing instructions in the following environment variables:

- **SVC_FATAL**
- **SVC_ERROR**
- **SVC_WARNING**
- **SVC_NOTICE**
- **SVC_NOTICE_VERBOSE**

Each variable should contain a single string in the following format:

*out_form***:***dest***;[***out_form***:***dest* **. . .] [GOESTO:{***sev* **|** *comp***}]**

where *out_form* and *dest* have the same meanings and form as described in Section 4.3.4.1. Multiple routings can be specified with semicolon-separated additional strings specifying the additional routes, as shown.

4.3.4.3 Calling **dce_svc_routing()** to Set Routing

Message routing can be set up by the application itself, by calling the routine **dce_svc_routing()** and passing to it a string formatted in the same way as a line

of text from a routing file. The routine must be called separately for each severity level. When routing is specified this way, the routings so specified will override any conflicting routings specified by environment variable or routing file (as described in the preceding sections). This is especially useful for setting routes from command-line arguments.

For example, to set routing in this way for the **hello_svc.c** application described previously, use the following code:

```
unsigned_char_t *my_route = "NOTICE:STDOUT:-;TEXTFILE:/tmp/my_log";
unsigned_char_t *error_route = "ERROR:TEXTFILE:/tmp/errors_%ld";

dce_svc_routing(my_route, &status);
if (status != svc_s_ok)
{
printf("dce_svc_routing failed\n");
exit(1);
}

dce_svc_routing(error_route, &status);
if (status != svc_s_ok)
{
printf("dce_svc_routing failed\n");
exit(1);
}
```

4.3.4.4 Additional Routing by Attribute

Limited additional routing for messages can be specified by attribute, either in the message definition itself in the **sams** file or as part of the argument list to **dce_svc_printf()**. Two routing attribute specifiers are available:

svc_c_route_stderr
Route the message to standard error.

svc_c_route_nolog
Discard the message.

Note also the **svc_c_action_brief** attribute, which is described in Section 4.3.7.

4.3.5 Table of Message Processing Specifiers

As was seen, message processing can be specified either by text strings (read from an environment variable or routing file, or passed to a routine) or, to a limited degree, by attribute in the message definition or when the message is output. Table 4-2 shows all the available types of serviceability message processing; the *name* by which it is specified in strings, and the *attribute* (where it exists) by which it is specified in message definitions and calls are both given, along with the meaning of each.

Table 4–2. Serviceability Message Processing Specifiers

Name	Attribute	Meaning
BINFILE		Write binary log entry.
TEXTFILE		Write human-readable text.
FILE		Equivalent to **TEXTFILE**.
DISCARD	**svc_c_route_nolog**	Do not record.
STDOUT		Write human-readable text to standard output.
STDERR	**svc_c_route_stderr**	Write human-readable text to standard error.
GOESTO		Route messages in same way as named level or component.

4.3.6 Logging and Log Reading

The serviceability interface includes a set of functions for reading and manipulating log files written as **BINFILE**s (see Section 4.3.4.1).

dce_svc_log_open()
Opens a log file for reading.

dce_svc_log_get()
Reads the next entry from a log file. It returns the contents thereof in the form of a filled-in **prolog** structure to which it returns a pointer (see below for a description of the structure fields).

dce_svc_log_rewind()
Returns log processing back to the first message in the log file.

dce_svc_log_close()
Closes the open log file.

The contents of the log **prolog** structure (defined in **dce/svclog.h**) are as follows:

int *version* Version number of the interface that generated the message.

utc_t *t* Pointer to an opaque binary timestamp containing the time at which the message was written. The opaque timestamp can be converted to a **tm** structure by calling one of the DCE DTS **utc_***xxx* **()** routines.

unsigned32 *attributes*
Message attributes, ORed together (a bit flag).

unsigned32 *message_index*
Index number of message in message table (for example, **hel_s_hello** in the example at the beginning of this chapter).

pthread_t *thread_id*
ID of application thread that caused the message to be written.

char **argtypes*
The format-specifier string for the message.

int *argtypes_size*
The number of format specifiers for the message.

char **fac_name*
The component or subcomponent (‘‘facility’’) name string.

char **message_text*
Message text string.

char **progname*
Program name string, set by the application’s call to **dce_svc_set_progname()**.

char **file*
: Filename string identifying file from which entry was read.

int *line*
: Line number in *file* from where the message was printed.

int *file_size*
: Length of filename string.

4.3.7 Message Action Attributes

Routing and severity attributes affect what happens to the messages they are applied to, and nothing else. However, there is an additional set of attributes that, when applied to a message, mainly affect *what happens to the program* after the message is sent:

svc_c_action_abort
: Causes the program to abort (with core dump) as soon as the message is output.

svc_c_action_exit_bad
: Causes the program to exit (with failure status) as soon as the message is output.

svc_c_action_exit_ok
: Causes the program to exit (with successful status) as soon as the message is output.

svc_c_action_brief
: Suppresses the standard *prolog* of the message. The prolog of a serviceability includes all the nonmessage information that is output before the message text itself. The prologs of all messages can be suppressed by setting the **SVC_BRIEF** environment variable; see the next section.

4.3.8 Suppressing the Serviceability Message Prolog

You can suppress the prolog (nonmessage text) part of all serviceability messages generated by an application by setting the value of the **SVC_BRIEF** environment variable to 1.

The prolog of a serviceability consists of all the nonmessage information that is output before the message text itself. For example, examine the following message:

```
1994-04-05-20:13:34.500+00:00I----- PID#9467 \
          NOTICE hel main hello_svc.c  line_nr 0xa444e208
Hello World
```

In this example, the first line is the message prolog, and the second line is the message text. If the message were generated with the **SVC_BRIEF** environment variable set to 1, the message would appear as follows:

```
Hello World
```

Prologs of separate messages can be suppressed selectively through the use of the **svc_c_action_brief** attribute; see the previous section.

4.3.9 Serviceability Use of the __FILE__ Macro

Whenever a serviceability message is generated, information identifying the source file and line at which the invoked routine was called is included in the message information. This information appears in the text-form nonerror messages, and it is also written into the binary form serviceability logs (when binary logs are specified). The information also appears in the text form of messages announcing error situations. For example:

```
1994-07-20-11:11:09.906-04:00I----- sample_server FATAL \
          smp server sample_server.c 2851 0xa44b0c18
server_renew_identity(): login context has not been certified \
          (dce / sec)
```

(The preprocessor variable **DCE_SVC_WANT__FILE__** (in **dce/dce_svc.h**) will be defined or undefined depending on whether or not the serviceability component has been set up on your system to include the filename and line number information in serviceability messages.)

The serviceability routines receive the source file information from **DCE_SVC__FILE__**, which, by default, is defined to be the C preprocessor macro **__FILE__**. However, if you desire to avoid these macro expansions in your application code, you can redefine the symbol to be some kind of variable. For example:

```
#define DCE_SVC__FILE__ myfile
#include <dce/dce.h>
static char myfile[] = __FILE__;
```

4.3.10 Forcing Use of the In-Memory Message Table

As described elsewhere in this chapter, the **dce_msg_define_msg_table()** routine can be called by an application to initialize an in-memory copy of its message table, thus freeing the application from depending on its message catalog's being properly installed for its serviceability messages to be properly generated.

However, the serviceability routines will still, by default, attempt first to retrieve a specified message from the message catalog, even if an in-memory table has been initialized; only if the message catalog cannot be found will the in-memory table be used.

You can change the default behavior of the serviceability routines by setting the **SVC_NOXPGCAT** environment variable to 1 (or any nonzero value). This will force the routines to always go to the in-memory table for the specified message; they will never look for the message catalog.

4.3.11 Dynamically Filtering Messages Before Output

The serviceability interface provides for a hook into the message-output mechanism that allows applications to decide at the time of messaging whether the given message should be output or not. The application defines its own routine to perform whatever checking is desired, and installs the routine with a call to **dce_svc_define_filter()**.

In addition, an application that installs such a message-filtering routine can also define and install a routine that can be called remotely to alter the operation of the filter routine. The remote-control routine is installed by the same call to **dce_svc_define_filter()**.

The two routines must have the following signatures. The yes/no routine you define and install is as follows:

```
boolean your_filter_routine(
                dce_svc_prolog_t prolog,
                va_list args)
```

The filter remote-control call is as follows:

```
void your_filter_remote_control(
                idl_long_int arg_size;
                idl_byte *arg;
                error_status_t *status)
```

Once installed, the filter routine will be automatically invoked every time a serviceability routine is called to output a message. The filter receives a *prolog* argument that contains all the pertinent information about the message. If the filter returns TRUE, the message is output per the original serviceability call. If the filter returns FALSE, the message is not output. The information in the *prolog* allows such decisions to be made on the basis of severity level, subcomponent, message index, and so on. Its fields are as follows:

dce_svc_handle_t *handle*
: Serviceability handle of the application writing the message.

int *version*
Version number of the interface that generated the message.

utc_t *t*
Pointer to an opaque binary timestamp containing the time at which the message was written. The opaque timestamp can be converted to a **tm** structure by calling one of the DCE DTS **utc_...()** routines.

const char **argtypes*
The format-specifier string for the message.

unsigned32 *table_index*
sams file in Section 4.1.2.1.

unsigned32 *attributes*
Message attributes, ORed together.

unsigned32 *message_index*
Index number of the message in the message table (for example, **hel_s_hello** in the example at the beginning of this chapter).

char **format*
Format argument values for the message.

const char **file*
Filename string identifying the file to which the message is to be output.

char *progname[dce_svc_c_progname_buffsize]*
Program name string, set by the application's call to **dce_svc_set_progname()**.

int *line*
Line number in *file* from where the message was printed.

pthread_t *thread_id*
ID of the application thread that is causing the message to be output.

The filter remote control routine is part of the remote serviceability interface, which is described in detail in Section 4.3.14. Its operation is simple. If filter remote control is desired, the filter routine should be coded so that its operation can be switched to the various desired alternatives by the values of static variables to which it has access. These variables are also accessible to the remote control routine, and can be changed by it. The filter routine receives an argument string (which it uses to set the variables) whose contents are entirely application defined.

The following code fragments show a skeleton filter that can be added to the **hello_svc.c** example at the beginning of this chapter:

```
#include <stdarg.h>
#include <dce/svcfilter.h>

             <. . .>

/*****
* Filter routine-- once installed, this routine will be called
*                  automatically every time a serviceability
*                  routine (in our case, dce_svc_printf()) is
*                  called to write a message.
*****/
boolean hel_filter(dce_svc_prolog_t   prolog,
                   va_list            args)
{

    /* Code could be inserted here to test the values of static
       variables that would control the operation of the filter,
       and which could be altered by calling the filter control
       routine below. */

    printf("The progname is %s\n", prolog->progname);

    if (prolog->attributes | svc_c_sev_notice)
        printf("This is a Notice-type message\n");

    switch (prolog->table_index)
    {
        case hel_s_main:
            printf("Main subcomponent\n");
            break;
        default:
            printf("Error\n");
            break;
    }
```

```
    /* The routine returns 1, thus permitting the output
       operation to go ahead; if 0 were returned here, the
       operation would be suppressed ... */

    return 1;

}

/*****
* Filter Control routine-- this routine is normally called
*                          through the remote interface.
*****/
void hel_filter_control(idl_long_int arg_size,
                        idl_byte *arg,
                        error_status_t *status)
{

    /* Code would be inserted here to interpret the arg passed
       and, on the basis of that, change the value(s) of one
       or more static variables that control the operation of
       hel_filter()                                          */

}

/*****
* install_filters-- calls dce_svc_define_filter() to install
*                   the above 2 routines.  Note that this must
*                   be done after dce_svc_register() is
*      called, not before.
*****/
void install_filters()
{
    unsigned32  status;

    dce_svc_define_filter(hel_svc_handle, hel_filter, \
      hel_filter_control, &status);
}
```

4.3.12 Using Serviceability for Debug Messages

Apart from the **dce_svc_printf()** routine for writing production serviceability messages, the interface provides several macros that can be used for debug messaging in a server. The advantages in using these macros in debugging are the following:

- All of the debug messaging code can easily be compiled in or out of the executable by changing the value of a compilation switch.
- Nine levels of debug messaging are provided for; the active level of debug messaging can be controlled through the remote serviceability interface or by a value passed to the server at startup.
- One of the macros allows message text to be specified in the call itself, rather than extracting it by message ID from the message table.

The debug serviceability messaging routines are the following:

- **DCE_SVC_LOG()**

  Outputs a message specified by the message ID. The main differences between using this routine and using **dce_svc_printf()** to write a message are (1) that **DCE_SVC_LOG()** generates records *only* in binary format, and (2) the macro can be compiled out of the executable by turning off debugging.

  Suppose the following message had been defined in the **hel.sams** file for the example application at the beginning of this chapter:

```
start
code                hel_s_debug_message_1
subcomponent        hel_s_main
attributes          "svc_c_debug3 | svc_c_route_stderr"
text                "This is a level 1 test debug message"
explanation         "Debug level 3 test"
action              "None required."
end
```

  The following call in **hello_svc.c** would have written this message as a binary record to the specified route, provided that debug level 3 had been activated:

```
DCE_SVC_LOG((HEL_S_DEBUG_MESSAGE_1_MSG));
```

Note the use of the double parentheses. This is made necessary by the fact that it is a macro that takes a variable number of arguments. Note also the use of the convenience macro form of the message. A full form of the call, with all arguments explicitly specified, would have been as follows:

```
DCE_SVC_LOG((DCE_SVC(hel_svc_handle, ""), \
     hel_s_main, svc_c_debug3, hel_s_debug_message_1));
/*       |           |                 |                */
/*  table_index      |                 |                */
/*              debug level            |                */
/*                                message ID            */
```

Debug messages, like normal serviceability messages, can also contain format specifiers and argument lists.

- **DCE_SVC_DEBUG()**

  Outputs a message whose text is specified in the call. For example, the following call could have appeared in **hello_svc.c**:

```
DCE_SVC_DEBUG((hel_svc_handle, \
/*                |                                     */
/*              handle                                  */
/*                                                      */
    hel_s_main, svc_c_debug2, "A Debug Level %d message", 2));
/*       |           |                  |                |  */
/* table_index       |                  |                |  */
/*             debug level              |                |  */
/*                                 message text          |  */
/*                                                argument */
```

Note here too the use of the double parentheses.

Note also that **DCE_SVC_DEBUG** cannot be used with the convenience macro forms of serviceability messages.

- **DCE_SVC_DEBUG_ATLEAST()**

  Tests the active debug level for a subcomponent. Returns TRUE if the debug level (set by calling **dce_svc_debug_set_levels()**; see Section 4.3.12.1) is not less than the specified level; otherwise returns FALSE. For example, the following call would return TRUE if the debug level for the **hel_s_main** subcomponent of the **hello_svc** application had been set to **svc_c_debug2** or any higher value:

  ```
  DCE_SVC_DEBUG_ATLEAST(hel_svc_handle, hel_s_main, svc_c_debug2);
  ```

  This macro can be used to test the active debug level and avoid calling a debug output routine if the level of its message is disabled at the time of the call (disabling the level does not stop any routines from being executed; it only suppresses the output messages at that level). See Section 4.3.13 for more information.

- **DCE_SVC_DEBUG_IS()**

  Tests the active debug level for a subcomponent. Returns TRUE if the debug level is the same as that specified in the call; otherwise returns FALSE. For example, the following call would return TRUE only if the debug level for **hel_s_main** had been set to **svc_c_debug2**:

  ```
  DCE_SVC_DEBUG_IS(hel_svc_handle, hel_s_main, svc_c_debug2);
  ```

- **dce_assert()**

  Evaluates an **int** expression passed to it and, if the expression evaluates to 0 (that is, if the expression is false), automatically calls **dce_svc_printf()** with parameters that will cause a message with a severity level of **svc_c_sev_fatal** (that is, fatal) and an action attribute of **svc_c_action_abort** to be printed that will identify the following:

  — The expression

  — The source file in which the assertion failed

  — The line at which the assertion failed

  For example, the following call will cause the failed expression (namely, the string) to be printed and the program to be aborted.

```
dce_assert(hel_svc_handle, ("Test diagnostic message" == NULL))
```

A NULL can be substituted for the serviceability handle as the first argument.

It is very important that debug messages not be used for errors that can occur during ordinary operation. This is because the debug messaging code can be omitted when compiling for production.

4.3.12.1 Setting Debug Levels

Nine serviceability debug message levels are available. The precise meaning of each level for an application is left to the developer; but the general intention is that ascending to a higher level (for example, from **svc_c_debug2** to **svc_c_debug3**) should increase the level of information detail.

Setting debug messaging at a certain level means that all levels up to and including the specified level are enabled. For example, if the debug level is set at **svc_c_debug4**, then the **svc_c_debug1** , **svc_c_debug2**, and **svc_c_debug3** levels are enabled as well.

A message can have a debug level attached to it in either of two ways:

- The debug level can be specified as one of the **attributes** in the message's definition in the **sams** file.
- If **DCE_SVC_DEBUG()** or **DCE_SVC_LOG()** is used to output the message, the debug level is specified in the call.

The debug level can be set by calling **dce_svc_debug_set_levels()** and passing to it a specially formatted string (the debug level is also set when debug routing is specified; see the next section for further information). Levels can be separately specified for subcomponents. For example, suppose two subcomponents (rather than one) had been defined in the **sams** file for the **hello_svc** application at the beginning of this chapter, as follows:

```
# Part II
serviceability table hel_svc_table handle hel_svc_handle
start
```

```
    subcomponent   hel_s_main       "main"  hel_i_svc_main
    subcomponent   hel_s_utils      "utils" hel_i_svc_utils
end
```

The following string would, when passed to **dce_svc_debug_set_levels()**, set the debug level for the **main** subcomponent to be **svc_c_debug1**, and the debug level for the **utils** subcomponent to be **svc_c_debug4**:

```
unsigned_char_t *levels = "hel:main.1,utils.4";
```

The general format for the debug level specifier string is as follows:

*component***:***sub_comp***.***level***,***sub_comp***.***level***,**. . .

where:

component Is the three-character component code for the program.

*sub_comp***.***level*
Is a subcomponent name, followed (after a dot) by a debug level (expressed as a single digit from 1 to 9). Note that multiple subcomponent/level pairs can be specified in the string.

If there are multiple subcomponents, and it is desired to set the debug level to be the same for all of them, then the following form will do this (where the ***** (asterisk) specifies all subcomponents).

*component***:*.***level*

The string can be passed to **dce_svc_debug_set_levels()** as follows:

dce_svc_debug_set_levels(levels, &status);

where **levels** is a string declared similarly to the example shown earlier in this section.

The nine serviceability debug message level specifiers are as follows:

- **svc_c_debug1**
- **svc_c_debug2**
- **svc_c_debug3**
- **svc_c_debug4**
- **svc_c_debug5**
- **svc_c_debug6**
- **svc_c_debug7**
- **svc_c_debug8**
- **svc_c_debug9**

4.3.12.2 Routing Debug Messages

Routing for serviceability debug messages can be specified in any of four ways:

- By calling the **dce_svc_debug_routing()** routine
- By the contents of the **SVC_***CMP* **_DBG** environment variable (where *CMP* is the three-character serviceability name of the component, in uppercase)
- By the contents of the routing file *dce-local-path* **/svc/routing**
- By one of the message's **attributes** (as coded in the **sams** file)

In all but the last method, the routing is specified by the contents of a specially formatted string that is either included in the value of the environment variable, is part of the contents of the routing file, or is passed to the **dce_svc_debug_routing()** routine.

The general format for the debug routing specifier string is

*component***:***sub_comp***.***level***,**. . .**:***out_form***:***dest* **[***out_form***:***dest* **. . .] [GOESTO:{***sev* | *comp***}]**

where:

component Specifies the component name.

*sub_comp***.***level*
: Specifies a subcomponent name, followed (after a dot) by a debug level (expressed as a single digit from 1 to 9). Note that multiple subcomponent/level pairs can be specified in the string.

The meanings of the remaining elements of the string are the same as those for the identically named elements in Section 4.3.4.

Multiple routings for the same group of subcomponents can be specified by adding semicolon-separated strings of the following format:

*out_form***:***dest*

to the specification, in a form analogous to that followed for specifying production (nondebug) message routes, shown previously.

The following string would, when passed to **dce_svc_debug_routing()**, set the debug level and routing for all **hel** subcomponents:

```
unsigned_char_t *debug_routes = \
  "hel:*.4:TEXTFILE:/tmp/hel_debug_log_%ld;STDERR:-";
```

A debug level of **svc_c_debug4** is specified, and all debug messages of that level or lower will be written both to standard error and in text form to the following file:

/tmp/hel_debug_log_*process_ID*

where *process_ID* is the process ID of the program writing the messages.

The specification string could be passed to **dce_svc_debug_routing()** as follows:

```
dce_svc_debug_routing(debug_routes, &status);
```

To specify the same routing by environment variable, the string following value should be assigned to **SVC_***CMP* **_DBG**:

```
hel:*.4:TEXTFILE:/tmp/hel_debug_log_%ld;STDERR:-
```

The same string information could also be inserted into the **SVC_** *CMP* environment variable or into the contents of the routing file.

Debug routing by attribute (as specified in the **sams** file) is done in the same way as routing for normal messages. See Section 4.3.4.4.

4.3.13 Performance Costs of Serviceability Debugging

If serviceability debugging routines are used in an application, one of three different things can happen to any given debugging routine at runtime:

- The routine is called, and its output is generated (because the debug level associated with the message has been enabled).
- The routine is called, but its output is not generated (because the debug level associated with the message has been disabled).
- The routine call is not present in the application code because serviceability debugging has been compiled out (**DCE_DEBUG** was not defined when the application was compiled).

Note that, even if a certain debug level has been disabled, any routine or macro call to output a message with that level will still be executed unless other steps are taken to prevent this. The performance cost associated with such smothered calls will usually be insignificant, but situations can occur in which this will not be so.

For example, developers should understand the implications of supplying function calls as arguments to serviceability debug output routines (such as **DCE_SVC_DEBUG**). If the debug code is compiled in (that is, if **DCE_DEBUG** is defined), then the parameterized function calls will always be executed because the output routine itself will still be called—even though it will produce no output.

In situations like this, the desirable course of action is simply to not call the output routine at all if the currently set debug level has turned it into a no-op. This can be done by using the **DCE_SVC_DEBUG_ATLEAST** macro to check the current level, as shown in the following example:

```
if (DCE_SVC_DEBUG_ATLEAST(hel_svc_handle, hel_s_main, svc_c_debug3))
{
DCE_SVC_DEBUG((
hel_svc_handle,
hel_s_main,
svc_c_debug3,
" a_function_call() return value is: %s",
a_function_call(parm, status)));
}
```

The normal performance cost of a serviceability logging operation normally amounts to one mutex lock and (usually) one file lock access per operation.

4.3.14 Using the Remote Serviceability Interface

Serviceability is primarily a mechanism intended to be used by servers. Like other server functionality, it should be remotely controllable by properly authorized entities. This allows such things as message routing and debug levels to be adjusted without having to restart the server.

The standard remote serviceability interface is defined in the file **/usr/include/dce/service.idl**.

An application server using serviceability is responsible for providing routines that implement the operations defined in **service.idl**. However, implementing the operations themselves is a simple matter of calling library routines that actually perform them. The job of the application implementation is mainly to check the authorization of the remote caller and then either reject the request (if authorization is found to be insufficient) or call the appropriate library routine to perform the operation.

Table 4-3 lists such remote operations.

Table 4–3. Remote Operations by Application Servers

Server Implementation	Library Routine	Purpose
*com*_**svc_set_route()**	**dce_svc_routing()**	Remotely sets serviceability message routing.
*com*_**svc_set_dbg_route()**	**dce_svc_debug_routing()**	Remotely sets serviceability debug message routing.
*com*_**svc_set_dbg_levels()**	**dce_svc_debug_set_levels()**	Remotely sets serviceability debug message levels.
*com*_**svc_inq_components()**	**dce_svc_components()**	Returns a listing of all components that have been registered with the **dce_svc_register()** routine.
*com*_**svc_inq_table()**	**dce_svc_table()**	Returns the message table registered with a given component.
*com*_**svc_inq_routings()**	**dce_svc_routings()**	Returns a list of routings in effect for a component.
*com*_**svc_filter_control()**	**dce_svc_filter()**	Remotely controls the behavior of the serviceability message filtering routine (if one exists).
*com*_**svc_inq_stats()**	**dce_svc_inq_stats()**	Returns operating statistics.

4.3.14.1 Basic Steps in Setting Up the Remote Interface

To make the interface available, the developer must do the following:

1. Coding steps
   - Define the server implementation routines for the remote operations.
   - Initialize the serviceability interface manager entry point vector (manager EPV) with the implementation routines.
2. Build steps

- Process the **service.idl** file to produce the following:
  - Client stub

    This will be linked into the client object. The client itself can contain calls to the remote routines, expressed by their interface names.
  - Server stub

    This will be linked into the server object (just as its own stub(s) are) to produce the server executable. Note that the server stub is generated with the **-no_mepv** IDL option, which allows the implementation routines to be named anything that suits the developer. This is why the EPV must be explicitly initialized with the implementation routines' addresses.

3. Runtime steps

   - At server startup:

     The binding handles that the server receives from the RPC runtime, and which it then registers both with the Name Server Interface (NSI) and the endpoint mapper under its own interface, must also be registered to the endpoint mapper with the serviceability interface. Note that servers *do not* explicitly register the serviceability interface with the NSI. Instead, they use their existing namespace entries without change. They *do* register the serviceability interface with their endpoint mapper.

   - For a client application:

     To call one of a server's remote serviceability routines, the client must import a binding handle using a NULL UUID; this operation will yield a plain handle. The client can then pass this handle to the desired remote serviceability routine and make the call. The server's host endpoint mapper will recognize the incoming serviceability UUID in the RPC, and will send the RPC on to one of the registered endpoints.

The following code fragments illustrate how to define, export, and access the serviceability remote interface.

4.3.14.2 Implementing the Remote Routines

The following code fragments show in skeletal form how an application's remote serviceability routines should be implemented. The pseudo-code references to access

tests are calls to the application's ACL manager to assess the caller's authorization. For information on implementing an ACL manager, see the security chapters of the *DCE 1.2.2 Application Development—Introduction and Style Guide* and the *DCE 1.2.2 Administration Guide—Core Components*.

```
#include <dce/dce.h>
#include <dce/dce_msg.h>
#include <dce/dcesvcmsg.h>
#include <dce/svcremote.h>

struct serviceability_v1_0_epv_t       dce_svc_epv;

/*****
*
* hel_svc_set_route -- remote call-in to set routing.
*
*****/
static void
hel_svc_set_route(
    handle_t                h,
    idl_byte                where[],
    error_status_t          *st
)
{

    if (!your_test_write_access(h))
        *st = no_authorization_error;
    else
        dce_svc_routing(where, st);

}

/*****
*
* hel_svc_set_dbg_route -- remote call-in to set debug routing.
*
*****/
static void
hel_svc_set_dbg_route(
```

```
    handle_t                h,
    idl_byte                where[],
    error_status_t          *st
)
{

    if (!your_test_write_access(h))
        *st = no_authorization_error;
    else
        dce_svc_debug_routing(where, st);

}

             <. . .>

/*****
*
* hel_svc_inq_stats -- remote request for operating statistics.
*
*****/
static void
hel_svc_inq_stats(
    handle_t                h,
    dce_svc_stats_t         *stats,
    error_status_t          *st
)
{

    if (!your_test_access(h))
        *st = no_authorization_error;
    else
        /* operation is currently not implemented in library... */
        *st = svc_s_no_stats;

}

/*                                                              */
/* The table of slots is created by IDL from the service.idl    */
/* file, src/dce/utils/svc/service.idl, the output of which     */
/* is service.h.  It's then the job of the application that     */
```

```
/* wishes to offer the remote operations to fill in the table   */
/* with the implementations' entry points.  That's what's being */
/* done below.  Typically the application simply interposes an  */
/* appropriate ACL check between the entry into an              */
/* implementation and the subsequent call to the "real"         */
/* operation as implemented in the serviceability library.      */
/*                                                              */

serviceability_v1_0_epv_t dce_svc_epv = {
    hel_svc_set_route,
    hel_svc_set_dbg_route,
    hel_svc_set_dbg_levels,
    hel_svc_inq_components,
    hel_svc_inq_table,
    hel_svc_inq_routings,
    hel_svc_filter_ctl,
    hel_svc_inq_stats
};
```

4.3.14.3 Registering and Exporting the Remote Interface

The following code fragments show how the remote serviceability interface could be exported and registered by a **hello_svc** server. Note that only the steps that are closely or directly related to exporting and registering the server's and the serviceability remote interface are shown. For a full example of how to get a DCE server application up and running, see the *DCE 1.2.2 Application Development—Introduction and Style Guide*.

The steps shown are the following:

1. Register interfaces with the RPC runtime
2. Request binding handles for the server interface from the RPC runtime
3. Request binding handles for the serviceabilty interface from the RPC runtime
4. Register both sets of binding handles with the endpoint map
5. Export both sets of binding handles to the namespace

Note that (for brevity's sake) status return checks have been omitted from this code.

```
                <. . .>

/* Register server interface/type_uuid/epv associations        */
/* with rpc runtime.                                            */
rpc_server_register_if(timop_v1_0_s_ifspec, &type_uuid,
    (rpc_mgr_epv_t)&manager_epv, &status);

/* Register serviceability remote interface with rpc           */
/* runtime ...                                                  */
rpc_server_register_if(serviceability_v1_0_s_ifspec, &type_uuid,
   (rpc_mgr_epv_t)&dce_svc_epv, &status);

                <. . .>

/* Tell rpc runtime we want to use all supported protocol      */
/* sequences.                                                   */
rpc_server_use_all_protseqs(MAX_CONC_CALLS_PROTSEQ, &status);

/* Get server binding handles ...                               */
rpc_server_inq_bindings(&hello_bind_vector_p, &status);

/* Get binding handles for serviceability remote               */
/* interface ...                                                */
rpc_server_inq_bindings(&svc_bind_vector_p, &status);

                <. . .>

/* Register endpoints with server interface ...                  */
rpc_ep_register(hello_v1_0_s_ifspec, hello_bind_vector_p,
    (uuid_vector_t *)&obj_uuid_vec,
    (unsigned_char_t *)"hello server, version 1.0",
    &status);

/* Register endpoints with serviceability interface ...          */
rpc_ep_register(serviceability_v1_0_s_ifspec, svc_bind_vector_p,
    (uuid_vector_t *)&obj_uuid_vec,
    (unsigned_char_t *)"Hello SVC",
    &status);

/* Export server interface binding info to the namespace.        */
```

```
rpc_ns_binding_export(rpc_c_ns_syntax_dce, server_name,
    hello_v1_0_s_ifspec, hello_bind_vector_p,
    (uuid_vector_t *)&obj_uuid_vec, &status);
```

4.3.14.4 Importing and Accessing the Remote Interface

The following code fragments are intended to give an idea how a client might import both the **hello_svc** server's interface and its exported serviceability interface.

Note that (for brevity's sake) status return checks have been omitted from this code.

```
/* Import binding info from namespace. */
for (server_num = 0; server_num < nservers; server_num++)
{
    /* Begin the binding import loop. */
    rpc_ns_binding_import_begin(rpc_c_ns_syntax_dce,
        server_name[server_num], hello_v1_0_c_ifspec,
        &obj_uuid, &import_context, &status);

    /* Begin the svc binding import loop. */
    rpc_ns_binding_import_begin(rpc_c_ns_syntax_dce,
        server_name[server_num], NULL,
        &obj_uuid, &svc_import_context, &status);

    /* Import bindings one at a time. */
    while (1)
    {
        rpc_ns_binding_import_next(import_context,
            &bind_handle[server_num], &status);

        rpc_ns_binding_import_next(svc_import_context,
            &svc_bind_handle[server_num], &status);

        /* Select, say, the first binding over UDP. */
        rpc_binding_to_string_binding(bind_handle[server_num],
```

```
                &string_binding, &status);

            rpc_binding_to_string_binding(svc_bind_handle[server_num],
                &svc_string_binding, &status);

            rpc_string_binding_parse(string_binding, NULL,
                &protseq, NULL, NULL, NULL, &status);

            rpc_string_binding_parse(svc_string_binding, NULL,
                &svc_protseq, NULL, NULL, NULL, &status);

            rpc_string_free(&string_binding, &status);
            ret = strcmp((char *)protseq, "ncadg_ip_udp");
            rpc_string_free(&protseq, &status);

            rpc_string_free(&svc_string_binding, &status);
            svc_ret = strcmp((char *)svc_protseq, "ncadg_ip_udp");
            rpc_string_free(&svc_protseq, &status);

            if ((svc_ret == 0) || (ret == 0))
            {
                break;
            }

        }

        /* End the binding import loop. */
        rpc_ns_binding_import_done(&import_context, &status);
        rpc_ns_binding_import_done(&svc_import_context, &status);

    }

    /* Annotate binding handles for security. */
    for (server_num = 0; server_num < nservers; server_num += 1)
        rpc_binding_set_auth_info(bind_handle[server_num],
            SERVER_PRINC_NAME, rpc_c_protect_level_pkt_integ,
            rpc_c_authn_dce_secret, NULL /*default login context*/,
            rpc_c_authz_name, &status);

    for (server_num = 0; server_num < nservers; server_num += 1)
```

```
rpc_binding_set_auth_info(svc_bind_handle[server_num],
    SERVER_PRINC_NAME, rpc_c_protect_level_pkt_integ,
    rpc_c_authn_dce_secret, NULL /*default login context*/,
    rpc_c_authz_name, &status);
```

Chapter 5

The DCE Backing Store

This chapter describes the *backing store library* that DCE provides for the convenience of programmers who are writing DCE servers. A backing store is a *persistent database* or *persistent object store* from which typed data can be stored and retrieved by a key.

Note: Sometimes the backing store is called a *database*. For instance, the associated IDL file is **dce/database.idl**, and the name of the backing store routines begin with **dce_db_**. The backing store is, however, not a full-fledged database in the conventional sense, and it has no support for SQL or for any other query system.

Servers generally need to manage several objects. Good design often requires that the state of the objects be maintained over sequential instances of a particular server. For example, the ACLs used by a server should not need to be recalculated each time the system is rebooted. The backing store interface provides a way to store, into a file, any data that can be described with IDL so that it can persist across instances of software that run from time to time. For example, the ACL library uses the backing store library. The backing store routines can be used in servers, in clients or in standalone programs that do not involve remote procedure calls (RPCs). Backing store data should not be used for sharing data between processes.

5.1 Data in a Backing Store

The backing store interface provides the applications programmer with the capability for tagged storage and retrieval of typed data. The tag (or retrieval key) can be either a UUID or a standard C string. For a specific backing store, the data type must be specified at compile time and is established through the IDL encoding services. Each backing store can contain only a single data type.

Each *data item* (which may also be called a *data object*, or a *data record*) consists of the data stored in a single call to a storage routine. The storage routines are **dce_db_store()**, **dce_db_store_by_name()**, and **dce_db_store_by_uuid()**. Optionally, data items may have standard headers. If a backing store has been created to use headers, then every data item has the header.

A program can have more than one backing store open at the same time.

5.2 Using a Backing Store

Although the backing store library is a generalized service, you are encouraged to use it in a particular, standardized way. You should use the header and the recommended IDL interface format that are described in the following sections. Standardized use will ease the transition to later developments in DCE.

5.3 Header for Data

An optional standard header is available for data objects or items in the backing store. If it is employed, then the backing store library automatically maintains the **created**, **modified**, and **modified_count** fields, as shown in the following IDL description, taken from the **dce/database.idl** file:

```
/* The standard header for each "object" in the database. */

typedef struct dce_db_dataheader_s_t {
    uuid_t              uuid;
```

```
    uuid_t              owner_id;
    uuid_t              group_id;
    uuid_t              acl_uuid;
    uuid_t              def_object_acl;
    uuid_t              def_container_acl;
    unsigned32          ref_count;
    /* The following fields are updated by the library */
    utc_t               created;
    utc_t               modified;
    unsigned32          modified_count;
} dce_db_dataheader_t;

typedef enum {
    dce_db_header_std,
    dce_db_header_acl_uuid,
    dce_db_header_none
} dce_db_header_type_t;

typedef union switch (dce_db_header_type_t type) tagged_union {
    case dce_db_header_none:            /* none */ ;
    case dce_db_header_std:             dce_db_dataheader_t h;
    case dce_db_header_acl_uuid:        uuid_t  acl_uuid;
} dce_db_header_t;

void dce_db_header_convert(
    [in]        handle_t                h,
    [in,out]    dce_db_header_t         *data,
    [out]       error_status_t          *st
);
```

The **acl_uuid** field is intended for use as a UUID retrieval key in a server's ACL database.

5.4 The User Interface

The recommended, standardized backing store IDL interface for a server looks like the following, where *XXX* is the server name:

```
interface XXX_convert
{
    import "dce/database.idl"

    typedef XXX_data_s_t {
        dce_db_header_t  header;   /* Header must be first! */
        /* (server-specific data goes here) */
    } XXX_data_t;

    void XXX_data_convert(
        [in]         handle_t         h,
        [in, out]    XXX_data_t       *data
        [out]        error_status_t   *st
    );
}
```

It should be compiled with the following Attribute Configuration File (ACF), which instructs the **idl** compiler to write the data conversion routine into the *XXX*_**cstub.c** file:

```
interface XXX
{
    [encode, decode] XXX_data_convert([comm_status] st);
}
```

5.5 The IDL Encoding Services

When remote procedure call sends data between a client and a server, it serializes the user's data structures by using the IDL encoding services, described in Chapter 16 of this book.

5.5.1 Encoding and Decoding in the Backing Store

The backing store uses this same serialization scheme for encoding and decoding, informally called *pickling*, when storing data structures to disk. The IDL compiler,

idl, writes the routine that encodes and decodes the data. This routine is passed to **dce_db_open()**, remembered in the handle, and used by the following store and fetch routines:

- **dce_db_fetch()**
- **dce_db_fetch_by_name()**
- **dce_db_fetch_by_uuid()**
- **dce_db_header_fetch()**
- **dce_db_store()**
- **dce_db_store_by_name()**
- **dce_db_store_by_uuid()**

5.5.2 Conformant Arrays Not Allowed

You cannot use conformant arrays in objects stored to a backing store. This is because the IDL-generated code that encodes (pickles) the structure has no way to predict or detect the size of the array. When the object is fetched, there will likely be insufficient space provided for the structure, and the array's data will destroy whatever is in memory after the structure.

To illustrate the problem more clearly, here is an example. An IDL file has a conformant array, **na**, as an object in a **struct**:

```
typedef struct {
    unsigned32 length;
    [size_is(length)]
    unsigned32 numbers[];
} num_array_t
typedef struct {
    char          *name;
    num_array_t   na;
} my_type_t;
```

The **idl** compiler turns the IDL specification into the following **.h** file contents:

```
typedef struct  {
    unsigned32 length;
    unsigned32 numbers[1];
} num_array_t
typedef struct {
    idl_char        *name;
    num_array_t     na;
} my_type_t;
```

When the object is fetched, and the array length is greater than the 1 (one) assumed in the **.h** file, the decoding operation destroys whatever follows **my_struct** in memory:

```
my_type_t  my_struct;
dce_db_fetch(dbh, key, &my_struct, &st);
```

The correct method is to use a pointer to the array, not the array itself, in the IDL file. For example:

```
typedef struct {
    char            *name;
    num_array_t     *na;
} my_type_t;
```

5.6 The Backing Store Routines

Many of the backing store routines appear in three versions: plain, by name, and by UUID. The plain version will work with backing stores that were created to be indexed either by name, or by UUID; the restricted versions accept only the matching type. It is advantageous to use the restricted versions when they are appropriate because they provide type checking by the compiler, as well as visual clarity of purpose.

The backing store operations described in the following sections are supported.

5.6.1 Opening a Backing Store

The **dce_db_open()** routine creates a new backing store or opens an existing one. The backing store is identified by a filename. There are flags to permit the following choices:

- Create a new backing store or open an existing one.
- Create a new backing store indexed by name or UUID. (The choice depends upon the server's purpose.) This index is called the *backing store key*.
- Open an existing backing store read/write or read-only.
- Use the standard header or not.

Every backing store is created with one of the two possible index schemes, by name or by UUID, and you cannot subsequently open it for use with the other scheme. Also, once a backing store has been created with (or without) standard headers, you cannot subsequently open it the other way.

The routine returns a handle by which subsequent operations identify the backing store.

The following conventions for filenames are recommended:

*xxx***.acl** ACL storage.

*xxx***.db** Backing store filename.

5.6.2 Closing a Backing Store

The **dce_db_close()** routine frees the handle. It closes any open files and releases all other resources associated with the backing store.

5.6.3 Storing or Retrieving Data

The following routines store data into a backing store:

dce_db_store()
: This routine can store into a backing store that is indexed by name or by UUID. The key's type must match the flag that was used in **dce_db_open()**.

dce_db_store_by_name()
: This routine can store only into a backing store that is indexed by name.

dce_db_store_by_uuid()
: This routine can store only into a backing store that is indexed by UUID.

To retrieve data from a backing store, use the appropriate one of the following routines:

dce_db_fetch()
: This routine can retrieve data from a backing store that is indexed by name or by UUID. The key's type must match the flag that was used in **dce_db_open()**.

dce_db_fetch_by_name()
: This routine can retrieve data only from a backing store that is indexed by name.

dce_db_fetch_by_uuid()
: This routine can retrieve data only from a backing store that is indexed by UUID.

When storing or retrieving data, a function that was specified at open time converts between native format and on-disk (serialized) format. This function is generated from the IDL file by the IDL compiler.

5.6.4 Freeing Data

When fetching data, the encoding services allocate memory for the data structures that are returned. These services accept a structure and use **rpc_sm_allocate()** to provide additional memory needed to hold the data.

The backing store library does not know what memory has been allocated and, therefore, cannot free it. For fetch calls that are made from a server stub, this is not a problem because the memory is freed automatically when the server call terminates. For fetch calls that are made from a nonserver, the programmer is responsible for freeing the memory.

Programs that call the fetch or store routines, such as **dce_db_fetch()**, outside of a server operation (for instance, if a server does some backing store initialization, or in a standalone program) must call **rpc_sm_enable_allocate()** first.

5.6.5 Making or Retrieving Headers

The **dce_db_std_header_init()** routine initializes a standard backing store header from the values the caller provides in its arguments. It places the values into the header only and does not write into the backing store file. The **dce_db_header_fetch()** routine retrieves the header of an object in the backing store.

5.6.6 Performing Iteration

The following routines iteratively traverse all of the keys (name or UUID) in a backing store. The order of retrieval of the keys is indeterminate; they are not sorted, nor are they necessarily returned in the order in which they were originally stored. It is strongly recommended to use the locking and unlocking routines, **dce_db_lock()** and **dce_db_unlock()**, whenever performing iteration.

dce_db_iter_start()
This routine prepares for the start of iteration.

dce_db_iter_next()
This routine returns the key for the next item from a backing store that is indexed by name or by UUID. The **db_s_no_more** status code indicates that there are no more items.

dce_db_iter_next_by_name()
This routine returns the key for the next item only from a backing store that is indexed by name. Again, **db_s_no_more** indicates that no items remain.

dce_db_iter_next_by_uuid()
This routine returns the key for the next item only from a backing store that is indexed by UUID. Again, **db_s_no_more** indicates that no items remain.

dce_db_iter_done()
This routine is counterpart to **dce_db_iter_start()** and should be called when iteration is done.

dce_db_inq_count()
This routine returns the number of items in a backing store.

5.6.7 Deleting Items from a Backing Store

The following routines delete an item from a backing store.

dce_db_delete()
This routine deletes an item from a backing store that is indexed by name or by UUID. The key's type must match the flag that was used in **dce_db_open()**.

dce_db_delete_by_name()
This routine deletes an item only from a backing store that is indexed by name.

dce_db_delete_by_uuid()
This routine deletes an item only from a backing store that is indexed by UUID.

To delete an entire backing store, ensure that the data file is not open, and remove it. There is only one file.

5.6.8 Locking and Unlocking a Backing Store

The **dce_db_lock()** and **dce_db_unlock()** routines lock and unlock a backing store. If a backing store is already locked, **dce_db_lock()** provides an indication. A lock is associated with an open backing store's handle. The storage routines, **dce_db_store()**, **dce_db_store_by_name()**, and **dce_db_store_by_uuid()**, all acquire the lock before updating. Explicit use of locking is appropriate in some circumstances; for example, when reading or writing pairs (or multiples) of closely associated items in a backing store, or when using iteration.

The locks are advisory. It is possible to write a backing store even if it is locked so, if you want to rely upon the locks, you must always check them.

5.7 Example of Backing Store Use

For a full example of backing store use, see the *DCE 1.2.2 Application Development—Introduction and Style Guide*.

The following brief example shows a portion of a server that manages an office telephone directory. Following are the relevant structures, defined in an IDL file:

```
typedef struct phone_record_s_t {
    [string,ptr] char       *name;
    [string,ptr] char       *email;
    [string,ptr] char       *phone;
    [string,ptr] char       *office;
} phone_record_t;

typedef struct phone_record_array_s_t {
                            unsigned32      count;
    [ptr,size_is(count)]    phone_record_t  *entry;
} phone_record_array_t;

typedef struct phone_data_s_t {
    dce_db_header_t h;
    phone_record_t  ph;
} phone_data_t;

/*
 * The following routine returns the entire contents of the
 * directory from the backing store by using the iteration
 * routines.  First, the portion of the IDL file that
 * defines the routine's RPC format:
 */
[idempotent] void entire_phone_book(
    [in]        handle_t                h,
```

```
    [out]       phone_record_array_t  *e_array,
    [out]       error_status_t        *st
    );
```

Next the routine itself, written in C:

```
/* global variables */
dce_db_handle__t db_h;  /* handle to phonebook backing store */

/* Other routines are not shown here, including the routine
 * that opened the backing store.
 */

void
entire_phone_book(
    /* [in]  */ handle_t        h,  /* For RPC, but not used
                                     * here.  An ACL check
                                     * would use it. */

    /* [out] */ phone_record_array_t  *e_array,
    /* [out] */ error_status_t        *st
)
{
    uuid_t             *dbkey;
    phone_data_t        pd;
    unsigned32          i;
    error_status_t      st2;

    *st = error_status_ok;
    /* Lock before starting work, so that the backing
     * store does not change until after all the info
     * has been returned.
     */
    dce_db_lock(db_h, st);
    /* Count the entries so enough storage can be allocated */
    e_array->count = 0;
    dce_db_inq_count(db_h, &e_array->count, st);
    if (*st != error_status_ok) {
        dce_fprintf(stderr, *st); /* or some other treatment */
```

```
        dce_db_unlock(db_h, st);
        return;
    }
    if (e_array->count == 0) {    /* No items, nothing to do */
        dce_db_unlock(db_h, st);
        return;
    }
    /* Allocate the space for the output. */
    e_array->entry = rpc_sm_allocate(
                e_array->count*sizeof(e_array->entry[0]),st);
    if (*st != rpc_s_ok) {
        dce_fprintf(stderr, *st); /* or some other treatment */
        return
    }
    dce_db_iter_start(db_h, st);
    i = 0;
    while (TRUE) {
        /* Get the next key. */
        dce_db_iter_next(db_h, &dbkey, st);
        /* break when we've scanned the entire backing store */
        if (*st == db_s_no_more) break;
        /* Get the data associated with the next key. */
        dce_db_fetch_by_uuid(db_h, dbkey, (void *)&pd, st);
        if (*st != error_status_ok) {
            dce_fprintf(stderr, *st);
            /* Don't forget to stop iterating and unlock after
      * an error. */
            dce_db_iter_done(db_h, &st2);
            dce_db_unlock(db_h, &st2);
            return;
        }
        /* Stick the item into the array to be returned
         * when done. */
        e_array->entry[i].name   = strdup(pd.ph.name);
        e_array->entry[i].email  = strdup(pd.ph.email);
        e_array->entry[i].phone  = strdup(pd.ph.phone);
        e_array->entry[i].office = strdup(pd.ph.office);
        i++;
        /* The use of strdup() above is illustrative, but it
         * is not correct within a server, because the
```

```
      * allocated memory is never freed.  Correct code
      * would involve the use of rpc_sm_allocate().
            */
       }
       /* The iteration is finished. */
       dce_db_iter_done(db_h, st);
       dce_db_unlock(db_h, st);
}
```

Part 2

DCE Threads

Chapter 6

Introduction to Multithreaded Programming

DCE Threads is a user-level (nonkernel) threads package based on the pthreads interface specified by POSIX in 1003.4a, Draft 4. This chapter introduces multithreaded programming, which is the division of a program into multiple threads (parts) that execute concurrently. In addition, this chapter describes four software models that improve multithreaded programming performance.

A thread is a single sequential flow of control within a program. It is the active execution of a designated routine, including any nested routine invocations. Within a single thread, there is a single point of execution. Most traditional programs consist of a single thread.

Threads are lightweight processes that share a single address space. Each thread shares all the resources of the originating process, including signal handlers and descriptors. Each thread has its own thread identifier, scheduling policy and priority, **errno** value, thread-specific data bindings, and the required system resources to support a flow of control.

6.1 Advantages of Using Threads

With a threads package, a programmer can create multiple threads within a process. Threads execute concurrently and, within a multithreaded process, there are at any time multiple points of execution. Threads execute within a single address space. Multithreaded programming offers the following advantages:

- Performance

  Threads improve the performance (throughput, computational speed, responsiveness, or some combination of these) of a program. Multiple threads are useful in a multiprocessor system where threads run concurrently on separate processors. In addition, multiple threads also improve program performance on single processor systems by permitting the overlap of input and output or other slow operations with computational operations.

  You can think of threads as executing simultaneously, regardless of the number of processors present. You cannot make any assumptions about the start or finish times of threads or the sequence in which they execute, unless explicitly synchronized.

- Shared Resources

  An advantage of using multiple threads over using separate processes is that the former share a single address space, all open files, and other resources.

- Potential Simplicity

  Multiple threads can reduce the complexity of some applications that are inherently suited for threads.

6.2 Software Models for Multithreaded Programming

The following subsections describe four software models for which multithreaded programming is especially well suited:

- Boss/worker model
- Work crew model
- Pipelining model
- Combinations of models

6.2.1 Boss/Worker Model

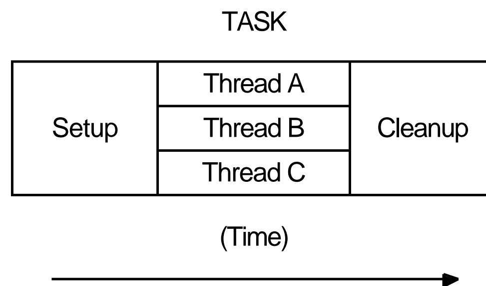
In a boss/worker model of program design, one thread functions as the boss because it assigns tasks to worker threads. Each worker performs a different type of task until it is finished, at which point the worker interrupts the boss to indicate that it is ready to receive another task. Alternatively, the boss polls workers periodically to see whether or not each worker is ready to receive another task.

A variation of the boss/worker model is the work queue model. The boss places tasks in a queue, and workers check the queue and take tasks to perform. An example of the work queue model in an office environment is a secretarial typing pool. The office manager puts documents to be typed in a basket, and typists take documents from the basket to work on.

6.2.2 Work Crew Model

In the work crew model, multiple threads work together on a single task. The task is divided into pieces that are performed in parallel, and each thread performs one piece. An example of a work crew is a group of people cleaning a house. Each person cleans certain rooms or performs certain types of work (washing floors, polishing furniture, and so forth), and each works independently. Figure 6-1 shows a task performed by three threads in a work crew model.

Figure 6–1. Work Crew Model



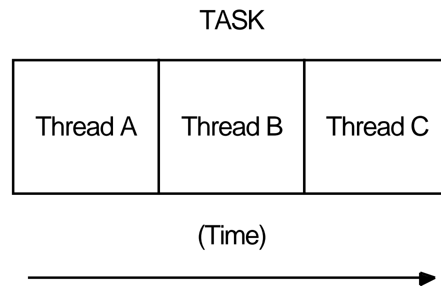
6.2.3 Pipelining Model

In the pipelining model, a task is divided into steps. The steps must be performed in sequence to produce a single instance of the desired output, and the work done in each step (except for the first and last) is based on the preceding step and is a prerequisite for the work in the next step. However, the program is designed to produce multiple instances of the desired output, and the steps are designed to operate in a parallel time frame so that each step is kept busy.

An example of the pipelining model is an automobile assembly line. Each step or stage in the assembly line is continually busy receiving the product of the previous stage's work, performing its assigned work, and passing the product along to the next stage. A car needs a body before it can be painted, but at any one time numerous cars are receiving bodies, and then numerous cars are being painted.

In a multithreaded program using the pipelining model, each thread represents a step in the task. Figure 6-2 shows a task performed by three threads in a pipelining model.

Figure 6–2. Pipelining Model



6.2.4 Combinations of Models

You may find it appropriate to combine the software models in a single program if your task is complex. For example, a program could be designed using the pipelining model, but one or more steps could be handled by a work crew. In addition, tasks

could be assigned to a work crew by taking a task from a work queue and deciding (based on the task characteristics) which threads are needed for the work crew.

6.3 Potential Disadvantages of Multithreaded Programming

When you design and code a multithreaded program, consider the following problems and accommodate or eliminate each problem as appropriate:

- Potential Complexity

  The level of expertise required for designing, coding, and maintaining multithreaded programs may be higher than for most single-threaded programs because multithreaded programs may need shared access to resources, mutexes, and condition variables. Weigh the potential benefits against the complexity and its associated risks.

- Nonreentrant Software

  If a thread calls a routine or library that is not reentrant, use the global locking mechanism to prevent the nonreentrant routines from modifying a variable that another thread modifies. Chapter 8 discusses nonreentrant software in more detail.

  Note: A multithreaded program must be reentrant; that is, it must allow multiple threads to execute at the same time. Therefore, be sure that your compiler generates reentrant code before you do any design or coding work for multithreading. (Many C, Ada, Pascal, and BLISS compilers generate reentrant code by default.)

  If your program is nonreentrant, any thread synchronization techniques that you use are not guaranteed to be effective.

- Priority Inversion

  Priority inversion prevents high-priority threads from executing when interdependencies exist among three or more threads. Chapter 8 discusses priority inversion in more detail.

- Race Conditions

  A type of programming error called a *race condition* causes unpredictable and erroneous program behavior. Chapter 8 discusses race conditions in more detail.

- Deadlocks

  A type of programming error called a *deadlock* causes two or more threads to be blocked from executing. Chapter 8 discusses deadlocks in more detail.

- Blocking Calls

  Certain system or library calls may cause an entire process to block while waiting for the call to complete, thus causing all other threads to stop executing. Chapter 8 discusses blocking in more detail.

Chapter 7

Thread Concepts and Operations

This chapter discusses concepts and techniques related to DCE Threads. The following topics are covered:

- Thread operations
- New primitives
- Attributes objects
- Synchronization objects
- One-time initialization code
- Thread-specific data
- Thread cancellation
- Thread scheduling

For detailed information on the multithreading routines referred to in this chapter, see the reference page for that routine in the *DCE 1.2.2 Application Development Reference*.

7.1 Thread Operations

A thread changes states as it runs, waits to synchronize, or is ready to be run. A thread is in one of the following states:

- Waiting

  The thread is not eligible to execute because it is synchronizing with another thread or with an external event.

- Ready

  The thread is eligible to be executed by a processor.

- Running

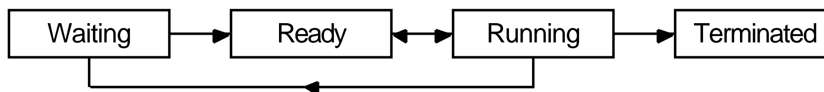
  The thread is currently being executed by a processor.

- Terminated

  The thread has completed all of its work.

Figure 7-1 shows the transitions between states for a typical thread implementation.

Figure 7–1. Thread State Transitions



The operations that you can perform include starting, waiting for, terminating, and deleting threads.

7.1.1 Starting a Thread

To start a thread, create it using the **pthread_create()** routine. This routine creates the thread, assigns specified or default attributes, and starts execution of the function you specified as the thread's start routine. A unique identifier (handle) for that thread is returned from the **pthread_create()** routine.

7.1.2 Terminating a Thread

A thread exists until it terminates and the **pthread_detach()** routine is called for the thread. The **pthread_detach()** routine can be called for a thread before or after it terminates. If the thread terminates before **pthread_detach()** is called for it, then the thread continues to exist and can be synchronized (joined) until it is detached. Thus, the object (thread) can be detached by any thread that has access to a handle to the object.

Note that **pthread_detach()** must be called to release the memory allocated for the thread objects so that this storage does not build up and cause the process to run out of memory. For example, after a thread returns from a call to join, it detaches the joined-to thread if no other threads join with it. Similarly, if a thread has no other threads joining with it, it detaches itself so that its thread object is deallocated as soon as it terminates.

A thread terminates for any of the following reasons:

- The thread returns from its start routine; this is the usual case.
- The thread calls the **pthread_exit()** routine.

  The **pthread_exit()** routine terminates the calling thread and returns a status value, indicating the thread's exit status to any potential joiners.
- The thread is canceled by a call to the **pthread_cancel()** routine.

  The **pthread_cancel()** routine requests termination of a specified thread if cancellation is permitted. (See Section 7.7 for more information on canceling threads and controlling whether or not cancellation is permitted.)
- An error occurs in the thread.

  Examples of errors that cause thread termination are programming errors, segmentation faults, or unhandled exceptions.

7.1.3 Waiting for a Thread to Terminate

A thread waits for the termination of another thread by calling the **pthread_join()** routine. Execution in the current thread is suspended until the specified thread

terminates. If multiple threads call this routine and specify the same thread, all threads resume execution when the specified thread terminates.

If you specify the current thread with the **pthread_join()** routine, a deadlock results.

Do not confuse **pthread_join()** with other routines that cause waits and that are related to the use of a particular multithreading feature. For example, use **pthread_cond_wait()** or **pthread_cond_timedwait()** to wait for a condition variable to be signaled or broadcast.

7.1.4 Deleting a Thread

A thread is automatically deleted after it terminates; that is, no explicit deletion operation is required. Use **pthread_detach()** to free the storage of a terminated thread. Use **pthread_cancel()** to request that a running thread terminate itself.

If the thread has not yet terminated, the **pthread_detach()** routine marks the thread for deletion, and its storage is reclaimed immediately when the thread terminates. A thread cannot be joined or canceled after the **pthread_detach()** routine is called for the thread, even if the thread has not yet terminated.

If a thread that is not detached terminates, its storage remains so that other threads can join with it. Storage is reclaimed when the thread is eventually detached.

7.2 New Primitives

Routines implemented by DCE Threads that are not specified by Draft 4 of the POSIX 1003.4a standard are indicated by an **_np** suffix to the name. These routines have not been incorporated into the POSIX standard, and as such are extensions to that document. The routines are fully portable.

7.3 Attributes Objects

An attributes object is used to describe the behavior of threads, mutexes, and condition variables. This description consists of the individual attribute values that are used to create an attributes object. Whether an attribute is valid depends on whether it describes threads, mutexes, or condition variables.

When you create an object, you can accept the default attributes for that object, or you can specify an attributes object that contains individual attributes that you have set. For a thread, you can also change one or more attributes after thread execution starts; for example, calling the **pthread_setprio()** routine to change the priority that you specified with the **pthread_attr_setprio()** routine.

The following subsections describe how to create and delete attributes objects and describe the individual attributes that you can specify for different objects.

7.3.1 Creating an Attributes Object

To create an attributes object, use one of the following routines, depending on the type of object to which the attributes apply:

- The **pthread_attr_create()** routine for thread attributes objects
- The **pthread_condattr_create()** routine for condition variable attributes objects
- The **pthread_mutexattr_create()** routine for mutex attributes objects

These routines create an attributes object containing default values for the individual attributes. To modify any attribute values in an attributes object, use one of the set routines described in the following subsections.

Creating an attributes object or changing the values in an attributes object does not affect the attributes of objects previously created.

7.3.2 Deleting an Attributes Object

To delete an attributes object, use one of the following routines:

- The **pthread_attr_delete()** routine for thread attributes objects
- The **pthread_condattr_delete()** routine for condition variable attributes objects
- The **pthread_mutexattr_delete()** routine for mutex attributes objects

Deleting an attributes object does not affect the attributes of objects previously created.

7.3.3 Thread Attributes

A thread attributes object allows you to specify values for thread attributes other than the defaults when you create a thread with the **pthread_create()** routine. To use a thread attributes object, perform the following steps:

1. Create a thread attributes object by calling the routine **pthread_attr_create()**.
2. Call the routines discussed in the following subsections to set the individual attributes of the thread attributes object.
3. Create a new thread by calling the **pthread_create()** routine and specifying the identifier of the thread attributes object.

You have control over the following attributes of a new thread:

- Scheduling policy attribute
- Scheduling priority attribute
- Inherit scheduling attribute
- Stacksize attribute

7.3.3.1 Scheduling Policy Attribute

The scheduling policy attribute describes the overall scheduling policy of the threads in your application. A thread has one of the following scheduling policies:

- **SCHED_FIFO** (First In, First Out)

  The highest-priority thread runs until it blocks. If there is more than one thread with the same priority, and that priority is the highest among other threads, the first thread to begin running continues until it blocks.

- **SCHED_RR** (Round Robin)

  The highest-priority thread runs until it blocks; however, threads of equal priority, if that priority is the highest among other threads, are timesliced. (Timeslicing is a mechanism that ensures that every thread is allowed time to execute by preempting running threads at fixed intervals.)

- **SCHED_OTHER, SCHED_FG_NP** (Default)

  All threads are timesliced. **SCHED_OTHER** and **SCHED_FG_NP** do the same thing; however, **SCHED_FG_NP** is simply more precise terminology. The **FG** stands for *foreground* and the **NP** for *new primitive*. All threads running under the **SCHED_OTHER** and **SCHED_FG_NP** policy, regardless of priority, receive some scheduling. Therefore, no thread is completely denied execution time. However, **SCHED_OTHER** and **SCHED_FG_NP** threads can be denied execution time by **SCHED_FIFO** or **SCHED_RR** threads.

- **SCHED_BG_NP** (Background)

  Like **SCHED_OTHER** and **SCHED_FG_NP**, **SCHED_BG_NP** ensures that all threads, regardless of priority, receive some scheduling. However, **SCHED_BG_NP** can be denied execution by the **SCHED_FIFO** or **SCHED_RR** policies. The **BG** stands for *background*.

The following two methods are used to set the scheduling policy attribute:

- Set the scheduling policy attribute in the attributes object, which establishes the scheduling policy of a new thread when it is created. To do this, call the **pthread_attr_setsched()** routine.
- Change the scheduling policy of an existing thread (and, at the same time, the scheduling priority) by calling the **pthread_setscheduler()** routine.

Section 7.8 describes and shows the effect of scheduling policy on thread scheduling.

7.3.3.2 Scheduling Priority Attribute

The scheduling priority attribute specifies the execution of a thread. This attribute is expressed relative to other threads on a continuum of minimum to maximum for each scheduling policy. A thread's priority falls within one of the following ranges, which are implementation defined:

- **PRI_FIFO_MIN** to **PRI_FIFO_MAX**
- **PRI_RR_MIN** to **PRI_RR_MAX**
- **PRI_OTHER_MIN** to **PRI_OTHER_MAX**
- **PRI_FG_MIN_NP** to **PRI_FG_MAX_NP**
- **PRI_BG_MIN_NP** to **PRI_BG_MAX_NP**

The following two methods are used to set the scheduling priority attribute:

- Set the scheduling priority attribute in the attributes object, which establishes the execution priority of a new thread when it is created. To do this, call the **pthread_attr_setprio()** routine.
- Change the scheduling priority attribute of an existing thread by calling the **pthread_setprio()** routine. (Call the **pthread_setscheduler()** routine to change both the scheduling priority and scheduling policy of an existing thread.)

7.3.3.3 Inherit Scheduling Attribute

The inherit scheduling attribute specifies whether a newly created thread inherits the scheduling attributes (scheduling priority and policy) of the creating thread (the default), or uses the scheduling attributes stored in the attributes object. Set this attribute by calling the routine **pthread_attr_setinheritsched()**.

7.3.3.4 Stacksize Attribute

The stacksize attribute is the minimum size (in bytes) of the memory required for a thread's stack. The default value is machine dependent. Set this attribute by calling the **pthread_attr_setstacksize()** routine.

7.3.4 Mutex Attributes

A mutex attributes object allows you to specify values for mutex attributes other than the defaults when you create a mutex with the routine **pthread_mutex_init()**.

The mutex type attribute specifies whether a mutex is fast, recursive, or nonrecursive. Set the mutex type attribute by calling the routine **pthread_mutexattr_setkind_np()**. (Any routine with the **_np** suffix is a new primitive; see Section 7.2.) If you do not use a mutex attributes object to select a mutex type, calling the **pthread_mutex_init()** routine creates a fast mutex by default.

7.3.5 Condition Variable Attributes

Currently, attributes affecting condition variables are not defined. You cannot change any attributes in the condition variable attributes object.

Section 7.4.2 describes the purpose and uses of condition variables.

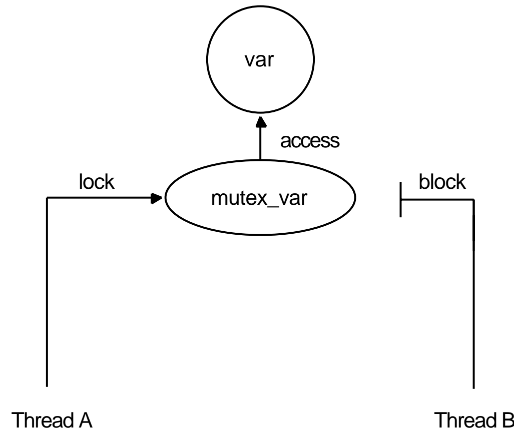
7.4 Synchronization Objects

In a multithreaded program, you must use synchronization objects whenever there is a possibility of corruption of shared data or conflicting scheduling of threads that have mutual scheduling dependencies. The following subsections discuss two kinds of synchronization objects: mutexes and condition variables.

7.4.1 Mutexes

A mutex (*mut*ual *ex*clusion) is an object that multiple threads use to ensure the integrity of a shared resource that they access, most commonly shared data. A mutex has two states: locked and unlocked. For each piece of shared data, all threads accessing that data must use the same mutex; each thread locks the mutex before it accesses the shared data and unlocks the mutex when it is finished accessing that data. If the mutex is locked by another thread, the thread requesting the lock is blocked when it tries to lock the mutex if you call **pthread_mutex_lock()** (see Figure 7-2). The blocked thread continues and is not blocked if you call **pthread_mutex_trylock()**.

Figure 7–2. Only One Thread Can Lock a Mutex



Each mutex must be initialized. (To initialize mutexes as part of the program's one-time initialization code, see Section 7.5.) To initialize a mutex, use the **pthread_mutex_init()** routine. This routine allows you to specify an attributes object, which allows you to specify the mutex type. The following are types of mutexes:

- A fast mutex (the default) is locked only once by a thread. If the thread tries to lock the mutex again without first unlocking it, the thread waits for itself to release the first lock and deadlocks on itself.

  This type of mutex is called *fast* because it can be locked and unlocked more rapidly than a recursive mutex. It is the most efficient form of mutex.

- A recursive mutex can be locked more than once by a given thread without causing a deadlock. The thread must call the **pthread_mutex_unlock()** routine the same number of times that it called the **pthread_mutex_lock()** routine before another thread can lock the mutex. Recursive mutexes have the notion of a mutex owner. When a thread successfully locks a recursive mutex, it owns that mutex and the lock count is set to 1. Any other thread attempting to lock the mutex blocks until the mutex becomes unlocked. If the owner of the mutex attempts to lock the mutex again, the lock count is incremented, and the thread continues running. When an owner unlocks a recursive mutex, the lock count is decremented. The mutex remains locked and owned until the count reaches 0 (zero). It is an error for any thread other than the owner to attempt to unlock the mutex.

A recursive mutex is useful if a thread needs exclusive access to a piece of data, and it needs to call another routine (or itself) that needs exclusive access to the data. A recursive mutex allows nested attempts to lock the mutex to succeed rather than deadlock.

This type of mutex requires more careful programming. Never use a recursive mutex with condition variables because the implicit unlock performed for a **pthread_cond_wait()** or **pthread_cond_timedwait()** may not actually release the mutex. In that case, no other thread can satisfy the condition of the predicate.

- A nonrecursive mutex is locked only once by a thread, like a fast mutex. If the thread tries to lock the mutex again without first unlocking it, the thread receives an error. Thus, nonrecursive mutexes are more informative than fast mutexes because fast mutexes block in such a case, leaving it up to you to determine why the thread no longer executes. Also, if someone other than the owner tries to unlock a nonrecursive mutex, an error is returned.

To lock a mutex, use one of the following routines, depending on what you want to happen if the mutex is locked:

- The **pthread_mutex_lock()** routine

  If the mutex is locked, the thread waits for the mutex to become available.

- The **pthread_mutex_trylock()** routine

  If the mutex is locked, the thread continues without waiting for the mutex to become available. The thread immediately checks the return status to see if the lock was successful, and then takes whatever action is appropriate if it was not.

When a thread is finished accessing a piece of shared data, it unlocks the associated mutex by calling the **pthread_mutex_unlock()** routine.

If another thread is waiting on the mutex, its execution is unblocked. If more than one thread is waiting on the mutex, the scheduling policy and the thread scheduling priority determine which thread acquires the mutex.

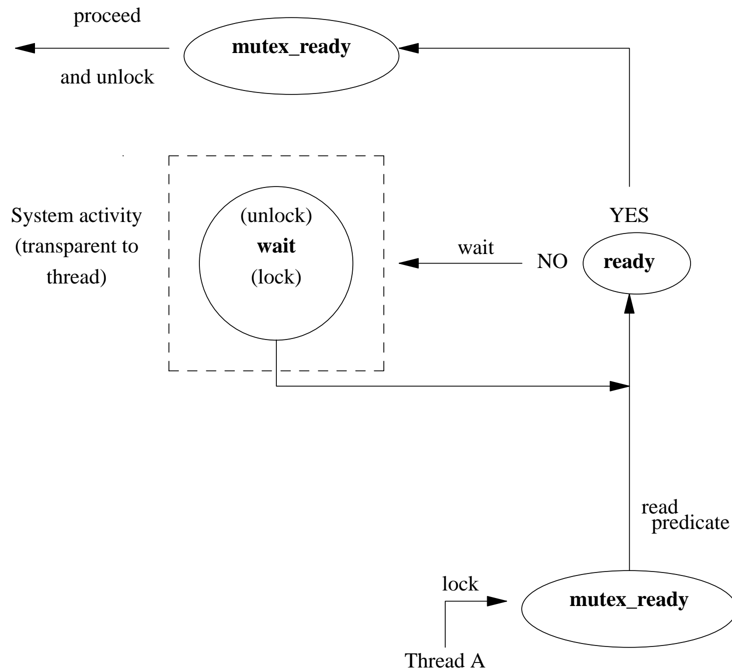
You can delete a mutex and reclaim its storage by calling the **pthread_mutex_destroy()** routine. Use this routine only after the mutex is no longer needed by any thread. Mutexes are automatically deleted when the program terminates.

7.4.2 Condition Variables

A condition variable allows a thread to block its own execution until some shared data reaches a particular state. Cooperating threads check the shared data and wait on the condition variable. For example, one thread in a program produces work-to-do packets and another thread consumes these packets (does the work). If the work queue is empty when the consumer thread checks it, that thread waits on a work-to-do condition variable. When the producer thread puts a packet on the queue, it signals the work-to-do condition variable.

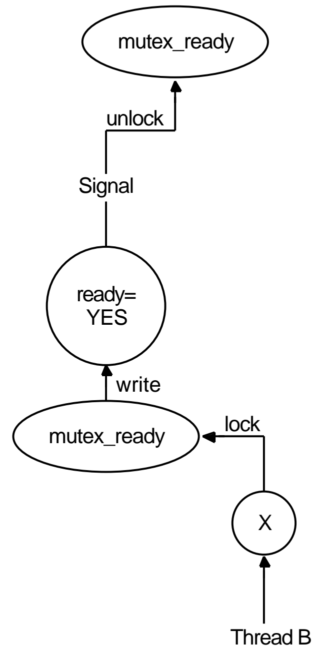
A condition variable is used to wait for a shared resource to assume some specific state (a predicate). A mutex, on the other hand, is used to reserve some shared resource while the resource is being manipulated. For example, a thread A may need to wait for a thread B to finish a task X before thread A proceeds to execute a task Y. Thread B can tell thread A that it has finished task X by using a variable they both have access to, a condition variable. When thread A is ready to execute task Y, it looks at the condition variable to see if thread B is finished (see Figure 7-3).

Figure 7–3. Thread A Waits on Condition Ready, Then Wakes Up and Proceeds



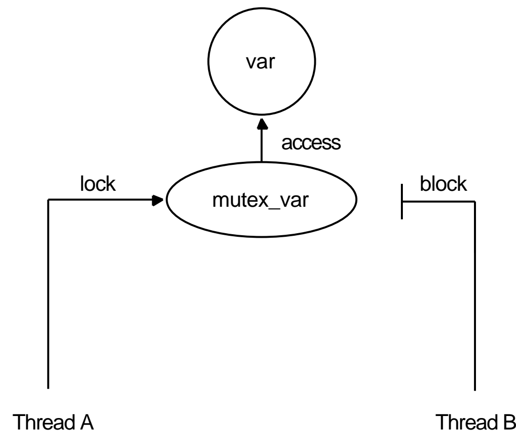
First, thread A locks the mutex named **mutex_ready** that is associated with the condition variable. Then it reads the predicate associated with the condition variable named **ready**. If the predicate indicates that thread B has finished task X, then thread A can unlock the mutex and proceed with task Y. If the condition variable predicate indicated that thread B has not yet finished task X, however, then thread A waits for the condition variable to change. Thread A calls the **wait** primitive. Waiting on the condition variable automatically unlocks the mutex, allowing thread B to lock the mutex when it has finished task X (see Figure 7-4).

Figure 7–4. Thread B Signals Condition Ready



Thread B updates the predicate named **ready** associated with the condition variable to the state thread A is waiting for. It also executes a signal on the condition variable while holding the mutex **mutex_ready**.

Figure 7–5. Thread A Wakes Up and Proceeds



Thread A wakes up, verifies that the condition variable is in the correct state, and proceeds to execute task Y (see Figure 7-3).

Note that, although the condition variable is used for explicit communications among threads, the communications are anonymous. Thread B does not necessarily know that thread A is waiting on the condition variable that thread B signals. And thread A does not know that it was thread B that woke it up from its wait on the condition variable.

Use the **pthread_cond_init()** routine to create a condition variable. To create condition variables as part of the program's one-time initialization code, see Section 7.5.

Use the **pthread_cond_wait()** routine to cause a thread to wait until the condition is signaled or broadcast. This routine specifies a condition variable and a mutex that you have locked. (If you have not locked the mutex, the results of **pthread_cond_wait()** are unpredictable.) This routine unlocks the mutex and causes the calling thread to wait on the condition variable until another thread calls one of the following routines:

- The **pthread_cond_signal()** routine to wake one thread that is waiting on the condition variable
- The **pthread_cond_broadcast()** routine to wake all threads that are waiting on a condition variable

If you want to limit the time that a thread waits for a condition to be signaled or broadcast, use the **pthread_cond_timedwait()** routine. This routine specifies the condition variable, mutex, and absolute time at which the wait should expire if the condition variable is not signaled or broadcast.

You can delete a condition variable and reclaim its storage by calling the **pthread_cond_destroy()** routine. Use this routine only after the condition variable is no longer needed by any thread. Condition variables are automatically deleted when the program terminates.

7.4.3 Other Synchronization Methods

There is another synchronization method that is not anonymous: the **join** primitive. This allows a thread to wait for another specific thread to complete its execution. When the second thread is finished, the first thread unblocks and continues its execution. Unlike mutexes and condition variables, the **join** primitive is not associated with any particular shared data.

7.5 One-Time Initialization Routines

You probably have one or more routines that must be executed *before* any thread executes code in your application, but must be executed *only once* regardless of the sequence in which threads start executing. For example, you may want to create mutexes and condition variables (each of which must be created only once) in an initialization routine. Multiple threads can call the **pthread_once()** routine, or the **pthread_once()** routine can be called multiple times in the same thread, resulting in only one call to the specified routine.

Use the **pthread_once()** routine to ensure that your application initialization routine is executed only a single time, that is, by the first thread that tries to initialize the application. This routine is the only way to guarantee that one-time initialization is performed in a multithreaded environment on a given platform. The **pthread_once()** routine is of particular use for runtime libraries, which are often called for the first time after multiple threads are created.

Refer to the **thr_intro(3thr)** reference page for a list of the DCE Threads routines which, when called, implicitly perform any necessary initialization of the threads package. Any application that uses DCE Threads must call one of these routines before calling any other threads routines.

7.6 Thread-Specific Data

The thread-specific data interfaces allow each thread to associate an arbitrary value with a shared key value created by the program.

Thread-specific data is like a global variable in which each thread can keep its own value, but is accessible to the thread anywhere in the program.

Use the following routines to create and access thread-specific data:

- The **pthread_keycreate()** routine to create a unique key value
- The **pthread_setspecific()** routine to associate data with a key
- The **pthread_getspecific()** routine to obtain the data associated with a key

The **pthread_keycreate()** routine generates a unique key value that is shared by all threads in the process. This key is the identifier of a piece of thread-specific data. Each thread uses the same key value to assign or retrieve a thread-specific value. This keeps your data separate from other thread-specific data. One call to the **pthread_keycreate()** routine creates a cell in all threads. Call this routine to specify a routine to be called to destroy the context value associated with this key when the thread terminates.

The **pthread_setspecific()** routine associates the address of some data with a specific key. Multiple threads associate different data (by specifying different addresses) with the same key. For example, each thread points to a different block of dynamically allocated memory that it has reserved.

The **pthread_getspecific()** routine obtains the address of the thread-specific data value associated with a specified key. Use this routine to locate the data associated with the current thread's context.

7.7 Thread Cancellation

Canceling is a mechanism by which one thread terminates another thread (or itself). When you request that a thread be canceled, you are requesting that it terminate as soon as possible. However, the target thread can control how quickly it terminates by controlling its general cancelability and its asynchronous cancelability.

The following is a list of the pthread calls that are cancellation points:

- The **pthread_setasynccancel()** routine
- The **pthread_testcancel()** routine
- The **pthread_delay_np()** routine
- The **pthread_join()** routine
- The **pthread_cond_wait()** routine
- The **pthread_cond_timedwait()** routine

General cancelability is enabled by default. A thread is canceled only at specific places in the program; for example, when a call to the **pthread_cond_wait()** routine is made. If general cancelability is enabled, request the delivery of any pending cancel request by using the **pthread_testcancel()** routine. This routine allows you to permit cancellation to occur at places where it may not otherwise be permitted under general cancelability, and it is especially useful within very long loops to ensure that cancel requests are noticed within a reasonable time.

If you disable general cancelability, the thread cannot be terminated by any cancel request. Disabling general cancelability means that a thread could wait indefinitely if it does not come to a normal conclusion. Therefore, be careful about disabling general cancelability.

Asynchronous cancelability, when it is enabled, allows cancels to be delivered to the enabling thread at any time, not only at those times that are permitted when just general cancelability is enabled. Thus, use asynchronous cancellation primarily during long processes that do not have specific places for cancel requests. Asynchronous cancelability is disabled by default. Disable asynchronous cancelability when calling threads routines or any other runtime library routines that are not explicitly documented as cancel-safe.

Note: If general cancelability is disabled, the thread cannot be canceled, regardless of whether asynchronous cancelability is enabled or disabled. The setting of asynchronous cancelability is relevant only when general cancelability is enabled.

Use the following routines to control the canceling of threads:

- The **pthread_setcancel()** routine to enable and disable general cancelability
- The **pthread_testcancel()** routine to request delivery of a pending cancel to the current thread
- The **pthread_setasynccancel()** routine to enable and disable asynchronous cancelability
- The **pthread_cancel()** routine to request that a thread be canceled

7.8 Thread Scheduling

Threads are scheduled according to their scheduling priority and how the scheduling policy treats those priorities. To understand the discussion in this section, you must understand the concepts in the following sections of this chapter:

- Section 7.3.3.1 discusses scheduling policies, including the way in which each policy handles thread scheduling priority.
- Section 7.3.3.2 discusses thread scheduling priorities.
- Section 7.3.3.3 discusses inheritance of scheduling attributes by created threads.

To specify the minimum or maximum priority, use the appropriate symbol; for example, **PRI_OTHER_MIN** or **PRI_OTHER_MAX**. To specify a value between the minimum and maximum priority, use an appropriate arithmetic expression.

For example, to specify a priority midway between the minimum and maximum for the default scheduling policy, specify the following concept using your programming language's syntax:

```
pri_other_mid = (PRI_OTHER_MIN + PRI_OTHER_MAX)/2
```

If your expression results in a value outside the range of minimum to maximum, an error results when you use it. Priority values are integers.

To show results of the different scheduling policies, consider the following example: a program has four threads, called threads A, B, C, and D. For each scheduling policy, three scheduling priorities have been defined: minimum, middle, and maximum. The threads have the priorities shown in Table 7-1.

Table 7–1. Sample Thread Properties

Thread	**Priority**
A	Minimum
B	Middle
C	Middle
D	Maximum

Figures 7-6 through 7-8 show execution flows, depending on whether the threads use the **SCHED_FIFO**, **SCHED_RR**, or **SCHED_OTHER** (default) scheduling policy. Assume that all waiting threads are ready to execute when the current thread waits or terminates and that no higher-priority thread is awakened while a thread is executing (during the flow shown in each figure).

Figure 7-6 shows a flow with **SCHED_FIFO** (First In, First Out) scheduling.

Figure 7–6. Flow with SCHED_FIFO Scheduling

Thread D executes until it waits or terminates, then Thread B starts because it has been waiting longer than Thread C and it executes until it waits or terminates, then Thread C executes until it waits or terminates, then Thread A executes.

Figure 7-7 shows a flow with **SCHED_RR** (Round Robin) scheduling.

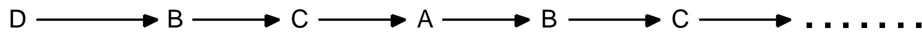
Figure 7–7. Flow with SCHED_RR Scheduling

All four threads are timesliced. Threads with higher priority are generally scheduled when more than one thread is ready to run; however, to ensure fairness, all threads are given some time. The effective priority of threads may be modified over time by the scheduler, depending on the use of processor resources.

Thread D executes until it waits or terminates, then threads B and C are timesliced because they both have middle priority, then thread A executes.

Figure 7-8 shows a flow with **SCHED_OTHER** (default) scheduling.

Figure 7–8. Flow with SCHED_OTHER Scheduling



Thread D executes until it waits or terminates; then threads B, C, and A are timesliced, even though thread A has a lower priority than the other two. Thread A receives less execution time than thread B or C if either is ready to execute as often as thread A is. However, the default scheduling policy protects thread A against being blocked from executing indefinitely.

Because low-priority threads eventually run, the default scheduling policy protects against the problem of priority inversion discussed in Chapter 8.

Chapter 8

Programming with Threads

This chapter discusses issues you face when writing a multithreaded program and how to deal with those issues.

The topics discussed in this chapter are as follows:

- Calling UNIX services
- Using signals
- Nonthreaded libraries
- Avoiding nonreentrant software
- Avoiding priority inversion
- Using synchronization objects
- Signaling a condition variable

8.1 Calling UNIX Services

On a UNIX system that does not have kernel support for threads, making system and library calls from within a multithreaded program raises the following issues:

- System calls may not be thread-reentrant.
- If a system call blocks, it blocks the entire process instead of blocking the calling thread only.

8.1.1 Jacket Routines

To resolve the previous two issues, DCE Threads provides jacket routines for a number of UNIX system calls. Threads call the jacket routine instead of the UNIX system service; this allows DCE Threads to take action on behalf of the thread before or after calling the system service. For example, the jacket routines ensure that only one thread calls any particular service at a time to avoid problems with system calls that are not thread-reentrant.

Jacket routines are provided for UNIX input and output system calls (documented in any UNIX programmer's manual) and the **fork()** and **sigaction()** system calls. Jackets are not provided for any other UNIX system calls or for any of the C runtime library services. See **/usr/include/dce/cma_ux.h** for the full list of jacket routines.

8.1.1.1 Input and Output Jacket Routines

Jacket routines are provided for routines that perform input and output operations. Examples of these operations are as follows:

- Open or create files, pipe symbols, and sockets
- Send and receive messages on sockets
- Read and write files and pipe symbols

Jacket routines are provided for Input/Output services so that DCE Threads can determine when to issue or block the service call based on the results of the **select()** system call. For these UNIX services, DCE Threads can determine whether issuing

the system call causes the process to block. If the system call causes the process to block, DCE Threads blocks only the calling thread and schedules another thread to run in its place.

Periodically, DCE Threads checks whether the original calling thread can issue its operation without blocking the process. When the thread runs without blocking the process, that thread is placed back into the queue of ready threads and, at its turn, the thread resumes execution and issues the system call. Therefore, the jacket routines provide thread-synchronous I/O operations where otherwise the system calls block the entire process.

8.1.1.2 The **fork()** Jacket Routine

Jackets are provided for the **fork()** system call. A specific thread environment must exist in the forked process when it resumes (begins) execution. These jacket routines allow code to be executed in the context of the new process before the user code resumes execution in it.

8.1.1.3 The **atfork()** Routine

The **atfork()** routine allows an application or library to ensure predicted behavior when the **fork()** routine is used in a multithreaded environment. Using the **fork()** routine from a threaded application or from an application that uses threaded libraries can result in unpredictable behavior. For example, one thread has a mutex locked, and the state covered by that mutex is inconsistent while another thread calls the **fork()** routine. In the child process, the mutex will be in the locked state, and it cannot be unlocked because only the forking thread exists in the child process. Having the child reinitialize the mutex is unsatisfactory because this approach does not resolve the question of how to correct the inconsistent state in the child.

The **atfork()** routine provides a way for threaded applications or libraries to protect themselves when a **fork()** occurs. The **atfork()** routine allows you to set up routines that will run at the following times:

- Prior to the **fork()** in the parent process
- After the **fork()** in the child process

- After the **fork()** in the parent process

Within these routines, you can ensure that all mutexes are locked prior to the **fork()** and that they are unlocked after the **fork()**, thereby protecting any data or resources associated with the mutexes. You can register any number of sets of **atfork()** routines; that is, any number of libraries or user programs can set up **atfork()** routines and they will all execute at **fork()** time.

Note: Using the **atfork()** routine can potentially cause a deadlock if two applications or libraries call into one another using calls that require locking. Specifically, when these component's routines use the **atfork()** routine to run prior to the fork in the parent process, a deadlock may occur when these routines are executing.

8.1.1.4 Using the Jacketed System Calls

You do not have to rename your system calls to take advantage of the jacket routines. Macros put the jacket routines into place when you compile your program; these macros rename the jacketed system calls to the name of the DCE Threads jacket routine. Thus, a reference to the DCE Threads jacket routine is compiled into your code instead of a reference to the system call. When the code is executed, it calls the jacket routine, which then calls the system on your code's behalf.

If you do not wish to use any of the jacket routines, you can add the following line to your program before any of the thread header files:

```
#define _CMA_NOWRAPPERS_
```

By adding this definition, you prevent the jacket routines from being substituted for the real routines.

If you wish to use most of the jackets but do not wish to use a specific jacket, you can undefine a specific jacket by adding the following directive after the thread header files:

#undef *routine_name*

For example, to not use the fork jacket, you can add the following:

```
#undef fork
```

8.1.2 Blocking System Calls

DCE Threads provides jacket routines that make certain system calls thread-synchronous. If calling one of these jacketed system calls would normally block the process, the jacket routine ensures that only the calling thread is blocked and that the process remains available to execute other threads. Examples of jacketed system calls include **read**(), **write**(), **open**(), **socket**(), **send**(), and **recv**().

If a thread makes a call to any of the other nonjacketed blocking system calls (or if it calls one of the jacketed system calls without going through the jacket), then when the system call blocks the thread, it blocks the whole process, preventing any other threads in the process from executing. Examples of nonjacketed system calls include **wait**(), **sigpause**(), **msgsnd**(), **msgrcv**(), and **semop**().

Some care must be used when calling nonjacketed blocking system calls from a multithreaded program. Other threads in the program may not be able to tolerate not running for an extended period of time while the process blocks for the system call. If your program must make use of such system calls, the calling thread should specify a nonblocking or polling option to the system call. If the call is not successful, then the calling thread should retry; however, to prevent the retry code from becoming a hot loop, a yield or delay function call should be inserted into the path. This gives other threads in the program a chance to run between poll attempts.

8.1.3 Calling fork() in a Multithreaded Environment

The **fork()** system call creates an exact duplicate of the address space from which it is called, resulting in two address spaces executing the same code. Problems can occur if the forking address space has multiple threads executing at the time of the **fork**(). When multithreading is a result of library invocation, threads are not necessarily aware

of each other's presence, purpose, actions, and so on. Suppose that one of the other threads (any thread other than the one doing the **fork()**) has the job of deducting money from your checking account. Clearly, you do not want this to happen twice as a result of some other thread's decision to call **fork()**.

Because of these types of problems, which in general are problems of threads modifying persistent state, POSIX defined the behavior of **fork()** in the presence of threads to propagate only the forking thread. This solves the problem of improper changes being made to persistent state. However, it causes other problems, as discussed in the next paragraph.

In the POSIX model, only the forking thread is propagated. All the other threads are eliminated without any form of notice; no cancels are sent and no handlers are run. However, all the other portions of the address space are cloned, including all the mutex state. If the other thread has a mutex locked, the mutex will be locked in the child process, but the lock owner will not exist to unlock it. Therefore, the resource protected by the lock will be permanently unavailable.

The fact that there may be mutexes outstanding only becomes a problem if your code attempts to lock a mutex that could be locked by another thread at the time of the **fork()**. This means that you cannot call outside of your own code between the call to **fork()** and the call to **exec()**. Note that a call to **malloc()**, for example, is a call outside of the currently executing application program and may have a mutex outstanding. The following code obeys these guidelines and is therefore safe:

```
fork ();
a = 1+2;  /* some inline processing */
exec();
```

Similarly, if your code calls some of your own code that does not make any calls outside of your code and does not lock any mutexes that could possibly be locked in another thread, then your code is safe.

One solution to the problem of calling **fork()** in a multithreaded environment exists. (Note that this method will not work for server application code or any other application code that is invoked by a callback from a library.) Before an application performs a **fork()** followed by something other than **exec()**, it must cancel all of the other threads. After it joins the canceled threads, it can safely **fork()** because it is the only thread in existence. This means that libraries that create threads must establish

cancel handlers that propagate the cancel to the created threads and join them. The application should save enough state so that the threads can be recreated and restarted after the **fork()** processing completes.

8.2 Using Signals

The following subsections cover three topics: types of signals, DCE Threads signal handling, and alternatives to using signals.

8.2.1 Types of Signals

Signals are delivered as a result of some event. UNIX signals are grouped into the following four categories of pairs that are orthogonal to each other:

- Terminating and synchronous
- Terminating and asynchronous
- Nonterminating and synchronous
- Nonterminating and asynchronous

The action that DCE Threads takes when a particular signal is delivered depends on the characteristics of that signal.

8.2.1.1 Terminating Signals

Terminating signals result in the termination of the process by default. Whether a particular signal is terminating or not is independent of whether it is synchronously or asynchronously delivered.

8.2.1.2 Nonterminating Signals

Nonterminating signals do not result in the termination of the process by default.

Nonterminating signals represent events that can be either internal or external to the process. The process may require notification or ignore these events. When a nonterminating asynchronous signal is delivered to the process, DCE Threads awakens any threads that are waiting for the signal. This is the only action that DCE Threads takes because, by default, the signal has no effect.

8.2.1.3 Synchronous Signals

Synchronous signals are the result of an event that occurs inside a process and are delivered synchronously with respect to that event. For example, if a floating-point calculation results in an overflow, then a **SIGFPE** (floating-point exception signal) is delivered to the process immediately following the instruction that resulted in the overflow.

The default behavior of DCE Threads in DCE Version 1.0.2 when a synchronous terminating signal occurs is to dump core; that is, to not handle the signal. This differs from the behavior prior to DCE Version 1.0.2, in which such a signal would be turned into an exception and propagated out to whatever process was the original owner of the thread (namely the client, even though the exception might have occurred in the server). Therefore, if an application using DCE Threads wants to handle such signals, it must now set up a signal handler to do so by calling **sigaction()**. Note that the new DCE Threads behavior is in fact similar to the default behavior of most UNIX programs.

Synchronous, terminating signals represent an error that has occurred in the currently executing thread.

8.2.1.4 Asynchronous Signals

Asynchronous signals are the result of an event that is external to the process and are delivered at any point in a thread's execution when such an event occurs. For example, when a user running a program types the interrupt character at the terminal (generally **<Ctrl-C>**), a **SIGINT** (interrupt signal) is delivered to the process.

Asynchronous, terminating signals represent an occurrence of an event that is external to the process and, if unhandled, results in the termination of the process. When an

asynchronous terminating signal is delivered, DCE Threads catches it and checks to see if any threads are waiting for it. If threads are waiting, they are awakened, and the signal is considered handled and is dismissed. If there are no waiting threads, then DCE Threads causes the process to be terminated as if the signal had not been handled.

8.2.2 DCE Threads Signal Handling

DCE Threads provides the POSIX **sigwait()** service to allow threads to perform activities similar to signal handling without having to deal with signals directly. It also provides a jacket for **sigaction()** that allows each thread to have its own handler for synchronous signals.

In order to provide these mechanisms, DCE Threads installs signal handlers for most of the UNIX signals during initialization.

DCE Threads do not provide handlers for several UNIX signals. Those signals and the reasons why handlers are not provided are shown in Table 8-1.

Table 8–1. Signals for Which Handlers Are Not Provided

Signal	Reason Handler Is Not Provided
SIGKILL and **SIGSTOP**	These signals cannot be caught by user mode code.
SIGTRAP	Catching this signal interferes with debugging.
SIGTSTP and **SIGQUIT**	These signals are caught only while a thread has issued a **sigwait()** call because their default actions are otherwise valuable.

8.2.2.1 The POSIX **sigwait**() Service

The DCE Threads implementation of the POSIX **sigwait()** service allows any thread to block until one of a specified set of signals is delivered. A thread waits for any of the asynchronous signals, except for **SIGKILL** and **SIGSTOP**.

A thread cannot wait for a synchronous signal. This is because synchronous signals are the result of an error during the execution of a thread; if the thread is waiting for a signal, then it is not executing. Therefore, a synchronous signal cannot occur for a particular thread while it is waiting, and so the thread waits forever. POSIX stipulates that the thread must block the signals (using the UNIX system service **sigprocmask**()) it waits for before calling **sigwait**().

8.2.2.2 The POSIX **sigaction()** Service

The DCE Threads implementation of the POSIX **sigaction()** service allows for per-thread handlers to be installed for catching synchronous signals. The **sigaction()** routine modifies behavior only for individual threads and works only for synchronous signals. Setting the signal action to **SIG_DFL** for a specific signal will restore the thread's default behavior for that signal. Attempting to set a signal action for an asynchronous signal is an error.

8.2.2.3 The **itimer VTALARM**

DCE Threads installs a handler for the **itimer VTALARM**. Therefore, **VTALARM** is unavailable for use by other applications.

8.2.3 Alternatives to Using Signals

Avoid using UNIX signals in multithreaded programs. DCE Threads provides alternatives to signal handling. These alternatives are discussed in more detail in Sections 8.6 and 8.7.

Note: In order to implement these alternatives, DCE Threads must install its own signal handlers. These are installed when DCE Threads initializes itself, typically on the first thread-function call. At this time, any existing signal handlers are replaced.

Following are several reasons for avoiding signals:

- They cannot be used in a modular way in a multithreaded program.
- They are unnecessary when used as an asynchronous programming technique in a multithreaded program.
- There are almost no threads services available at signal level.
- There is no reliable, portable way to modify predicates.
- The signal-handler interface is unsuitable for use with threads. (For example, there is one signal action per signal per process, there is one signal mask per process, and **sigpause()** blocks the whole process.)

In a multithreaded program, signals cannot be used in a modular way because, on most current UNIX implementations, signals are inherently a process construct. There is only one instantiation of each signal and of each signal handler routine for all of the threads in an application. If one thread handles a particular signal in one way, and a different thread handles the same signal in a different way, then the thread that installs its signal handler last handles the signal. This applies only to asynchronously generated signals; synchronous signals can be handled on a per-thread basis using the DCE Threads **sigaction()** jacket.

Do not use asynchronous programming techniques in conjunction with threads, particularly those that increase parallelism such as using timer signals and I/O signals. These techniques can be complicated. They are also unnecessary because threads provide a mechanism for parallel execution that is simpler and less prone to error where concurrence can be of value. Furthermore, most of the threads routines are not supported for use in interrupt routines (such as signal handlers), and portions of runtime libraries cannot be used reliably inside a signal handler.

8.3 Nonthreaded Libraries

As programming with threads becomes common practice, you need to ensure that threaded code and nonthreaded code (code that is not designed to work with threads) work properly together in the same application. For example, you may write a new application that uses threads (for example, an RPC server), and link it with a library that does not use threads (and is thus not thread-safe). In such a situation you can do one of the following:

- Work with the nonthreaded software.
- Change the nonthreaded software to be thread-safe.

8.3.1 Working with Nonthreaded Software

Thread-safe code is code that works properly in a threaded environment. To work with nonthread-safe code, associate the global lock with all calls to such code.

You can implement the lock on the side of the routine user or the routine provider. For example, you can implement the lock on the side of the routine user if you write a new application like an RPC server that uses threads, and you link it with a library that does not. Or, if you have access to the nonthreaded code, the locks can be placed on the side of the routine provider, within the actual routine. Implement the locks as follows:

1. Associate one lock, a global lock, with execution of such code.
2. Require all of your threads to lock prior to execution of nonthreaded code.
3. Perform an unlock when execution is complete.

By using the global lock, you ensure that only one thread executes in outside libraries, which may call each other, and in unknown code. Using a single global lock is safer than using multiple local locks because it is difficult to be aware of everything a library may be doing or of the interactions that library can have with other libraries.

8.3.2 Making Nonthreaded Code Thread-Reentrant

Thread-reentrant code is code that works properly while multiple threads execute it concurrently. Thread-reentrant code is thread-safe, but thread-safe code may not be thread-reentrant. Document your code as being thread-safe or thread-reentrant.

More work is involved in making code thread-reentrant than in making code thread-safe. To make code thread-reentrant, do the following:

1. Use proper locking protocols to access global or static variables.
2. Use proper locking protocols when you use code that is not thread-safe.
3. Store thread-specific data on the stack or heap.
4. Ensure that the compiler produces thread-reentrant code.
5. Document your code as being thread-reentrant.

8.4 Avoiding Nonreentrant Software

The following subsections discuss two methods to help you avoid the pitfalls of nonreentrant software. These methods are as follows:

- Global lock
- Thread-specific storage

8.4.1 Global Lock

Use a global lock, which has the characteristics of a recursive mutex, instead of a regular mutex when calling routines that you think are nonreentrant. (When in doubt, assume the code is nonreentrant.)

The **pthread_lock_global_np()** routine is a locking protocol that is used to call nonreentrant routines, often found in existing library packages that were not designed to run in a multithreaded environment.

The way to call a library function that is not reentrant from a multithreaded program is to protect the function with a mutex. If every function that calls a library locks a particular mutex before the call and releases the mutex after the call, then the function completes without interference. However, this is difficult to do successfully because the function may be called by many libraries. A global lock solves this problem by providing a universal lock. Any code that calls any nonreentrant function uses the same lock.

To lock a global lock, call the **pthread_lock_global_np()** routine. To unlock a global lock, call the **pthread_unlock_global_np()** routine.

Note: Many COBOL and FORTRAN compilers generate inherently nonreentrant code. Many C, Ada, Pascal, and BLISS compilers generate reentrant code by default. It is possible to write nonreentrant code in the reentrant languages by not following a locking protocol.

8.4.2 Thread-Specific Storage

To avoid nonreentrancy when writing new software, avoid using global variables to store data that is thread-specific data.

Alternatively, allocate thread-specific data on the stack or heap and explicitly pass its address to called routines.

8.5 Avoiding Priority Inversion

Priority inversion occurs when interaction among three or more threads blocks the highest-priority thread from executing. For example, a high-priority thread waits for a resource locked by a low-priority thread, and the low-priority thread waits while a middle-priority thread executes. The high-priority thread is made to wait while a thread of lower priority (the middle-priority thread) executes.

To avoid priority inversion, associate a priority with each resource and force any thread using that object to first raise its priority to that associated with the object. This method of avoiding priority inversion is not a complete solution because all threads

will then block at the same ceiling priority and be unblocked in FIFO order rather than by their actual priority.

The **SCHED_OTHER** (default) scheduling policy prevents priority inversion from causing a complete blockage of the high-priority thread because the low-priority thread is permitted to execute and release the resource. The **SCHED_FIFO** and **SCHED_RR** policies, however, do not force resumption of the low-priority thread if the middle-priority thread executes indefinitely.

8.6 Using Synchronization Objects

The following subsections discuss the use of mutexes to prevent two potential problems: race conditions and deadlocks. Also discussed is why you should signal a condition variable with the associated mutex locked.

8.6.1 Race Conditions

A race condition occurs when two or more threads perform an operation, and the result of the operation depends on unpredictable timing factors; specifically, when each thread executes and waits and when each thread completes the operation.

An example of a race condition is as follows:

1. Both A and B are executing (X = X + 1).
2. A reads the value of X (for example, X = 5).
3. B comes in and reads the value of X and increments it (making X = 6).
4. A gets rescheduled and now increments X. Based on its earlier read operation, A thinks (X+1 = 5+1 = 6). X is now 6. It should be 7 because it was incremented once by A and once by B.

To avoid race conditions, ensure that any variable modified by more than one thread has only one mutex associated with it. Do not assume that a simple add operation can be completed without allowing another thread to execute. Such operations are generally not portable, especially to multiprocessor systems. If it is possible for two threads to share a data point, use a mutex.

8.6.2 Deadlocks

A deadlock occurs when one or more threads are permanently blocked from executing because each thread waits on a resource held by another thread in the deadlock. A thread can also deadlock on itself.

The following is one technique for avoiding deadlocks:

1. Associate a sequence number with each mutex.
2. Lock mutexes in sequence.
3. Do not attempt to lock a mutex with a sequence number lower than that of a mutex the thread already holds.

Another technique, which is useful when a thread needs to lock the same mutex more than once before unlocking it, is to use a recursive mutex. This technique prevents a thread from deadlocking on itself.

8.7 Signaling a Condition Variable

When you are signaling a condition variable and that signal may cause the condition variable to be deleted, it is recommended that you signal or broadcast with the mutex locked.

The recommended coding for signaling a condition variable appears at the end of this chapter. The following two C code fragments show coding that is *not recommended*. The following C code fragment is executed by a releasing thread:

```
pthread_mutex_lock (m);
/* Change shared variables to allow */
/* another thread to proceed */

pthread_mutex_unlock (m); <---- Point A
pthread_cond_signal (cv); <---- Statement 1
```

The following C code fragment is executed by a potentially blocking thread:

```
pthread_mutex_lock (m);
while (!predicate ...
 pthread_cond_wait (cv, m);

pthread_mutex_unlock (m);
```

Note: It is possible for a potentially blocking thread to be running at *Point A* while another thread is interrupted. The potentially blocking thread can then see the predicate true and therefore not become blocked on the condition variable.

Signaling a condition variable without first locking a mutex is not a problem. However, if the released thread deletes the condition variable without any further synchronization at *Point A*, then the releasing thread will fail when it attempts to execute *Statement 1* because the condition variable no longer exists.

This problem occurs when the releasing thread is a worker thread and the waiting thread is the boss thread, and the last worker thread tells the boss thread to delete the variables that are being shared by boss and worker.

The following C code fragment shows the *recommended* coding for signaling a condition variable while the mutex is locked:

```
pthread_mutex_lock (m);
/* Change shared variables to allow */
/* some other thread to proceed */

pthread_cond_signal (cv);   <---- Statement 1
pthread_mutex_unlock (m);
```

Chapter 9

Using the DCE Threads Exception-Returning Interface

DCE Threads provides the following two ways to obtain information about the status of a threads routine:

- The routine returns a status value to the thread.
- The routine raises an exception.

Before you write a multithreaded program, you must choose only one of the preceding two methods of receiving status. These two methods cannot be used together in the same code module.

The POSIX P1003.4a (pthreads) draft standard specifies that errors be reported to the thread by setting the external variable **errno** to an error code and returning a function value of −1. The threads reference pages document this status-value-returning interface (see the *DCE 1.2.2 Application Development Reference*). However, an alternative to status values is provided by DCE Threads in the exception-returning interface.

This chapter introduces and provides conventions for the modular use of the exception-returning interface to DCE Threads.

9.1 Syntax for C

Access to exceptions from the C language is defined by the macros in the **exc_handling.h** file. The **exc_handling.h** header file is included automatically when you include **pthread_exc.h** (see Section 9.2).

The following example shows the syntax for handling exceptions:

```
TRY
    try_block
[CATCH (exception_name)
    handler_block]...
[CATCH_ALL
    handler_block]
ENDTRY
```

A **try_block** or a **handler_block** is a sequence of statements, the first of which may be declarations, as in a normal block. If an exception is raised in the **try_block**, the catch clauses are evaluated in order to see if any one matches the current exception.

The **CATCH** or **CATCH_ALL** clauses absorb an exception; that is, they catch an exception propagating out of the **try_block**, and direct execution into the associated **handler_block**. Propagation of the exception, by default, then ends. Within the lexical scope of a handler, it is possible to explicitly cause propagation of the same exception to resume (this is called *reraising* the exception), or it is possible to raise some new exception.

The **RERAISE** statement is allowed in any handler statements and causes the current exception to be reraised. Propagation of the caught exception resumes.

The **RAISE** (*exception_name*) statement is allowed anywhere and causes a particular exception to start propagating. For example:

```
TRY
    sort(); /* Call a function that may raise an exception.
             * An exception is accomplished by longjumping
             * out of some nested routine back to the TRY
             * clause.  Any output parameters or return
             * values of the called routine are therefore
             * indeterminate.
             */

CATCH (pthread_cancel_e)
    printf("Alerted while sorting\n"); RERAISE;

CATCH_ALL
    printf("Some other exception while sorting\n"); RERAISE;

ENDTRY
```

In the preceding example, if the **pthread_cancel_e** exception propagates out of the function call, the first **printf** is executed. If any other exception propagates out of sort, the second **printf** is executed. In either situation, propagation of the exception resumes because of the **RERAISE** statement. (If the code is unable to fully recover from the error, or does not understand the error, it needs to do what it did in the previous example and further propagate the error to its callers.)

The following shows the syntax for an epilogue:

```
TRY       try_block
[FINALLY  final_block]
ENDTRY
```

The **final_block** is executed whether the **try_block** executes to completion without raising an exception, or if an exception is raised in the **try_block**. If an exception is raised in the **try_block**, propagation of the exception is resumed after executing the **final_block**.

Note that a **CATCH_ALL** handler and **RERAISE** could be used to do this, but the epilogue code would then have to be duplicated in two places, as follows:

```
TRY
     try_block
CATCH_ALL
     final_block
     RERAISE;
ENDTRY
{ final_block }
```

A **FINALLY** statement has exactly this meaning, but avoids code duplication.

Note: The behavior of **FINALLY** along with the **CATCH** or **CATCH_ALL** clauses is undefined. Do *not* combine them for the same **try_block**.

Another example of the **FINALLY** statement is as follows:

```
pthread__mutex_lock (some_object.mutex);
some_object.num_waiters = some_object.num_waiters + 1;
TRY
    while (! some_object.data_available)
        pthread_cond_wait (some_object.condition);
    /* The code to act on the data_available goes here */
FINALLY
    some_object.num_waiters = some_object.num_waiters - 1;
    pthread_mutex_unlock (some_object.mutex);
ENDTRY
```

In the preceding example, the call to **pthread_cond_wait()** could raise the **pthread_cancel_e** exception. The **final_block** ensures that the shared data associated with the lock is correct for the next thread that acquires the mutex.

9.2 Invoking the Exception-Returning Interface

To use the exception-returning interface, replace the first statement that follows with the second:

```
#include <pthread.h>

#include <pthread_exc.h>
```

9.3 Operations on Exceptions

An exception is an object that describes an error condition. Operations on exception objects allow errors to be reported and handled. If an exception is handled properly, the program can recover from errors. For example, if an exception is raised from a parity error while reading a tape, the recovery action may be to retry 100 times before giving up.

The DCE Threads exception-returning interface allows you to perform the following operations on exceptions:

- Declare and initialize an exception object
- Raise an exception
- Define a region of code over which exceptions are caught
- Catch a particular exception or all exceptions
- Define epilogue actions for a block
- Import a system-defined error status into the program as an exception

These operations are discussed in the following subsections.

9.3.1 Declaring and Initializing an Exception Object

Declaring and initializing an exception object documents that a program reports or handles a particular error. Having the error expressed as an exception object provides future extensibility as well as portability. Following is an example of declaring and initializing an exception object:

```
EXCEPTION parity_error;         /* Declare it */
EXCEPTION_INIT (parity_error);  /* Initialize it */
```

9.3.2 Raising an Exception

Raising an exception reports an error, not by returning a value, but by propagating an exception. Propagation involves searching all active scopes for code written to handle the error or code written to perform scope-completion actions in case of any error, and then causing that code to execute. If a scope does not define a handler or epilogue block, then the scope is simply torn down as the exception propagates through the stack. This is sometimes referred to as *unwinding the stack*. DCE Threads exceptions are terminating; there is no option to make execution resume at the point of the error. (Execution resumes at the point where the exception was caught.)

If an exception is unhandled, the entire application process is terminated. Aborting the process, rather than just the faulting thread, provides clean termination at the point of error. This prevents the disappearance of the faulting thread from causing problems at some later point.

An example of raising an exception is as follows:

```
RAISE (parity_error);
```

9.3.3 Defining a Region of Code over Which Exceptions Are Caught

Defining a region of code over which exceptions are caught allows you to call functions that can raise an exception and specify the recovery action.

Following is an example of defining an exception-handling region (without indicating any recovery actions):

```
TRY {
   read_tape ();
    }
ENDTRY;
```

9.3.4 Catching a Particular Exception or All Exceptions

It is possible to discriminate among errors and perform different actions for each error.

Following is an example of catching a particular exception and specifying the recovery action (in this case, a message). The exception is reraised (passed to its callers) after catching the exception and executing the recovery action:

```
TRY {
   read_tape ();
    }
CATCH (parity_error) {
   printf ("Oops, parity error, program terminating\n");
   printf ("Try cleaning the heads!\n");
   RERAISE;
   }
ENDTRY
```

9.3.5 Defining Epilogue Actions for a Block

A **FINALLY** mechanism is provided so that multithreaded programs can restore invariants as certain scopes are unwound; for example, restoring shared data to a correct state and releasing locks. This is often the ideal way to define, in one place, the cleanup activities for normal or abnormal exit from a block that has changed some invariant.

Following is an example of specifying an invariant action whether or not there is an error:

```
lock_tape_drive (t);
TRY
    TRY
       read_tape ();
    CATCH (parity_error)
       printf ("Oops, parity error, program terminating\n");
```

```
        printf ("Try cleaning the heads!\n");
        RERAISE;
    ENDTRY
    /* Control gets here only if no exception is raised */
    /* ... Now we can use the data off the tape */
FINALLY
    /* Control gets here normally, or if any exception is */
    raised unlock_tape_drive (t);
ENDTRY
```

9.3.6 Importing a System-Defined Error Status into the Program as an Exception

Most systems define error messages by integer-sized status values. Each status value corresponds to some error message text that should be expressed in the user's own language. The capability to import a status value as an exception permits the DCE Threads exception-returning interface to raise or handle system-defined errors as well as programmer-defined exceptions.

An example of importing an error status into an exception is as follows:

```
exc_set_status (&parity_error, EPARITY);
```

The **parity_error** exception can then be raised and handled like any other exception.

9.4 Rules and Conventions for Modular Use of Exceptions

The following rules ensure that exceptions are used in a modular way so that independent software components can be written without requiring knowledge of each other:

- Use unique names for exceptions.

A naming convention makes sure that the names for exceptions that are declared **EXTERN** from different modules do not clash. The following convention is recommended:

```
<facility-prefix>_<error_name>_e
```

For example, **pthread_cancel_e**.

- Avoid putting code in a **TRY** routine that belongs before it.

  The **TRY** only guards statements for which the statements in the **FINALLY**, **CATCH**, or **CATCH_ALL** clauses are always valid.

  A common misuse of **TRY** is to put code in the **try_block** that needs to be placed before **TRY**. An example of this misuse is as follows:

```
TRY
    handle = open_file (file_name);
    /* Statements that may raise an exception here */
FINALLY
    close (handle);
ENDTRY
```

  The preceding **FINALLY** code assumes that no exception is raised by **open_file**. This is because the code accesses an invalid identifier in the **FINALLY** part if **open_file** is modified to raise an exception. The preceding example needs to be rewritten as follows:

```
handle = open_file (file_name);
TRY
    {
    /* Statements that may raise an exception here */
    }
FINALLY
    close (handle);
ENDTRY
```

The code that opens the file belongs prior to **TRY**, and the code that closes the file belongs in the **FINALLY** statement. (If **open_file** raises exceptions, it may need a separate **try_block**.)

- Raise exceptions to their proper scope.

  Write functions that propagate exceptions to their callers so that the function does not modify any persistent process state before raising the exception. A call to the matching **close** call is required only if the **open_file** operation is successful in the current scope.

  If **open_file** raises an exception, the identifier will not be written, so **open_file** must not require that **close** be called when **open_file** raises an exception; that is, **open_file** should not be part of the **TRY** clause because that means **close** is called if **open_file** fails, and you cannot close an unopened file.

- Do not place a **RETURN** or nonlocal **GOTO** between **TRY** and **ENDTRY**.

  It is invalid to use **RETURN** or **GOTO**, or to leave by any other means, a **TRY**, **CATCH**, **CATCH_ALL**, or **FINALLY** block. Special code is generated by the **ENDTRY** macro, and it must be executed.

- Use the ANSI C volatile attribute.

  Variables that are read or written by exception-handling code must be declared with the ANSI C volatile attribute. Run your tests with the optimize compiler option to ensure that the compiler thoroughly tests your exception-handling code.

- Reraise exceptions that are not fully handled.

  You need to reraise any exception that you catch, unless your handler performs the complete recovery action for the error. This rule permits an unhandled exception to propagate to some final default handler that prints an error message to terminate the offending thread. (An unhandled exception is an exception for which recovery is incomplete.)

  A corollary of this rule is that **CATCH_ALL** handlers must reraise the exception because they may catch any exception, and usually cannot do recovery actions that are proper for every exception.

  Following this convention is important so that you also do not absorb a cancel or thread-exit request. These are mapped into exceptions so that exception handling has the full power to handle all exceptional conditions from access violations to thread exit. (In some applications, it is important to be able to catch these to work

around an erroneously written library package, for example, or to provide a fully fault-tolerant thread.)

- Declare only static exceptions.

  For compatibility with C++, you need to only declare static exceptions.

9.5 DCE Threads Exceptions and Definitions

Table 9-1 lists the DCE Threads exceptions and briefly explains the meaning of each exception. Exception names beginning with **pthread_** are raised as the result of something happening internal to the DCE Threads facility and are not meant to be raised by your code. Exceptions beginning with **exc_** are generic and belong to the exception facility, the underlying system, or both. The pthread-specific extensions are listed followed by the generic extensions, each in alphabetical order.

Table 9–1. DCE Threads Exceptions

Exception	**Definition**
pthread_badparam_e	An improper parameter was used.
pthread_cancel_e	A thread cancellation is in progress.
pthread_defer_q_full_e	No space is currently available to process an interrupt request.
pthread_existence_e	The object referenced does not exist.
pthread_in_use_e	The object referenced is already in use.
pthread_nostackmem_e	No space is currently available to create a new stack.
pthread_notstack_e	The current stack was not created by DCE Threads.
pthread_signal_q_full_e	Unable to process condition signal from interrupt level.
pthread_stackovf_e	An attempted stack overflow was detected.
pthread_unimp_e	This is an unimplemented feature.

Exception	Definition
pthread_use_error_e	The requested operation is improperly invoked.
exc_decovf_e	An unhandled decimal overflow trap exception occurred.
exc_exquota_e	The operation failed due to an insufficient quota.
exc_fltdiv_e	An unhandled floating-point division by zero trap exception occurred.
exc_fltovf_e	An unhandled floating-point overflow trap exception occurred.
exc_fltund_e	An unhandled floating-point underflow trap exception occurred.
exc_illaddr_e	The data or object could not be referenced.
exc_insfmem_e	There is insufficient virtual memory for the requested operation.
exc_intdiv_e	An unhandled integer divide by zero trap exception occurred.
exc_intovf_e	An unhandled integer overflow trap exception occurred.
exc_nopriv_e	There is insufficient privilege for the requested operation.
exc_privinst_e	An unhandled privileged instruction fault exception occurred.
exc_resaddr_e	An unhandled reserved addressing fault exception occurred.
exc_resoper_e	An unhandled reserved operand fault exception occurred.
exc_SIGBUS_e	An unhandled bus error signal occurred.
exc_SIGEMT_e	An unhandled EMT trap signal occurred.
exc_SIGFPE_e	An unhandled floating-point exception signal occurred.

Exception	Definition
exc_SIGILL_e	An unhandled illegal instruction signal occurred.
exc_SIGIOT_e	An unhandled IOT trap signal occurred.
exc_SIGPIPE_e	An unhandled broken pipe signal occurred.
exc_SIGSEGV_e	An unhandled segmentation violation signal occurred.
exc_SIGSYS_e	An unhandled bad system call signal occurred.
exc_SIGTRAP_e	An unhandled trace or breakpoint trap signal occurred.
exc_SIGXCPU_e	An unhandled CPU time limit exceeded signal occurred.
exc_SIGXFSZ_e	An unhandled file-size limit exceeded signal occurred.
exc_subrng_e	An unhandled subscript out-of-range trap exception occurred.
exc_uninitexc_e	An uninitialized exception was raised.

Chapter 10

DCE Threads Example

The example in this chapter shows the use of DCE Threads in a C program that performs a prime number search. The program finds a specified number of prime numbers, then sorts and displays these numbers. Several threads participate in the search: each thread takes a number (the next one to be checked), sees if it is a prime, records it if it is prime, and then takes another number, and so on.

This program shows the work crew model of programming (see Chapter 6). The workers (threads) increment a number (**current_num**) to get their next work assignment, which in this case is the same task as before, but with a different number to check for a prime. As a whole, the worker threads are responsible for finding a specified number of prime numbers, at which point their work is completed.

10.1 Details of Program Logic and Implementation

The number of workers to be used and the requested number of prime numbers to be found are defined constants. A macro is used to check for bad status (bad status returns a value of −1), and to print a given string and the associated error value upon

bad status. Data to be accessed by all threads (mutexes, condition variables, and so forth) are declared as global items.

Worker threads execute the prime search routine, which begins by synchronizing with the boss (or parent) thread by using a predicate and a condition variable. Always enclose a condition wait in a predicate loop to prevent a thread from continuing if it receives a spurious wakeup. The lock associated with the condition variable must be held by the thread when the condition wait call is made. The lock is implicitly released within the condition wait call and acquired again when the thread resumes. The same mutex must be used for all operations performed on a specific condition variable.

After the parent sets the predicate and broadcasts, the workers begin finding prime numbers until canceled by a fellow worker who has found the last requested prime number. Upon each iteration, the workers increment the current number to be worked on and take the new value as their work item. A mutex is locked and unlocked around getting the next work item. The purpose of the mutex is to ensure the atomicity of this operation and the visibility of the new value across all threads. This type of locking protocol needs to be performed on all global data to ensure its visibility and protect its integrity.

Each worker thread then determines if its current work item (a number) is prime by trying to divide numbers into it. If the number proves to be nondivisible, it is put on the list of primes. Cancels are explicitly turned off while working with the list of primes in order to better control any cancels that do occur. The list and its current count are protected by locks, which also protect the cancellation process of all other worker threads upon finding the last requested prime. While still under the prime list lock, the current worker checks to see if it has found the last requested prime, and if so unsets a predicate and cancels all other worker threads. Cancels are then reenabled. The canceling thread falls out of the work loop as a result of the predicate that it unsets.

The parent thread's flow of execution is as follows: set up the environment, create worker threads, broadcast to them that they can start, join each thread as it finishes, and sort and print the list of primes.

- Setting up of the environment requires initializing mutexes and the one condition variable used in the example.
- Creation of worker threads is straightforward and utilizes the default attributes (**pthread_attr_default**). Note again that locking is performed around the predicate

on which the condition variable wait loops. In this case, the locking is simply done for visibility and is not related to the broadcast function.

- As the parent joins each of the returning worker threads, it receives an exit value from them that indicates whether a thread exited normally or not. In this case the exit values on all but one of the worker threads are **−1**, indicating that they were canceled.
- The list is then sorted to ensure that the prime numbers are in order from lowest to highest.

The following pthread routines are used in this example:

- **pthread_cancel()**
- **pthread_cond_broadcast()**
- **pthread_cond_init()**
- **pthread_cond_wait()**
- **pthread_create()**
- **pthread_detach()**
- **pthread_exit()**
- **pthread_join()**
- **pthread_mutex_init()**
- **pthread_mutex_lock()**
- **pthread_mutex_unlock()**
- **pthread_setcancel()**
- **pthread_testcancel()**

10.2 DCE Threads Example Body

The following is the DCE Threads example.

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
/*
* Constants used by the example.
*/
#define     workers     5           /* Threads to perform prime check*/
#define     request     110         /* Number of primes to find      */
/*
* Macros
*/
#define check(status,string) \
 if (status == -1) perror (string)
/*
* Global data
*/
pthread_mutex_t prime_list;  /* Mutex for use in accessing the prime */
pthread_mutex_t current_mutex;/* Mutex associated with current number */
pthread_mutex_t cond_mutex;  /* Mutex used for ensuring CV integrity */
pthread_cond_t  cond_var;    /* Condition variable for thread start  */
int          current_num= -1;/* Next number to be checked, start odd */
int          thread_hold= 1; /* Number associated w/condition state  */
int          count=0;        /* Prime numbers count;/index to primes */
int          primes[request];/* Store primes; synchronize access     */
pthread_t    threads[workers]; /* Array of worker threads            */
/*
* Worker thread routine.
*
* Worker threads start with this routine, which begins with a condition
* wait designed to synchronize the workers and the parent.  Each worker
* thread then takes a turn taking a number for which it will determine
* whether or not it is prime.
*
*/
void
prime_search (pthread_addr_t arg)
{
div_t   div_results;          /* DIV results: quot and rem        */
int     numerator;            /* Used for determining primeness   */
int     denominator;          /* Used for determining primeness   */
```

```
int     cut_off;             /* Number being checked div 2       */
int     notifiee;            /* Used during a cancellation       */
int     prime;               /* Flag used to indicate primeness  */
int     my_number;           /* Worker thread identifier         */
int     status;              /* Hold status from pthread calls   */
int     not_done=1;          /* Work loop predicate              */
my_number = (int)arg;
/*
* Synchronize threads and the parent using a condition variable,
* for which the predicate (thread_hold) will be set by the parent.
*/
status = pthread_mutex_lock (&cond_mutex);
check(status,"1:Mutex_lock bad status\n");

while (thread_hold) {
status = pthread_cond_wait (&cond_var, &cond_mutex);
check(status,"3:Cond_wait bad status\n");
}

status = pthread_mutex_unlock (&cond_mutex);
check(status,"4:Mutex_unlock bad status\n");
/*
* Perform checks on ever larger integers until the requested
* number of primes is found.
*/
while (not_done) {

/* cancellation point */
pthread_testcancel ();

        /* Get next integer to be checked */
status = pthread_mutex_lock (&current_mutex);
check(status,"6:Mutex_lock bad status\n");

current_num = current_num + 2;          /* Skip even numbers */
numerator = current_num;

status = pthread_mutex_unlock (&current_mutex);
check(status,"9:Mutex_unlock bad status\n");
```

```
/* Only need to divide in half of number to verify not prime */
cut_off = numerator/2 + 1;
prime = 1;

/* Check for prime; exit if something evenly divides */
for (denominator = 2; ((denominator < cut_off) && (prime));
denominator++) {
prime = numerator % denominator;
}
if (prime != 0) {

/* Explicitly turn off all cancels */
pthread_setcancel(CANCEL_OFF);

/*
* Lock a mutex and add this prime number to the list.  Also,
* if this fulfills the request, cancel all other threads.
*/
status = pthread_mutex_lock (&prime_list);
check(status,"10:Mutex_lock bad status\n");

if (count < request)  {
primes[count] = numerator;
count++;
}
else if (count == request) {
not_done = 0;
count++;
for (notifiee = 0; notifiee < workers; notifiee++) {
if (notifiee != my_number) {
status = pthread_cancel ( threads[notifiee] );
check(status,"12:Cancel bad status\n");
}
}
}

status = pthread_mutex_unlock (&prime_list);
check(status,"13:Mutex_unlock bad status\n");

            /* Reenable cancels */
```

```
pthread_setcancel(CANCEL_ON);
}
pthread_testcancel ();
}
pthread_exit (my_number);
}
main()
{
int     worker_num;     /* Counter used when indexing workers   */
int     exit_value;     /* Individual worker's return status    */
int     list;           /* Used to print list of found primes   */
int     status;         /* Hold status from pthread calls       */
int     index1;         /* Used in sorting prime numbers        */
int     index2;         /* Used in sorting prime numbers        */
int     temp;           /* Used in a swap; part of sort         */
int     not_done;       /* Indicates swap made in sort          */

* Create mutexes
*/
status = pthread_mutex_init (&prime_list, pthread_mutexattr_default);
check(status,"15:Mutex_init bad status\n");
status = pthread_mutex_init (&cond_mutex, pthread_mutexattr_default);
check(status,"16:Mutex_init bad status\n");
status = pthread_mutex_init (&current_mutex, pthread_mutexattr_default);
check(status,"17:Mutex_init bad status\n");

/*
* Create condition variable
*/
status = pthread_cond_init (&cond_var, pthread_condattr_default);
check(status,"45:Cond_init bad status\n");

/*
* Create the worker threads.
*/
for (worker_num = 0; worker_num < workers; worker_num++) {
status = pthread_create (
&threads[worker_num],
pthread_attr_default,
prime_search,
```

```
(pthread_addr_t)worker_num);
check(status,"19:Pthread_create bad status\n");
}

    /*
* Set the predicate thread_hold to zero, and broadcast on the
* condition variable that the worker threads may proceed.
*/
status = pthread_mutex_lock (&cond_mutex);
check(status,"20:Mutex_lock bad status\n");

thread_hold = 0;

status = pthread_cond_broadcast (&cond_var);
check(status,"20.5:cond_broadcast bad status\n");

status = pthread_mutex_unlock (&cond_mutex);
check(status,"21:Mutex_unlock bad status\n");
/*
* Join each of the worker threads inorder to obtain their
* summation totals, and to ensure each has completed
* successfully.
*
* Mark thread storage free to be reclaimed upon termination by
* detaching it.
*/
for (worker_num = 0; worker_num < workers; worker_num++) {

status = pthread_join (
threads[worker_num],
&exit_value );
check(status,"23:Pthread_join bad status\n");

if (exit_value == worker_num) printf("thread terminated normally\n");

status = pthread_detach ( &threads[worker_num] );
check(status,"25:Pthread_detach bad status\n");
}

   /*
```

```
* Take the list of prime numbers found by the worker threads and
* sort them from lowest value to highest.  The worker threads work
* concurrently; there is no guarantee that the prime numbers
* will be found in order.  Therefore, a sort is performed.
*/
not_done = 1;
for (index1 = 1; ((index1 < request) && (not_done)); index1++) {
for (index2 = 0; index2 < index1; index2++) {
if (primes[index1] < primes[index2]) {
temp = primes[index2];
primes[index2] = primes[index1];
primes[index1] = temp;
not_done = 0;
}
}
}

/*
* Print out the list of prime numbers that the worker threads
* found.
*/
printf ("The list of %d primes follows:\n", request);
printf("%d",primes[0]);

for (list = 1; list < request; list++) {
printf (", %d", primes[list]);
}

printf ("\n");
}
```

Part 3

DCE Remote Procedure Call

Chapter 11

Developing a Simple RPC Application

This chapter first explains how to write an interface definition in the DCE RPC Interface Definition Language (IDL) and illustrates the basic features of IDL. As an example, we present an interface definition for **greet**, a very simple application that prints greetings from a client and a remote server. The remainder of the chapter describes how to develop, build, and run the **greet** client and server programs.

The *DCE 1.2.2 Application Development—Introduction and Style Guide* describes how to develop a DCE application by using many of the features of DCE. The following chapters use the term *remote procedure call application* (*RPC application*) to mean essentially the same thing, except in this context an RPC application concentrates on the features of the RPC technology, glossing over other DCE issues such as security, threads, and messaging. Since the RPC mechanism is the root technology for all DCE applications, the basic development approach is the same.

11.1 The Remote Procedure Call Model

A remote procedure call executes a procedure located in a separate address space from the calling code. The RPC model is a well-tested, industry-wide framework for distributing applications. The RPC model is derived from the programming model of local procedure calls and takes advantage of the fact that every procedure contains a procedure declaration. The procedure declaration defines the interface between the calling code and the called procedure. The procedure declaration defines the call syntax and parameters of the procedure. All calls to a procedure must conform to the procedure declaration.

Applications that use remote procedure calls look and behave much like local applications. However, an RPC application is divided into two parts: a server, which offers one or more sets of remote procedures, and a client, which makes remote procedure calls to RPC servers. A server and its clients generally reside on separate systems and communicate over a network. RPC applications depend on the RPC runtime to control network communications for them. The DCE RPC runtime supports additional tasks, such as finding servers for clients and managing servers.

A distributes application uses dispersed computing resources such as CPUs, databases, devices, and services. The following are examples:

- A calendar-management application that allows authorized users to access the personal calendars of other users.
- A graphics application that processes data on central CPUs and displays the results on workstations.
- A manufacturing application that shares information about assembly components among design, inventory, scheduling, and accounting programs located on different computers.

DCE RPC meets the basic requirements of a distributed application, including

- Clients finding the appropriate servers
- Data conversion for operating in a heterogeneous environment
- Network communications

Distributed applications include tasks such as managing communications, finding servers, providing security, and so forth. A standalone distributed application needs to

perform all of these tasks itself. Without a convenient mechanism for these distributed computing tasks, writing distributed applications is difficult, expensive, and error-prone.

DCE RPC software provides the code, called stubs, and the RPC runtime that perform distributed computing tasks for your applications. This code and the runtime libraries are linked with client and server application code to form an RPC application.

Table 11-1 shows the basic tasks for the client and server of a distributed application. Calling the procedure and executing the remote procedure, shown in bold text, are performed by your application code (just as in a local application) but here they are in the client and server address spaces. For the other tasks, some are performed automatically by the stubs and RPC runtime, while others are performed by the RPC runtime via API calls in your application.

Table 11–1. Basic Tasks of an RPC Application

	Client Tasks	**Server Tasks**
1.		Select network protocols.
2.		Register RPC interfaces.
3.		Register endpoints in endpoint map.
4.		Advertise RPC interfaces and objects in the namespace.
5.		Listen for calls.
6.	Find compatible servers that offer the procedures.	
7.	**Call the remote procedure**.	
8.	Establish a binding with the server.	
9.	Convert input arguments into network data.	
10.	Transmit arguments to the server's runtime.	
11.		Receive a call.

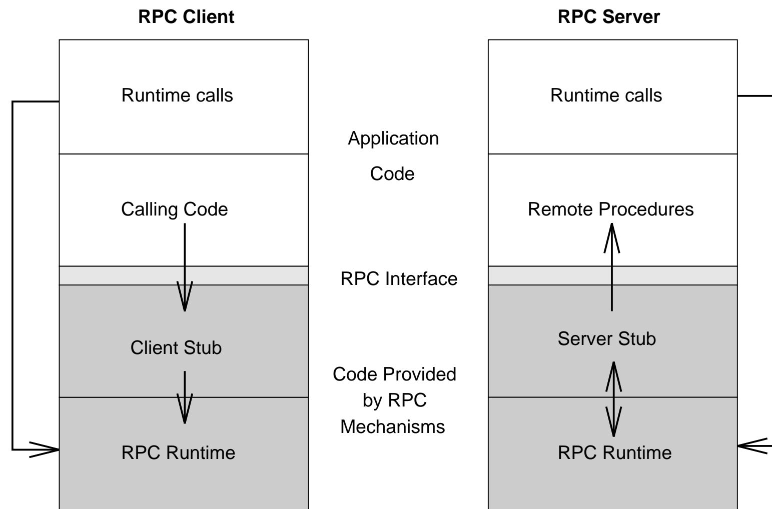
	Client Tasks	Server Tasks
12.		Disassemble network data and convert input arguments into local data.
13.		Locate and invoke the called procedure.
14.		**Execute the remote procedure**.
15.		Convert the output arguments and return value into network data.
16.		Transmit results to the client's runtime.
17.	Receive results.	
18.	Disassemble network data and convert output arguments into local data.	
19.	Return results and control to calling code.	

11.1.1 RPC Application Code

An RPC server or client contains application code, one or more RPC stubs, and the RPC runtime. RPC application code is the code written for a specific RPC application by the application developer. Application code implements and calls remote procedures, and also calls any RPC runtime routines the application needs. An RPC stub is an interface-specific code module that uses an RPC interface to pass and receive arguments. A server and a client contain complementary stubs for each RPC interface they share. The DCE RPC runtime manages communications for RPC applications. In addition, the DCE RPC runtime supports an application programming interface (API) used by RPC application code to enable RPC applications to set up their communications, manipulate information about servers, and perform optional tasks such as remotely managing servers and accessing security information.

Figure 11-1 shows the relationship of application code, stubs, and the RPC runtime in the server and client portions of an RPC application. The arrows show the direction calls are made by pointing to the called code.

Figure 11–1. The Parts of an RPC Application



RPC application code differs for servers and clients. Minimally, server application code contains the remote procedures that implement one RPC interface, and the corresponding client contains calls to those remote procedures.

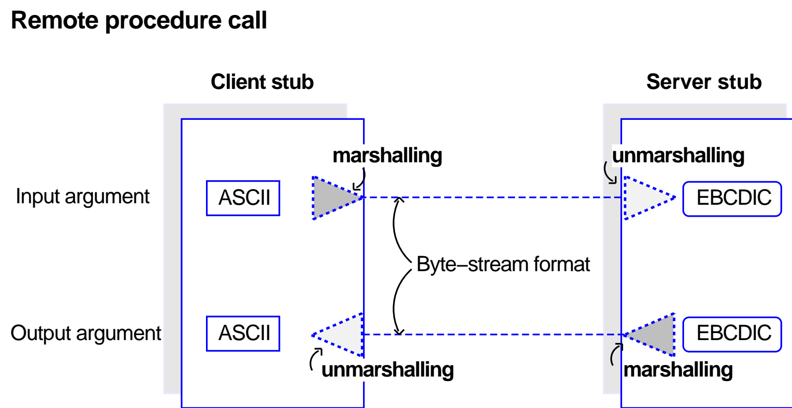
11.1.2 Stubs

The stub performs basic support functions for remote procedure calls. For instance, stubs prepare input and output arguments for transmission between systems with different forms of data representation. The stubs use the RPC runtime to handle the transmission between the client and server. The client stub can also use the runtime to find servers for the client.

When a client application calls a remote procedure, the client stub first prepares the input arguments for transmission. The process for preparing arguments for transmission is known as *marshalling*. Marshalling converts call arguments into a byte-

stream format and packages them for transmission. Upon receiving call arguments, a stub unmarshalls them. Unmarshalling is the process by which a stub disassembles incoming network data and converts it into application data by using a format that the local system understands. Marshalling and unmarshalling both occur twice for each remote procedure call; that is, the client stub marshalls input arguments and unmarshalls output arguments, and the server stub unmarshalls input arguments and marshalls output arguments. Marshalling and unmarshalling permit client and server systems to use different data representations for equivalent data. For example, the client system can use ASCII characters and the server system can use EBCDIC characters, as shown in Figure 11-2.

Figure 11–2. Marshalling and Unmarshalling Between ASCII and EBCDIC Data



The DCE IDL compiler (a tool for DCE application development) generates stubs by compiling an RPC interface definition written by application developers. The compiler generates marshalling and unmarshalling routines for platform-independent IDL data types.

To build the client for an RPC application, a developer links client application code with the client stubs of all the RPC interfaces the application uses. To build the server, the developer links the server application code with the corresponding server stubs.

11.1.3 The RPC Runtime

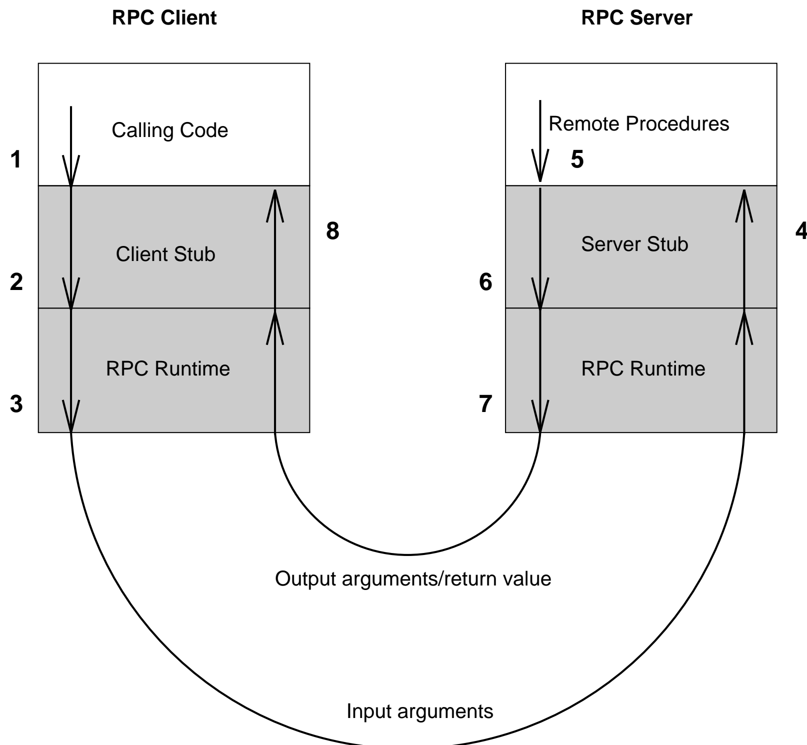
In addition to one or more RPC stubs, every RPC server and RPC client is linked with a copy of the RPC runtime. Runtime operations perform tasks such as controlling communications between clients and servers and finding servers for clients on request. An interface's client and server stubs exchange arguments through their local RPC runtimes. The client runtime transmits remote procedure calls to the server. The server runtime receives the calls and dispatches each call to the appropriate server stub. The server runtime sends the call results to the client runtime. The DCE RPC runtime supports the RPC API used by RPC application code to call runtime routines.

Server application code must also contain server initialization code that calls RPC runtime routines when the server is starting up and shutting down. Client application code can also call RPC runtime routines. Server and client application code can also contain calls to RPC stub-support routines. Stub-support routines allow applications to manage programming tasks such as allocating and freeing memory.

11.1.4 RPC Application Components That Work Together

Figure 11-3 shows the roles of application code, RPC stubs, and RPC runtimes during a remote procedure call.

Figure 11–3. Interrelationships During a Remote Procedure Call



The following steps describe the interrelationships of the components of RPC applications, as shown in Figure 11-3:

1. The client's application code invokes a remote procedure call, passing the input arguments to the stub for the particular RPC interface.
2. The client's stub marshalls the input arguments and dispatches the call to the client's RPC runtime.
3. The client's RPC runtime transmits the input arguments to the server's RPC runtime, which dispatches the call to the server stub for the RPC interface of the called procedure.
4. The server's stub unmarshalls the input arguments and passes them to the called remote procedure.

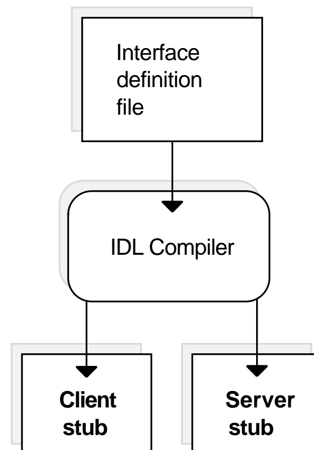
5. The procedure executes and then returns any results (output arguments or a return value or both) to the server's stub.
6. The server's stub marshalls the results and returns them to the server's RPC runtime.
7. The server's RPC runtime transmits the results to the client's RPC runtime, which dispatches them to the correct client stub.
8. The client's stub unmarshalls output arguments and returns them to the calling code.

11.1.5 Overview of DCE RPC Development Tasks

The tasks involved in developing an RPC application resemble those involved in developing a local application. As an RPC developer, you perform the following basic tasks:

1. Design your application, deciding what procedures you need, which will be remote procedures, and how the remote procedures will be grouped into RPC interfaces.
2. Use the Universal Unique Identifier (UUID) generator to generate a UUID for each new interface.
3. Use the IDL to describe the RPC interfaces for the planned data types and remote procedures.
4. Use the DCE IDL compiler to generate the client and server stubs. (The IDL compiler can invoke the C compiler to create the stub object code.) Figure 11-4 illustrates this task.

Figure 11–4. Generating Stubs



Note: Optionally, instead of generating stub object code (which is not portable), the IDL compiler can generate the stubs as ANSI C compliant source code.

5. Write or modify application code by using a compatible programming language, that is, a language that can be linked with C and can invoke C procedures, so the application code works with the stubs.

   Application code includes several kinds of code, as follows:

   a. Remote procedure calls

   b. Remote procedure implementations

   c. Initialization code (calls to RPC stub-support or runtime routines)

   d. Any non-RPC code your application requires

6. Generate object code from application code.

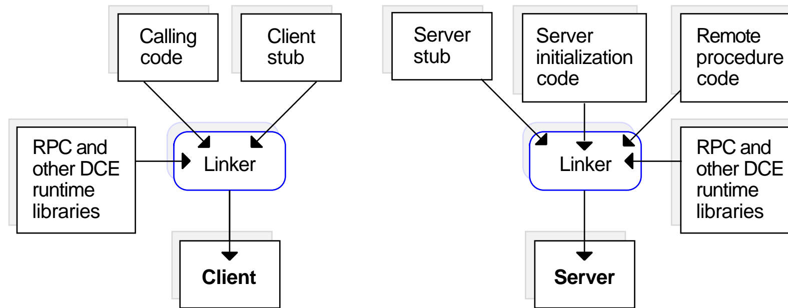
7. Create an executable client and server from the object files. Figure 11-5 illustrates this task.

   For the client, link object code of the client stub(s) and the client application with the RPC runtime and any other needed runtime libraries.

For the server, link object code for the server stub(s), the initialization routines, and the set(s) of remote procedures with the RPC runtime and any other needed runtime libraries.

8. After initial testing, distribute the new application by separately installing the server and client executable images on systems on the network.

Figure 11–5. Building a Simple Client and Server



11.2 Writing an Interface Definition

Traditionally, calling code and called procedures share the same address space. In an RPC application, the calling code and the called remote procedures are not linked; rather, they communicate indirectly through an RPC interface. An RPC interface is a logical grouping of operations, data types, and constants that serves as a contract for a set of remote procedures. DCE RPC interfaces are compiled from formal interface definitions written by application developers using IDL.

The first step in developing a distributed application is to write an interface definition file in IDL. The IDL compiler, **idl**, uses the interface definition to generate a header file, a client stub file, and a server stub file. The IDL compiler produces header files in C and can produce stubs as C source files or as object files.

For some applications, you may also need to write an Attribute Configuration File (ACF) to accompany the interface definition. If an ACF exists, the IDL compiler interprets the ACF when it compiles the interface definition. Information in the ACF is used to modify the code that the compiler generates. (The **greet** example does not require an ACF.)

The remainder of this section briefly explains how to create an interface definition and gives simple examples of each kind of IDL declaration. For a detailed description of IDL, see Chapter 18. For information on the IDL compiler, see the **idl(1rpc)** reference page.

An IDL interface definition consists of a header and a body. The following example shows the interface definition for the **greet** application:

```
/*
 * greet.idl
 *
 * The "greet" interface.
 */

[uuid(3d6ead56-06e3-11ca-8dd1-826901beabcd),
version(1.0)]

interface greetif
{
    const long int REPLY_SIZE = 100;

    void greet(
        [in]            handle_t h,
        [in, string]    char client_greeting[],
        [out, string]   char server_reply[REPLY_SIZE]
    );
}
```

The header of each RPC interface contains a UUID, which is a hexadecimal number that uniquely identifies an entity. A UUID that identifies an RPC interface is known as an *interface UUID*. The interface UUID ensures that the interface can be uniquely identified across all possible network configurations. In addition to an interface UUID, each RPC interface contains major and minor version numbers. Together, the interface UUID and version numbers form an interface identifier that identifies an instance of an RPC interface across systems and through time.

The interface body can contain the following constructs:

- Import declarations (not shown)

- Constant declarations (**REPLY_SIZE**)
- Data type declarations (not shown)
- Operation declarations (**void greet(...);**)

IDL declarations resemble declarations in ANSI C. IDL is purely a declarative language, so, in some ways, an IDL interface definition is like a C header file. However, an IDL interface definition must specify the extra information that is needed by the remote procedure call mechanism. Most of this information is expressed via IDL attributes. IDL attributes can apply to types, to type members, to operations, to operation parameters, or to an interface as a whole. An attribute is represented in **[ ]**(brackets) before the item to which it applies. In the **greet.idl** example, the **[in, string]** attributes associated with the **client_greeting** array means the parameter is for input only and that the array of characters has the properties of strings.

A comment can be inserted at any place in an interface definition where whitespace is permitted. IDL comments, like C comments, begin with **/*** (a slash and an asterisk) and end with ***/** (an asterisk and a slash).

11.2.1 RPC Interfaces That Represent Services

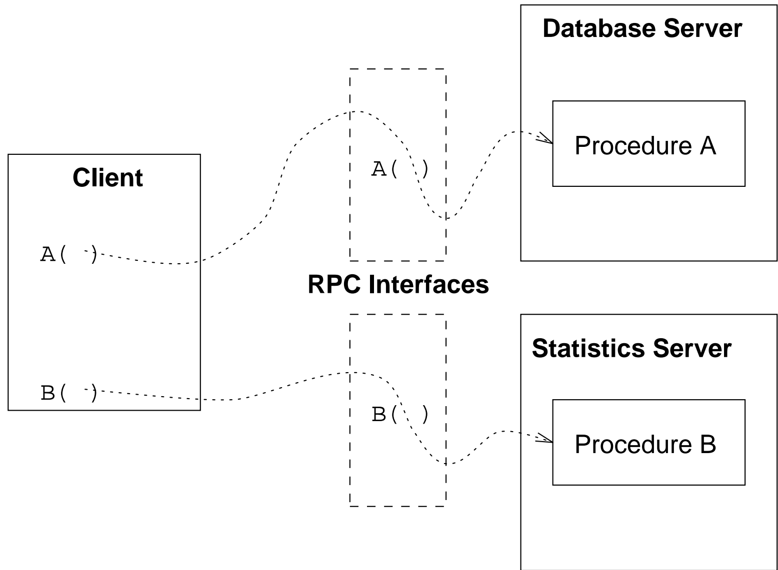
The simplest RPC application uses only one RPC interface. However, an application can use multiple RPC interfaces, and, frequently, an integral set of RPC interfaces work together as an RPC service. An RPC server is a logical grouping of one or more RPC interfaces. For example, you can write a calendar server that contains only a personal calendar interface or a calendar server that contains additional RPC interfaces such as a scheduling interface for meetings.

Different servers can share one or more RPC interfaces. For example, an administrative-support application can include an RPC interface from a calendar service.

An RPC interface exists independently of specific applications. Each RPC interface can be implemented by any set of procedures that conforms to the interface definition. The operations of an interface are exactly the same for all implementations of the same version of the interface. This makes it possible for clients from different implementations to call the same interface, and servers from different implementations to offer the same interface.

Figure 11-6 shows the role of RPC interfaces in remote procedure calls. This client contains calling code that makes two remote procedure calls. The first is a remote procedure call to Procedure A. The second is a remote procedure call to Procedure B.

Figure 11–6. Role of RPC Interfaces



Clients can use any practical combination of RPC interfaces, whether offered by the same or different servers. For this example, using a database access interface, a client on a graphics workstation can call a remote procedure on a database server to fetch data from a central database. Then, using a statistics interface, the client can call a procedure on another server on a parallel processor to analyze the data from the central database and return the results to the client for display.

11.2.2 Generating an Interface UUID

The first step in building an RPC application is to generate a skeletal interface definition file and a UUID for the interface. Every interface in an RPC application must have a UUID. When you define a new interface, you must generate a new UUID for it.

Typically, you run **uuidgen** with the **-i** option, which produces a skeletal interface definition file and includes the generated UUID for the interface. For example, the following command creates a file **chess.idl**:

uuidgen -i > chess.idl

The contents of the file are as follows:

```
[
uuid(443f4b20-a100-11c9-baed-08001e0218cb),
version(1)
]
interface INTERFACENAME {

}
```

The first part of the skeletal definition is the header, which specifies a UUID, a version number, and a name for the interface. The last part of the definition is **{ }** (an empty pair of braces); import, constant, type, and operation declarations go between these braces.

By convention, the names of interface definition files end with the suffix **.idl**. The IDL compiler constructs names for its output files based on the interface definition filename and uses the following default suffixes:

- **.h** for header files
- **_cstub.o** for client stub files
- **_sstub.o** for server stub files

For example, compilation of a **chess.idl** interface definition file would produce a **chess.h** header file, a **chess_cstub.o** client stub file, and a **chess_sstub.o** server stub file. (The IDL compiler creates C language intermediate files and by default invokes the C compiler to produce object files, but it can also retain the C language files.)

For more information on the UUID generator, see the **uuidgen(1rpc)** reference page.

11.2.3 Naming the Interface

After you have used **uuidgen** to generate a skeletal interface definition, replace the dummy string **INTERFACENAME** with the name of your interface.

By convention, the name of an interface definition file is the same as the name of the interface it defines, with the suffix **.idl** appended. For example, the definition for a **bank** interface would reside in a **bank.idl** interface definition file, and, if the application required an ACF, its name would be **bank.acf**.

The IDL compiler incorporates the interface name in identifiers it constructs for various data structures and data types in the **.h** file, so the length of an interface name can be at most 17 characters. (Most IDL identifiers have a maximum length of 31 characters.)

11.2.4 Specifying Interface Attributes

Interface attributes are defined within **[ ]**(brackets) in the header of the interface definition. The definition for any remote interface needs to specify the **uuid** and **version** interface attributes, so these are included in the skeletal definition that **uuidgen** produces.

If an interface is exported by servers on well-known endpoints, these endpoints must be specified via the **endpoint** attribute. Interfaces that use dynamic endpoints do not have this attribute. (A well-known endpoint is a stable address on the host, while a dynamic endpoint is an address that the RPC runtime requests when the server is started.)

The interface definition language can be used to specify procedure prototypes for any application, even if the procedures are never used remotely. If all of the procedures of an interface are called only locally and never remotely, the interface can be given the **local** attribute. Since local calls do not have any network overhead, the **local** attribute causes the compiler to generate only a header file, not stubs, for the interface.

11.2.5 Import Declarations

The IDL **import** declaration specifies another interface definition whose types and constants are used by the importing interface. (Similar to the **include** declaration in C.)

The **import** declaration allows you to collect declarations for types and constants that are used by several interfaces into one common file. For example, if you are defining two database interfaces named **dblookup** and **dbupdate**, and these interfaces have many data types and constants in common, you can declare those data types and constants in a **dbcommon.idl** file and import this file in the **dblookup.idl** and **dbupdate.idl** interface definitions. For example:

```
import "dbcommon.idl";
```

By default, the IDL compiler resolves relative pathnames of imported files by looking first in the current working directory and then in the system IDL directory. The **-I** option of the IDL compiler allows you to specify additional directories to search. You can thereby avoid putting absolute pathnames in your interface definitions. For example, if an imported file has the absolute pathname **/dbproject/src/dbconstants.idl**, then the IDL compiler option **-I/dbproject/src** allows you to import the file by its leaf name, **dbconstants.idl**.

11.2.6 Constant Declarations

The IDL **const** declaration allows you to declare integer, Boolean, character, string, and null pointer constants, some of which are shown in the following examples:

```
const short TEN = 10;
const boolean VRAI = TRUE;
const char* JSB = "Johann Sebastian Bach";
```

11.2.7 Type Declarations

To support application development in a variety of languages and to support the special needs of distributed applications, IDL provides an extensive set of data types, including the following:

- Simple types, such as integers, floating-pointing numbers, characters, Booleans, and the primitive binding-handle type **handle_t** (usually equivalent to **rpc_binding_handle_t**)
- Predefined types, including ISO international character types and the error status type **error_status_t**
- Constructed types, such as strings, structures, unions, arrays, pointers, and pipes

The IDL **typedef** declaration lets you give a name to any types you construct.

The general form of a type declaration is

typedef [*type_attribute***, . . .]** *type_specifier type_declarator***, . . . ;**

where the bracketed list of type attributes is optional. The *type_specifier* specifies a simple type, a constructed type, a predefined type, or a type previously named in the interface. Each *type_declarator* is a name for the type being defined. As in C, arrays and pointers are declared by the *type_declarator* constructs **[ ]**(brackets) and ***** (an asterisk).

The following type declaration uses the IDL's simple data type, **long** (a 32-bit data type), to define the **integer32** integer type:

```
typedef long integer32;
```

The *type_specifier* constructs for structures and unions permit the application of attributes to members. In the following example, one member of a structure is a conformant array (an array without a fixed upper bound), and the **size_is** attribute names another member of the structure that at runtime provides information about the size of the array:

```
typedef struct {
    long dsize;
    [size_is(dsize)] float darray[ ];
    } dataset;
```

11.2.8 Operation Declarations

Operation declarations specify the signature of each operation in the interface, including the operation name, the type of data returned, and the types of all parameters passed (if any) in a call.

The general form of an operation declaration is

[*operation_attribute***, ...]** *type_specifier operation_identifier* **([***parameter_declaration***, ...]);**

where the bracketed list of operation attributes is optional. Among the possible attributes of an operation are **idempotent**, **broadcast**, and **maybe**, which specify semantics to be applied by the RPC runtime mechanism when the operation is called. If an operation when called once can safely be executed more than once, the IDL declaration of the operation may specify the **idempotent** attribute; **idempotent** semantics allow remote procedure calls to execute more efficiently by letting the underlying RPC mechanism retry the procedure if it deems it necessary.

The *type_specifier* specifies the type of data returned by the operation.

The *operation_identifier* names the operation. Although operation names are arbitrary, a common convention is to use the name of an interface as a prefix for the names of its operations. For example, a **bank** interface may have operations named **bank_open**, **bank_close**, **bank_deposit**, **bank_withdraw**, and **bank_balance**.

Each *parameter_declaration* in an operation declaration declares a parameter of the operation. A *parameter_declaration* takes the following form:

[*parameter_attribute***, ...]** *type_specifier parameter_declarator*

Every parameter attribute must have at least one of the parameter attributes **in** or **out** to specify whether the parameter is passed as an input, as an output, or in both directions. The *type_specifier* and *parameter_declarator* specify the type and name of the parameter.

Output parameters must be passed by reference and therefore must be declared as pointers via the pointer operator ***** (an asterisk) or an array.

If you want an interface to always use explicit binding handles, the first parameter of each operation declaration must be a binding handle, as in the following example:

```
void greet(
    [in]            handle_t h,
    [in, string]    char client_greeting[],
    [out, string]   char server_reply[REPLY_SIZE]
);
```

However, if you want applications to use the ACF feature of an implicit binding handle (or even an automatic binding handle) for some or all procedures, operation declarations must not have binding handle parameters in the interface definition:

```
void greet_no_handle(
    [in, string]    char client_greeting[],
    [out, string]   char server_reply[REPLY_SIZE]
);
```

This form of operation declaration is the most flexible because applications can always specify explicit, implicit, or automatic binding handles through an ACF.

11.3 Running the IDL Compiler

After you have written an interface definition, run the IDL compiler to generate header and stub files. The compiler offers many options that, for example, allow you to choose what C compiler or C preprocessor commands are run, what directories are searched

for imported files, which of the possible output files are generated, and how the output files are named.

The **greet.idl** interface definition can be compiled by the following command:

```
idl greet.idl
```

This compilation produces a header file (**greet.h**), a client stub file (**greet_cstub.o**), and a server stub file (**greet_sstub.o**. For complete information on running the IDL compiler, see the **idl(1rpc)** reference page.

11.4 Writing the Client Code

This section describes the client program for the **greet** application, whose interface definition was shown earlier in this chapter.

The client performs the following major steps:

1. It checks the command-line arguments for an entry name to use for its search in the namespace.
2. It calls **rpc_ns_binding_import_begin()** to start the search in the namespace.
3. It calls **rpc_ns_binding_import_next()** to obtain a binding to a server.
4. It calls the **greet** remote procedure with a string greeting.
5. It prints the reply from the server.

The **greet_client.c** module is as follows:

```
/*
 * greet_client.c
 *
 * Client of "greet" interface.
 */
```

```
#include <stdio.h>
#include <dce/rpc.h>

#include "greet.h"
#include "util.h"

int
main(
    int argc,
    char *argv[]
)
{
    rpc_ns_handle_t import_context;
    handle_t binding_h;
    error_status_t status;
    idl_char reply[REPLY_SIZE];

    if (argc < 2) {
        fprintf(stderr, "usage: greet_client <CDS pathname>\n");
        exit(1);
    }
    /*
     * Start importing servers using the name specified
     * on the command line.
     */
    rpc_ns_binding_import_begin(
        rpc_c_ns_syntax_default, (unsigned_char_p_t) argv[1],
            greetif_v1_0_c_ifspec, NULL, &import_context, &status);
    ERROR_CHECK(status, "Can’t begin import");
    /*
     * Import the first server (we could iterate here,
     * but we’ll just take the first one).
     */
    rpc_ns_binding_import_next(import_context, &binding_h, &status);
    ERROR_CHECK(status, "Can’t import");
    /*
     * Make the remote call.
     */
    greet(binding_h, (idl_char *) "hello, server", reply);
```

```
    printf("The Greet Server said: %s\n", reply);
}
```

The module first includes **greet.h**, the header file for the **greet** interface generated by the IDL compiler.

In this example, after each call to an RPC runtime routine, the client program calls the application-specific **ERROR_CHECK** macro. If the status from the RPC runtime routine is not **error_status_ok**, **dce_error_inq_text()** is called and the error message is printed.

As specified in the **greet.idl** interface definition, the **greet** application uses explicit handles. The client therefore passes a binding handle of type **handle_t** as the first parameter of the **greet** procedure. At runtime, when the client makes its first remote procedure call, the handle is only partially bound because the client does not know the particular endpoint on which the server is listening; for delivery of its requests to the server endpoint, the client depends on the endpoint mapping service of the **dced** process on the server host.

11.5 Writing the Server Code

The following subsections describe the server program for the **greet** application. The **greet_server** program takes one argument and is invoked as follows:

greet_server *CDS_pathname*

The **greet_server** program uses the input argument to establish an entry for itself in the DCE CDS namespace.

The **greet** server program has two user-written modules:

- The **greet_server.c** module contains the server **main** function and performs the initialization and registration required to export the **greet** interface.
- The **greet_manager.c** module contains the code that actually implements the **greet** operation.

11.5.1 The greet_server.c Source Code

Most applications should use the DCE convenience routines for server initialization routines (routines that begin with **dce_server_**) to prepare servers to listen for remote procedure calls. These routines are simple to use, prepare a server so that **dced** can manage it, and they allow enough flexibility to do most typical initializations. However, for detailed control, applications can also use the lower-level RPC API to do server initialization. In this chapter, we describe how to use the RPC API for server initialization.

In this section, the **greet_server.c** module is described and shown in successive pieces.

11.5.1.1 Including **idl**-Generated Headers

Like **greet_client.c**, the **greet_server.c** module includes **greet.h** so that constants, data types, and procedure prototypes are available in the application. For example:

```
/*
 * greet_server.c
 *
 * Main program (initialization) for "greet" server.
 */

#include <stdio.h>
#include <dce/dce_error.h>
#include <dce/rpc.h>

#include "greet.h"
#include "util.h"

int
main(
    int argc,
    char *argv[]
)
{
```

```
    unsigned32 status;
    rpc_binding_vector_t *binding_vector;

    if (argc < 2) {
        fprintf(stderr, "usage: greet_server <CDS pathname>\n");
        exit(1);
    }
```

11.5.1.2 Registering the Interface

The server calls **rpc_server_register_if()**, supplying its interface specifier (defined in **greet.h**), to register each interface with the RPC runtime:

```
/*
 * Register interface with RPC runtime.
 */
rpc_server_register_if(greetif_v1_0_s_ifspec, NULL, NULL,
    &status);
ERROR_CHECK(status, "Can't register interface");
```

11.5.1.3 Selecting Protocol Sequences

The server calls **rpc_server_use_all_protseqs()** to obtain endpoints on which to listen for remote procedure calls:

```
/*
 * Use all protocol sequences that are available.
 */
rpc_server_use_all_protseqs(rpc_c_protseq_max_reqs_default,
    &status);
ERROR_CHECK(status, "Can't use protocol sequences");
```

11.5.1.4 Obtaining the Server's Binding Handles

To obtain a vector of binding handles that it can use when registering endpoints, the server calls **rpc_server_inq_bindings**():

```
/*
 * Get the binding handles generated by the runtime.
 */
rpc_server_inq_bindings(&binding_vector, &status);
ERROR_CHECK(status, "Can't get bindings for server");
```

11.5.1.5 Registering Endpoints

A call to **rpc_ep_register()** registers the server endpoints in the endpoint mapper service of the local **dced**:

```
/*
 * Register assigned endpoints with endpoint mapper.
 */
rpc_ep_register(
    greetif_v1_0_s_ifspec, binding_vector, NULL,
    (unsigned_char_p_t) "greet server version 1.0", &status);
ERROR_CHECK(status, "Can't register with endpoint map");
```

11.5.1.6 Exporting to CDS

To advertise itself to clients, the server calls **rpc_ns_binding_export()**. The server entry for the namespace is obtained from the argument input when the server is invoked (**argv[1]**).

```
/*
 * Export ourselves into the CDS namespace.
```

```
 */
rpc_ns_binding_export(
    rpc_c_ns_syntax_default, (unsigned_char_p_t) argv[1],
    greetif_v1_0_s_ifspec, binding_vector, NULL, &status);
ERROR_CHECK(status, "Can’t export into CDS namespace");
```

11.5.1.7 Listening for Calls

To begin listening for remote procedure call requests, the server calls **rpc_server_listen()**.

```
/*
 * Start listening for calls.
 */
printf("Listening...\n");

rpc_server_listen(rpc_c_listen_max_calls_default, &status);
ERROR_CHECK(status, "Can’t start listening for calls");
```

11.5.2 The greet_manager.c Source Code

The **greet_manager.c** module includes **greet.h** and it also defines the routine **greet**, as follows:

```
/*
 * greet_manager.c
 *
 * Implementation of "greet" interface.
 */

#include <stdio.h>
#include "greet.h"
```

```
void
greet(
    handle_t h,
    idl_char *client_greeting,
    idl_char *server_reply
)
{
    printf("The client says: %s\n", client_greeting);

    strcpy(server_reply, "Hi, client!");
}
```

11.6 Building the greet Programs

The client side of the **greet** application is the **greet_client** program, which is built from the following:

- The user-written **greet_client.c** client module
- The IDL-compiler-generated **greet_cstub.o** client stub module
- The user-written **util.c** module containing the error-checking routine
- DCE libraries

The server side of the **greet** application is the **greet_server** program, which is built from the following:

- The user-written **greet_server.c** server module
- The user-written **greet_manager.c** manager module
- The user-written **util.c** module containing the error-checking routine
- The IDL-compiler-generated **greet_sstub.o** server stub module
- DCE libraries

These programs can be built by **make** with a makefile such as the following:

```
DCEROOT  = /opt/dcelocal
CC  = /bin/cc
IDL  = idl
LIBDIRS  = -L${DCEROOT}/usr/lib
LIBS  = -ldce
LIBALL  = ${LIBDIRS} ${LIBS}
INCDIRS  = -I. -I${DCEROOT}/share/include
CFLAGS  = -g ${INCDIRS}
IDLFLAGS = -v ${INCDIRS} -cc_cmd "${CC} ${CFLAGS} -c"

all: greet_client greet_server

greet.h greet_cstub.o greet_sstub.o: greet.idl
 ${IDL} ${IDLFLAGS} greet.idl

greet_client: greet.h greet_client.o util.o greet_cstub.o
 ${CC} -o greet_client greet_client.o greet_cstub.o util.o \
   ${LIBALL}

greet_server: greet.h greet_server.o greet_manager.o util.o \
  greet_sstub.o
 ${CC} -o greet_server greet_server.o greet_manager.o \
       greet_sstub.o util.o ${LIBALL}

greet_client.c greet_server.c util.c: util.h
greet_manager.c greet_client.c greet_server.c: greet.h
```

11.7 Running the greet Programs

Running the **greet** application involves starting the server program and then running the client program. Before starting the server program, you need write access to the CDS namespace and you need to ensure that the **dced** process is running on the server host. For more information, see the **dced(8dce)** reference page.

You start the server program by using a CDS entry such as the following:

greet_server /.:/greet_entry
```
Listening...
```

You start the client on another host (or even the same host) by using the same CDS entry as follows:

greet_client /.:/greet_entry

The following message is printed on the server's host:

```
The client says: hello, server
```

The following reply is printed on the client's host:

```
The Greet Server said: Hi, client!
```

The server program can be terminated at any time by a signal, which on many systems can be generated by <**Ctrl-C**>.

When applications such as **greet** execute, many errors can occur that have nothing to do with your own code. In general, errors that occur when a remote procedure call executes are reported as exceptions. For example, exceptions that the client side of **greet_client** could raise if the server suddenly and unexpectedly halts include (but are not limited to) **rpc_x_comm_failure** and **rpc_x_call_timeout**. Other ways to respond to these errors are available through the **comm_status** and **fault_status** attributes in an interface definition or attribute configuration file. Explanations of these attributes appear in Chapter 19. Also, see Chapter 17, which explains the guidelines for error handling.

In addition, Part 2 of this guide contains information about the macros (such as those specified by **TRY**, **CATCH**, and **ENDTRY** statements) for exception handling. If an exception occurs that the client application does not handle, it causes the client to terminate with an error message. The client's termination could include a core dump or other system-dependent error-reporting method. Detailed explanations of RPC status codes and RPC exceptions are in the *DCE 1.2.2 Problem Determination Guide*.

Chapter 12

RPC Fundamentals

DCE RPC provides a call environment that behaves essentially like a local call environment. However, some special requirements are imposed on remote procedure calls by the remoteness of calling code to the called procedure. Therefore, a remote procedure call may not always behave exactly like a local procedure call.

This chapter discusses the following topics:

- Universal unique identifiers
- Communications protocols
- Binding information
- Endpoints
- Execution semantics
- Communication failures
- Scaling applications
- RPC Objects

Distributed applications have the following implications:

- Client/server relationship—binding

  Like a local procedure call, a remote procedure call depends on a static relationship between the calling code and the called procedure. In a local application, this relationship is established by linking the calling and called code. Linking gives the calling code access to the address of each procedure to be called. Enabling a remote procedure call to go to the right procedure requires a similar relationship (called a *binding*) between a client and a server. A binding is a temporary relationship that depends on a communications link between the client and server RPC runtimes. A client establishes a binding over a specific protocol sequence to a specific host system and endpoint.

- Independent address spaces

  The calling code and called remote procedure reside in different address spaces, generally on separate systems. The calling and called code cannot share global variables or other global program state such as open files. All data shared between the caller and the called remote procedure must be specified as procedure parameters in the IDL specification. Unlike a local procedure call that commonly uses the call-by-reference passing mechanism for input/output parameters, remote procedure calls with input/output parameters have copy-in/copy-out semantics due to the differing address spaces of the calling and called code. These two passing mechanisms are only slightly different, and most procedure calls are not sensitive to the differences between call-by-reference and copy-in/copy-out semantics.

- Independent failure

  Distributing a calling program and the called procedures to physically separate machines increases the complexity of procedure calls. Remoteness introduces issues such as a remote system crash, communications failures, naming and binding issues, security problems, and protocol incompatibilities. Such issues can require error handling that is unnecessary for local procedure calls. Also, as with local procedure calls, remote procedure calls are subject to execution errors that arise from the procedure call itself.

12.1 Universal Unique Identifiers

Each UUID contains information, including a timestamp and a host identifier. Applications use UUIDs to identify many kinds of entities. DCE RPC identifies several uses of UUIDs, according to the kind of entities each identifies:

- Interface UUID

  A UUID that identifies a specific RPC interface. An interface UUID is declared in an RPC interface definition (an IDL file) and is a required element of the interface. For example:

  ```
  uuid(2fac8900-31f8-11ca-b331-08002b13d56d),
  ```

- Object UUID

  A UUID that identifies an entity for an application; for example, a resource, a service, or a particular instance of a server. An application defines an RPC object by associating the object with its own UUID known as an *object UUID* . The object UUID exists independently of the object, unlike an interface UUID. A server usually generates UUIDs for its objects as part of initialization. A given object UUID is meaningful only while a server is offering the corresponding RPC object to clients.

  To distinguish a specific use of an object UUID, a UUID is sometimes labeled for the entity it identifies. For example, an object UUID that is used to identify a particular instance of a server is known as an *instance UUID*.

- Type UUID

  A UUID that identifies a set of RPC objects and an associated manager (the set of remote procedures that implements an RPC interface for objects of that type). This is often called a *manager type UUID*.

Servers can create object and type UUIDs by calling the **uuid_create()** routine.

12.2 Communications Protocols

A communications link depends on a set of communications protocols. A communications protocol is a clearly defined set of operational rules and procedures for communications.

Communications protocols include a transport protocol (from the Transport Layer of the OSI network architecture) such as the Transmission Control Protocol (TCP) or the User Datagram Protocol (UDP); and the corresponding network protocol (from the OSI Network Layer) such as the Internet Protocol (IP).

For an RPC client and server to communicate, their RPC runtimes must use at least one identical communications protocol, including a common RPC protocol, transport protocol, and network protocol. An RPC protocol is a communications protocol that supports the semantics of the DCE RPC API and runs over specific combinations of transport and network protocols. DCE RPC provides two RPC protocols: the connectionless RPC protocol and the connection-oriented RPC protocol.

- Connectionless (Datagram) RPC protocol

  This protocol runs over a connectionless transport protocol such as UDP. The connectionless protocol supports broadcast calls.

- Connection-oriented RPC protocol

  This protocol runs over a connection-oriented transport protocol such as TCP.

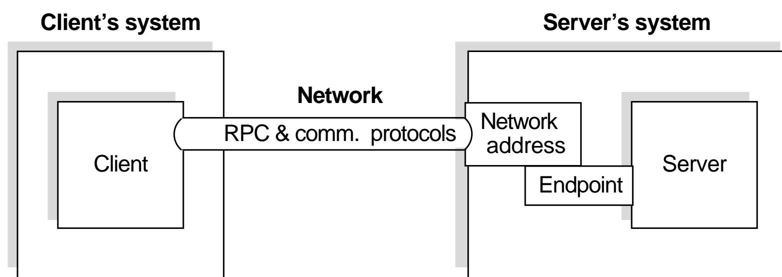
Each binding uses a single RPC protocol and a single pair of transport and network protocols. Only certain combinations of communications protocols are functionally valid (are actually useful for interoperation); for instance, the RPC connectionless protocol cannot run over connection-oriented transport protocols such as TCP. DCE RPC supports the following combinations of communications protocols (as provided by OSF):

- RPC connection-oriented protocol over the Internet Protocol Suite, Transmission Control Protocol (TCP/IP)
- RPC connectionless protocol over the Internet Protocol Suite, User Datagram Protocol (UDP/IP)

12.3 Binding Information

Binding information includes a set of information that identifies a server to a client or a client to a server. Each instance of binding information contains all or part of a single address. The RPC runtime maintains binding information for RPC servers and clients. To make a specific instance of locally maintained binding information available to a given server or client, the runtime creates a local reference known as a *binding handle*. Servers and clients use binding handles to refer to binding information in runtime calls or remote procedure calls. A server obtains a complete list of its binding handles from its RPC runtime. A client obtains one binding handle at a time from its RPC runtime. Figure 12-1 illustrates a binding.

Figure 12–1. A Binding



Binding information includes the following components:

- Protocol sequence

  A valid combination of communications protocols presented by the runtime as a character string. Each protocol sequence includes a network protocol, a transport protocol, and an RPC protocol that works with them.

  An RPC server tells the runtime which protocol sequences to use when listening for calls to the server, and its binding information contains those protocol sequences.

- Network addressing information

  Includes the network address and the endpoint of a server.

  — The network address identifies a specific host system on a network. The format of the address depends on the network protocol portion of the protocol sequence.

— The endpoint acts as the address of a specific server instance within the host system. The format of the endpoint depends on the transport protocol portion of the protocol sequence. For each protocol sequence a server instance uses, it requires a unique endpoint. A given endpoint can be used by only one server per system, assigned by the local system on a first-come, first-served basis.

- Transfer Syntax

  The server's RPC runtime must use a transfer syntax that matches one used by the client's RPC runtime. A transfer syntax is a set of encoding rules used for the network transmission of data and the conversion to and from different local data representations. A shared transfer syntax enables communications between systems that represent local data differently. DCE RPC currently uses a single transfer syntax, Network Data Representation (NDR). NDR encodes data into a byte stream for transmission over a network. A transfer syntax such as NDR enables machines with different formats to exchange data successfully. (The DCE RPC communications protocols support the negotiation of transfer syntax. However, at present, the outcome of a transfer-syntax negotiation is always NDR.)

- RPC protocol version numbers

  The client and server runtimes must use compatible versions of the RPC protocol specified by the client in the protocol sequence. The major version number of the RPC protocol used by the server must equal the specified major version number. The minor version number of the RPC protocol used by the server must be greater than or equal to the specified minor version number.

12.3.1 Server Binding Information

Binding information for a server is known as *server binding information*. A binding handle that refers to server binding information is known as a *server binding handle*. The use of server binding handles differs on servers and clients.

12.3.1.1 Server Binding On a Server

Servers use a list of server binding handles. Each represents one way to establish a binding with the server. Before exporting binding information to a namespace, a server tells the RPC runtime which RPC protocol sequences to use for the RPC interfaces the

server supports. For each protocol sequence, the server runtime creates one or more server binding handles. Each server binding handle refers to binding information for a single potential binding, including a protocol sequence, a network (host) address, an endpoint (server address), a transfer syntax, and an RPC protocol version number.

12.3.1.2 Server Binding On a Client

A client uses a single server binding handle that refers to the server binding information the client needs for making one or more remote procedure calls to a given server. Server binding information on a client contains binding information for one potential binding.

On a client, server binding information always includes a protocol sequence and the network address of the server's host system. However, sometimes a client obtains binding information that lacks an endpoint, resulting in a partially bound binding handle. A partially bound binding handle corresponds to a system, but not to a particular server instance. When a client makes a remote procedure call using a partially bound binding handle, the client runtime gets an endpoint either from the interface specification (if one a well-known endpoint is specified) or from the endpoint map on the server's system. Bindings almost never use well-known endpoints. Adding the endpoint to the server binding information results in a fully bound binding handle, which contains an endpoint and corresponds to a specific server instance. Note clients can get a partially bound handle even if a server is not running.

12.3.2 Defining a Compatible Server

Compatible binding information identifies a server whose communications capabilities (RPC protocol and protocol version, network and transport protocols, and transfer syntax) are compatible with those of the client. Compatible binding information is sufficient for establishing a binding. However, binding information is insufficient for ensuring that the binding is to a compatible server.

The additional information required that a client imposes on the RPC runtime includes an RPC interface identifier and an object UUID, as follows:

- Interface identifier

The interface UUID and version numbers of an RPC interface:

— Interface UUID: The interface UUID, unlike the interface name, clearly identifies the RPC interface across time and space.

— Interface version number: The combined major and minor version numbers identify one generation of an interface.

Version numbers allow multiple versions of an RPC interface to coexist. Strict rules govern valid changes to an interface and determine whether different versions of an interface are compatible. For a description of these rules, see Chapter 18 on IDL syntax and usage.

The runtime uses the version number of an RPC interface to decide whether the version offered by a given server is compatible with the version requested by a client. The offered and requested interface are compatible under the following conditions:

The interface requested by the client and the interface offered by the server have the same major version number.

The interface requested by the client has a minor version number less than or equal to that of the interface offered by the server.

- Object UUID

A UUID that identifies a particular object.

An object is a distinct computing resource, such as a particular database, a specific RPC service that a remote procedure can access, and so on; for example, personal calendars may be RPC objects to a calendar service. Accessing an object requires including its object UUID with the binding information used for establishing a binding. A client can request a specific RPC object when requesting new binding information, or the client can ask the runtime to associate an object UUID with binding information the client already has available.

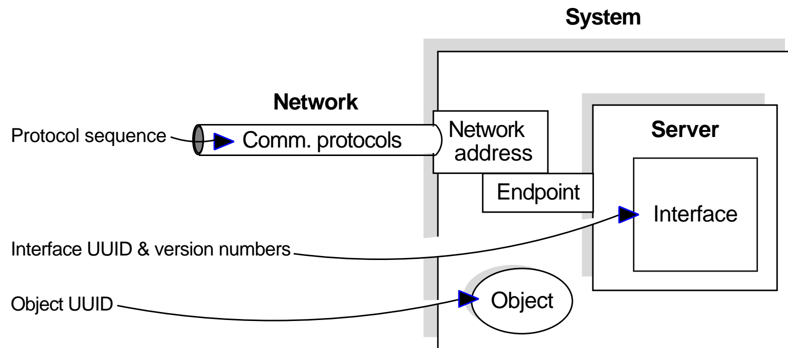
Sometimes the object UUID is the nil UUID; when calling an RPC runtime routine, you can represent the nil UUID by specifying NULL. In this case, the object UUID does not represent any object. Often, however, the object UUID represents a specific RPC object and is a non-nil value. To create a non-nil object UUID, a server calls the **uuid_create()** routine, which returns a UUID that the server then associates with a particular object.

If a client requests a non-nil object UUID, the client runtime uses that UUID as one of the criteria for a compatible server. When searching the namespace for

server binding information, the client runtime looks for the requested interface identifier and object UUID. The endpoint map service uses this same information to help find a compatible server.

Figure 12-2 illustrates the aspects of a server and its system that are identified by the client's server binding information, requested interface identifier, and requested object UUID.

Figure 12–2. Information Used to Identify a Compatible Server



12.3.3 How Clients Obtain Server Binding Information

When a client initiates a series of related remote procedure calls, the RPC runtime tries to establish a binding, which requires the address of a compatible server. An RPC client can use compatible binding information obtained from either a namespace or from a string representation of the binding information. Using the namespace is the most common approach.

Establishing a binding also involves requesting an endpoint from the endpoint mapper of the server's system.

12.3.3.1 Binding Information in a Namespace

Usually, a server exports binding information for one or more of its interface identifiers and its object UUIDs, if any, to an entry in a namespace. The namespace is provided by a directory service such as the DCE Cell Directory Service (CDS). The namespace entry to which a server exports binding information is known as a *server entry*.

To learn about a server that offers a given RPC interface and object, if any, a client can import binding information from a server entry belonging to that server. A client can delegate the finding of servers from the namespace to a stub. In this case, if a binding is accidentally broken, the RPC runtime automatically tries to establish a new binding with a compatible server.

Advantages of using a directory service to obtain binding information include the following:

- It is convenient for large RPC environments. Initial overhead of understanding and configuring a directory service is balanced by easier management over time.
- Management of data in a directory service is more automated.
- It is effective in dynamic end-user environments.
- Binding information is stored in a named server entry. Data can be dynamic. Servers can automatically place their binding information in the namespace. Changes in binding information are made once by a server or administrator and then propagated automatically by the directory service to the replicas of the data.
- There is centralized administration of data in a namespace. Sophisticated access control is possible.
- It supports searching for and choosing services based on an interface identifier and object UUID. Clients access data by specifying an entry name. Groups and profiles in directory service entries provide search paths for importing binding information.

12.3.3.2 Binding Information in Strings

Occasionally, a client can receive binding information in the form of a string (also known as a *string binding*). The client can receive a string binding (or the information to compose a string binding) from many sources; for example, an application-specific

environment variable, a file, or the application user. The client must call the RPC runtime to convert a string binding to a binding handle. The runtime returns this binding handle to the client to use for remote procedure calls.

String representations of binding information have several possible components. The binding information includes an RPC protocol sequence, a network address, and an endpoint. The protocol sequence is mandatory; the endpoint is optional; and for a server on the client's system, the network address is optional. Also, a string binding optionally associates an object UUID with the binding information.

The string bindings have the following format:

obj-uuid@*rpc-protocol-seq***:***network-addr***[***endpoint***,***option-name*=*opt-value***...]**

or

obj-uuid@*rpc-protocol-seq***:***network-addr***[endpoint**=*endpoint***,***option-name*=*opt-value***...]**

The following example string binding contains all possible components:

```
b07122e2-83df-11c9-be29-08002b1110fa@ncacn_ip_tcp:130.105.1.1.123[2001]
```

The following example string binding contains only the protocol sequence and network address:

```
ncacn_ip_tcp:130.105.1.1.123
```

For more information about the string binding format, see the RPC introduction reference page, **rpc_intro(3rpc)**.

String bindings are useful in small environments; for example, when developing and testing an application. However, string bindings are inappropriate as the principal way of providing binding information to clients. Applications should use the directory service to advertise binding information.

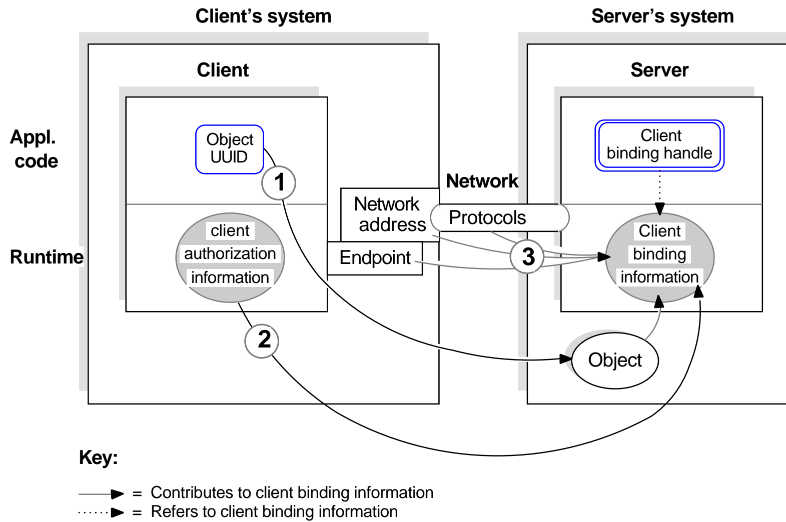
12.3.4 Client Binding Information for Servers

When making a remote procedure call, the client runtime provides information about the client to the server runtime. This information, known as *client binding information*, includes the following information:

- The address where the call originated (network address and endpoint)
- The RPC protocol used by the client for the call
- The object UUID that a client requests
- The client authentication information (if present)

The server runtime maintains the client binding information and makes it available to the server application by a client binding handle. Figure 12-3 illustrates the relationships between what a client supplies when establishing a binding and the corresponding client binding information.

Figure 12–3. Client Binding Information Resulting from a Remote Procedure Call



The callouts in the figure refer to the following:

1. The requested object UUID, which may be the nil UUID
2. Client authentication information, which is optional
3. The address from which the client is making the remote procedure call, which the communications protocols supply to the server

A server application can use the client binding handle to ask the RPC runtime about the object UUID requested by a client or about the client's authentication information.

12.4 Endpoints

An endpoint is the address of a specific server instance on a host system. Two kinds of endpoints exist: well-known endpoints and dynamic endpoints.

12.4.1 Well-Known Endpoints

A well-known endpoint is a preassigned stable address that a server uses every time it runs. Well-known endpoints typically are assigned by a central authority responsible for a transport protocol; for example, the Internet Assigned Numbers Authority assigns endpoint values for the IP family of protocols. If you use well-known endpoints for a server, you should register them with the appropriate authority.

Well-known endpoints can be declared for an interface (in the interface declaration) or for a server instance, as follows:

- Any interface definition can be associated with one or more endpoints, along with the RPC protocol sequence corresponding to each endpoint (the **endpoint** attribute).

  When compiling an interface, the IDL compiler stores each combination of endpoint and protocol sequence in the interface specification. If a call is made using binding information that lacks an endpoint, the RPC runtime automatically looks in the interface specification for a well-known endpoint specified for the protocol sequence obtained from the binding information. If the interface specification contains an appropriate endpoint, the runtime adds it to the binding information.

- Alternatively, server-specific, well-known endpoints can be defined in server application code. When asking the runtime to use a given protocol sequence, the server supplies the corresponding endpoints to the RPC runtime. On a given system, each endpoint can be used by only one server at a time. If server application code contains a hardcoded endpoint or the server's installers always specify the same well-known endpoint, only one instance of the server can run per system.

When a server exports its binding information to a namespace server entry, the export operation includes any well-known endpoints within the server binding information stored in the server entry.

12.4.2 Dynamic Endpoints

A dynamic endpoint is requested and assigned at runtime. For some transport protocols, the number of endpoints is limited; for example, TCP/IP and UDP/IP use

a 16-bit number for endpoints, which allows 65,535 endpoints. When the supply of endpoints for a transport protocol is limited, the protocol ensures an adequate supply of endpoints by limiting the portion that can be reserved as well-known endpoints. A transport, on request, dynamically makes its remaining endpoints available on a first-come, first-served basis to specific processes such as RPC server instances.

When a server requests dynamic endpoints, the server's RPC runtime asks the operating system for a unique dynamic endpoint for each protocol sequence the server is using. For a given protocol sequence, the local implementation of the corresponding transport protocol provides the requested endpoints. When an RPC server with dynamic endpoints stops listening, its dynamic endpoints are released.

Because of the transient nature of dynamic endpoints, the NSI of the RPC API does not export them to a namespace; however, NSI does export the rest of the server's binding information. References to expired endpoints would remain indefinitely in server entries, causing clients to import and try, unsuccessfully, to establish bindings to nonexistent endpoints. Therefore, the export operation removes dynamic endpoints before adding binding information to a server entry; the exported server address contains only network addressing information. The import operation returns a partially bound binding handle. The client makes its first remote procedure call with the partially bound handle, and the endpoint mapper service on the server's system resolves the binding handle with the endpoint of a compatible server. To make dynamic endpoints available to clients that are using partially bound binding handles, a server must register its dynamic endpoints in the local endpoint map.

By using object UUIDs, a server can ensure that a client that imports a partially bound handle obtains one of a particular server's endpoints. This requires that the server do the following:

1. Specify a list of one or more object UUIDs that are unique to the server.
2. Export the list of object UUIDs.
3. Supply the list of object UUIDs to the endpoint map service when registering endpoints.
4. If the server provides different managers that implement an interface for different types of objects, the server must specify the type of each object.

To request binding information for a particular server, a client specifies one of the server's object UUIDs, which is then associated with the server binding information the client uses for making a remote procedure call.

Note: If a client requests the nil object UUID when importing from a server entry containing object UUIDs, the client runtime selects one of those object UUIDs and associates it with the imported server binding information. This object UUID guarantees that the call goes to the server that exported the binding information and object UUID to the server entry.

12.5 Execution Semantics

Execution semantics identify the ability of a procedure to execute more than once during a given remote procedure call. The communications environment that underlies remote procedure calls affects their reliability. A communications link can break for a variety of reasons such as a server termination, a remote system crash, a network failure, and so forth; all invocations of remote procedures risk disruption due to communications failures. However, some procedures are more sensitive to such failures, and their impact depends partly on how reinvoking an operation affects its results.

To maximize valid outcomes for its operations, the operation declarations of an RPC interface definition indicate the effect of multiple invocations on the outcome of the operations.

Table 12-1 summarizes the execution semantics for DCE RPC calls.

Table 12–1. Execution Semantics for DCE RPC Calls

Semantics	Meaning
at-most-once	The operation must execute either once, partially, or not at all; for example, adding or deleting an appointment from a calendar can use **at-most-once** semantics. This is the default execution semantics for remote procedure calls.
idempotent	The operation can execute more than once; executing more than once using the same input arguments produces identical outcomes without undesirable side effects; for example, an operation that reads a block of an immutable file is **idempotent**. DCE RPC supports **maybe** semantics and **broadcast** semantics as special forms of **idempotent** operations.

Semantics	Meaning
maybe	The caller neither requires nor receives any response or fault indication for an operation, even though there is no guarantee that the operation completed. An operation with **maybe** semantics is implicitly idempotent and must lack output parameters.
broadcast	The operation is always broadcast to one server on each host system on the local network, rather than delivered to a specific server, and one reply is returned to the client. An operation with **broadcast** semantics is implicitly **idempotent**.

The broadcast capabilities of RPC runtime have a number of distinct limitations:

- Not all systems and networks support broadcasting. In particular, broadcasting is not supported by the RPC connection-oriented protocol.
- Broadcasts are limited to hosts on the local network.
- Broadcasts make inefficient use of network bandwidth and processor cycles.
- The RPC runtime library does not support **at-most-once** semantics for broadcast operations; it applies **idempotent** semantics to all such operations.
- The input arguments for broadcast calls are limited to 944 bytes.

12.6 Communications Failures

If a server detects a communications failure during a remote procedure call, the server runtime attempts to terminate the now orphaned call by sending a cancel to the called procedure. A *cancel* is a mechanism by which a client thread of execution notifies a server thread of execution (the to be canceled thread) to terminate as soon as possible. A cancel sent by the RPC runtime after a communications failure initiates orderly termination for a remote procedure call. (For a brief discussion of how cancels work with remote procedure calls, see the discussions with respect to Threads.)

Applications that use context handles to establish a client context require a context rundown procedure to enable the server to clean up client context when it is no longer needed. The name of the context rundown procedure is determined from the type name of the context handle declared in the interface definition; this ensures that the stub knows about the procedure in the server application code. If a communications

link with a client is lost while a server is maintaining context for the client, the RPC runtime will inform the server to invoke the context rundown procedure. For a more thorough discussion of context handles see Chapter 17 .

12.7 Scaling Applications

Unlike local applications, RPC applications require network resources, which are possible bottlenecks to scaling an RPC application. RPC clients and servers require network resources that are not required by local programs. The main network resources to consider are network bandwidth, endpoints, network descriptors (the identifiers of potential network channels such as UNIX sockets), kernel buffers and, for a connection-oriented transport, the connections. Also, RPC applications place extra demands on system resources such as memory buffers, various quotas, and the CPU.

The number of remote procedure calls that a server can support depends on various factors, such as the following:

- The resources of the server and the network
- The requirements of each call
- The number of calls that can be concurrently offered at some level of service
- The performance requirements

An accurate analysis of the requirements of a given server involves detailed work load and resource characterization and modeling techniques. Although measurement of live configurations under load will offer the best information, general guidelines apply. You should consider the connection, buffering, bandwidth, and CPU resources as the most likely RPC bottlenecks to scaling. Use these application requirements to scale resources.

Many system implementations limit the number of network connections per process. This limit provides an upper bound on the number of clients that can be served concurrently using the connection-oriented protocol. Some UNIX based systems set this limit at 64. However, except for applications that use context handles, the connection-oriented RPC runtime allows pooling of connections. Pooling permits simultaneously supporting more clients than the maximum number of connections, provided they do not all make calls at the same instant and occasionally can wait briefly.

12.8 RPC Objects

DCE RPC enables clients to find servers that offer specific RPC objects. An RPC object is an entity that an RPC server defines and identifies to its clients. Frequently, an RPC object is a distinct computing resource such as a particular database, directory, device, process, or processor. Identifying a resource as an RPC object enables an application to ensure that clients can use an RPC interface to operate on that resource. An RPC object can also be an abstraction that is meaningful to an application such as a service or the location of a server.

RPC objects are defined by application code. The RPC runtime provides substantial flexibility to applications about whether, when, and how they use RPC objects. RPC applications generally use RPC objects to enable clients to find and access a specific server. When servers are completely interchangeable, using RPC objects may be unnecessary. However, when clients need to distinguish between two servers that offer the same RPC interface, RPC objects are essential. If the servers offer distinct computing resources, each server can identify itself by treating its resources as RPC objects. Alternatively, each server can establish itself as an RPC object that is distinct from other instances of the same server.

RPC objects also enable a single server to distinguish among alternative implementations of an RPC interface, as long as each implementation operates on a distinct type of object. To offer multiple implementations of an RPC interface, a server must identify RPC objects, classify them into types, and associate each type with a specific implementation.

The set of remote procedures that implements an RPC interface for a given type of object is known as a *manager*. The tasks performed by a manager depend on the type of object on which the manager operates. For example, one manager of a queue-management interface may operate on print queues, while another manager may operate on batch queues.

Chapter 13

Basic RPC Routine Usage

This chapter introduces a number of basic DCE RPC routines for directory service, communications, and authentication operations and discusses major usage issues important for developing DCE RPC applications.

This chapter discusses the following topics:

- Overview of basic runtime routines
- Server initialization tasks
- How clients find servers

13.1 Overview of the RPC Routines

This section summarizes the major concerns of RPC communications, name service interface (NSI) usage, and authenticated RPCs.

13.1.1 Basic Operations of RPC Communications

The DCE RPC runtime provides the following communications operations for RPC applications:

- Managing communications for RPC applications

  As part of server initialization, a server sets up its communications capabilities by a series of calls to the RPC runtime. These runtime calls register the server's RPC interfaces, tell the RPC runtime what combination of communications protocols to use for the server, and register the endpoints of the server for each of its interfaces. After completing these and any other initialization tasks, the server tells the runtime to begin listening for incoming calls.

- Managing binding information

  A variety of communications operations allow servers to access and manipulate binding information. In addition, a set of communications operations enables applications to manipulate string representations of binding information (string bindings).

13.1.2 Basic Operations of the NSI

The NSI routines perform operations on a namespace for RPC applications. The fundamental operations include the following:

- Creating and deleting entries in namespaces

- Exporting

  A server uses the NSI export operation to place binding information associated with its RPC interfaces and objects into the namespace used by the RPC application.

- Importing

  Clients can search for exported binding information associated with an interface and object by using the NSI import operation or lookup operation. These two operations are collectively referred to as the *NSI search operations*.

- Unexporting

The unexport operation enables a server to remove some or all of its binding information from a server entry.

- Managing information in a namespace

  Applications use the NSI interface to place information about server entries into a namespace and to inquire about and manage that information.

13.1.3 Basic Operations of Authenticated RPCs

The authenticated RPC routines provide a mechanism for establishing secure communications between clients and servers.

To engage in authenticated RPC, a client and server must agree on the authentication service to be used. The server's responsibility is to register its principal name and the authentication service to be supported with the RPC runtime. The client's responsibility is to establish the authentication service, a given protection level, and an authorization service for the server binding handle. The protection level determines the degree of protection applied to individual messages between the client and server. The authorization service determines the form in which the client's credentials will be presented to the server (for access checking).

Once authenticated RPC has been established between a client and server, the client issues remote procedure calls in the usual fashion, with all authentication and protection being handled by the DCE Security Service and the RPC runtime.

Table 13-1 relates several of the RPC runtime operations just discussed with specific routines or sets of routines.

Table 13–1. Basic Runtime Routines

Description of Operation	Usage	Routine Name(s)
Communications Routines		
Set the type of an RPC object with the RPC runtime	Server	**rpc_object_set_type()**
Register RPC interfaces	Server	**rpc_server_register_if()**

Description of Operation	**Usage**	**Routine Name(s)**
Select RPC protocol sequences	Server	**rpc_network_inq_protseqs()**, **rpc_server_use_*protseq*_...()**
Obtain server binding handles	Server	**rpc_server_inq_bindings()**
Register endpoints	Server	**rpc_ep_register()**, **rpc_ep_register_no_replace()**
Unregister endpoints	Server	**rpc_ep_unregister()**
Listen for calls	Server	**rpc_server_listen()**
Manipulate string representations of binding information (string bindings)	Client	**rpc_binding_from_string_binding()**
	Client, Server	**rpc_binding_to_string_binding(), rpc_string_binding_compose()**, **rpc_string_binding_parse()**
Change the RPC object in server binding information	Client	**rpc_binding_set_object()**
Convert a client binding handle to a server binding handle	Server	**rpc_binding_server_from_client()**
Name Service Interface Routines		
Export binding information to a namespace	Server	**rpc_ns_binding_export()**
Search a namespace for binding information	Client	**rpc_ns_binding_import_...(), rpc_ns_binding_lookup_...()**, **rpc_ns_binding_select()**
Authentication Routines		
Authentication and authorization	Server, Client	**rpc_*auth...()**

13.2 Server Initialization Using the RPC Routines

Before a server can receive any remote procedure calls, it should usually initialize itself by calling the **dce_server_register()** routine so that the server is properly recognized by DCE. However, servers can instead use a series of the lower-level RPC runtime

routines. The server initialization code, written by the application developer, varies among servers. However, every server must set up its communications capabilities, which usually involves most of the following tasks:

1. Assigning types to objects
2. Registering at least one interface
3. Specifying which protocol sequences the server will use
4. Obtaining a list of references to a server's binding information (a list of binding handles)
5. Registering endpoints
6. Exporting binding information to a server entry or entries in the namespace
7. Listening for remote procedure calls
8. Performing cleanup tasks including unregistering endpoints

The following pseudocode illustrates the calls a server makes to accomplish these basic initialization tasks:

```
/* Initialization tasks */

    rpc_object_set_type(...);
    rpc_server_register_if(...);
    rpc_server_use_all_protseqs(...);
    rpc_server_inq_bindings(...);
    rpc_ep_register(...);
    rpc_ns_binding_export(...);
    rpc_server_listen(...);

/* Cleanup tasks */

    rpc_ep_unregister(...);
```

13.2.1 Assigning Types to Objects

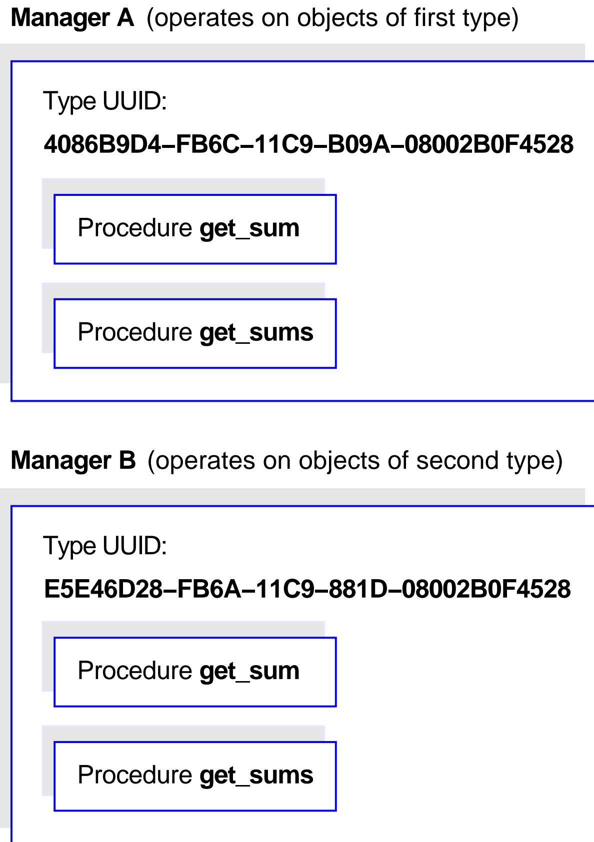
An *object type* is a mechanism for associating a set of RPC objects and the manager whose remote procedures implement an RPC interface for those objects. Object types allow an application to cluster objects, such as computing resources, according to any relevant criteria. For example, a single accounting interface can be implemented to operate on accounting databases that contain equivalent information but that are formatted differently; each database format represents a distinct type.

To simultaneously offer alternative implementations of an RPC interface for different types of objects, a server uses alternative managers. Servers that implement each of their interfaces with only one manager can usually avoid the tasks associated with assigning object types. However, when a server offers multiple managers, each manager must be dedicated to operating on a separate type of object. In this case, a server must classify some or all of its objects into types; for example, a calendar application that specifies one non-nil type UUID for departmental calendars and another non-nil type UUID for personal calendars.

By default, objects have the nil type. Only a server that implements different managers for different objects or sets of objects needs to type classify its RPC objects. To type classify an object, a server associates the object UUID of the object with a single type UUID by calling the **rpc_object_set_type()** procedure separately for each object. To create a UUID, a server calls the **uuid_create()** routine.

The exact implementation of a manager can vary with the type of object on which each manager operates. For example, a queue-management interface may be implemented to manage print queues as objects in one case and to manage batch queues as objects in another. Figure 13-1 illustrates the use of type UUIDs to identify two types of managers.

Figure 13–1. Manager Types



When the server receives an incoming call that specifies an object UUID, the server dispatches the call to the manager for the type to which the object belongs. For information on how a type is used to select a manager for an incoming call, see Chapter 17.

13.2.2 Registering Interfaces

A server calls the **rpc_server_register_if()** routine to tell the RPC runtime about a specific RPC interface. Registering an interface informs the runtime that the server is offering that interface and makes it available to clients. A server can register any number of interfaces with the RPC runtime by calling the **rpc_server_register_if()** routine once for each set of procedures, or manager, that implements an interface.

To offer more than one manager for an interface, a server must register each manager separately.

When registering an interface, the server provides the following information:

- Interface specification

  This is a reference to information about an RPC interface as offered by its server stub. The DCE IDL compiler generates an interface specification as part of the stub code. For a specific version of an interface, all managers use the same interface specification. Information in an interface specification that concerns application developers includes the following:

  — The interface identifier (UUID and major and minor version numbers)

  — The supported transfer syntaxes

  — A list of any well-known endpoints (and their associated protocol sequences) specified in the interface definition (**.idl**) file

  — The interface's default manager entry point vector (manager EPV), if present

  A default manager EPV, constructed using the operation names of the interface definition, is typically generated for stubs by the DCE IDL compiler (the **--no_mepv** compiler option suppresses this feature).

- A type UUID for the manager

  Each implementation of an interface, a manager, is represented by a type UUID.

- A manager EPV for the interface

  A server can register a given interface more than once by specifying a different type UUID and manager EPV each time it calls **rpc_server_register_if()**.

  A manager EPV is a list of the addresses (the entry points of the remote procedures provided by the manager) that represent the location of each remote procedure

implementation. A manager EPV must contain exactly one entry point for each procedure defined in the interface definition.

The server can use the default manager EPV only once, and only for a manager that uses the procedure names as they are declared in the interface definition. For any additional manager of the RPC interface, (and if the server needs to rename the implemented procedures), the server must create and register a unique manager EPV. Also, each manager must be associated with a distinct type UUID.

13.2.3 Selecting RPC Protocol Sequences

A server can inquire about whether the local RPC runtime supports a specific protocol sequence by using the **rpc_network_is_protseq_valid()** routine. The server can also use the **rpc_network_inq_protseqs()** routine to ask the RPC runtime for a list of all protocol sequences supported by both the RPC runtime and the operating system.

To prepare to receive remote procedure calls, a server uses **rpc_server_use_all_protseqs()** or **rpc_server_use_protseq()** calls to tell the RPC runtime to use at least one protocol sequence. For each protocol combination, the RPC runtime creates one or more binding handles with dynamic endpoints on which the server will listen for remote procedure calls. The server then can use a list of these binding handles to register dynamic endpoints in the endpoint map and to export its binding information (except the endpoints) to the name service.

As an option, an interface can contain one or more well-known endpoints, each of which is accompanied by a protocol sequence. A server uses the **rpc_server_use_all_protseqs_if()**, **rpc_server_use_protseq_if()**, or **rpc_server_use_protseq_ep()**, to notify the RPC runtime about which protocol sequence and well-known endpoint combinations will be used.

A server can use any protocol sequence declared in an interface endpoint declaration, or the server can ignore the endpoint declarations, as long as it registers at least one endpoint.

13.2.4 Obtaining a List of Server Binding Handles

After a server passes to the RPC runtime the protocol sequences over which it will listen for remote procedure calls, the RPC runtime constructs server binding handles. Each binding handle refers to a complement of binding information that defines one potential binding; that is, a specific RPC protocol sequence, RPC protocol major version, network address, endpoint, and transfer syntax that an RPC client can use to establish a binding with an RPC server.

Before registering endpoints or exporting binding information, a server must obtain a list of its binding handles from the RPC runtime by using the **rpc_server_inq_bindings()** routine. The server passes this list back to the runtime as an argument when registering endpoints and exporting binding information.

13.2.5 Registering Endpoints

Servers can use well-known or dynamic endpoints with any protocol sequence.

When a server asks the runtime to use a dynamic endpoint with a protocol sequence, the runtime asks the operating system to generate the endpoint. To use the dynamic endpoints, a server must register the server's binding information, including the endpoints, by using the **rpc_ep_register()** routine. For each combination of RPC interface identifier, object UUID, and binding information that the server offers, the endpoint mapper service creates an element in the local endpoint map.

A server does not necessarily need to register well-known endpoints; however, by registering well-known endpoints, the server ensures that clients can always obtain them. Registration also makes the endpoints accessible to administrators, who can use the DCE control program, **dcecp**, to show the map elements of an endpoint map by using the **endpoint show** operation.

Servers can remove map elements from a local endpoint map by using the **rpc_ep_unregister()** routine. Servers should unregister endpoints after they stop listening.

13.2.6 Making Binding Information Accessible to Clients

A server needs to make its binding information accessible to clients. Usually, a server uses the NSI export operation to place its binding information into a server entry. However, it is also possible for servers to make string bindings accessible to clients. In any case, the server obtains its binding information from the runtime by first using the **rpc_server_inq_bindings()** routine to ask for a list of binding handles.

13.2.6.1 Using String Bindings to Provide Binding Information

While implementing and debugging a server program you may temporarily want to communicate binding information to clients by using string bindings. This allows a server to establish a client/server relationship without registering endpoints in the local endpoint map or exporting binding information to a namespace.

The server can convert into a string each binding handle in the list obtained from the **rpc_server_inq_bindings()** call by calling **rpc_binding_to_string_binding()**. The resulting string binding is always fully bound. The server then makes some or all of its string bindings available to clients somehow; for example, by placing the string bindings in a file to be read by clients or users or both.

13.2.6.2 Exporting Binding Information

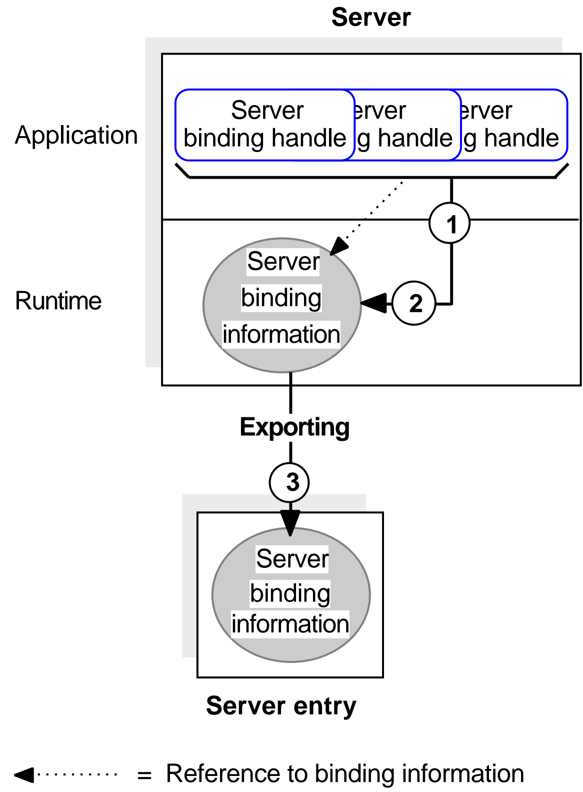
Servers can export binding information (and interface identifiers) or objects or both by calling the **rpc_ns_binding_export()** routine. To export binding information associated with a given RPC interface, a server uses an interface handle. The interface handle is created by the IDL compiler as a reference to information about the interface that the compiler stores in an interface specification.

To refer to binding information, the application code obtains a list of server binding handles from the RPC runtime and passes the list to the export operation. The list contains binding handles for all the protocol sequence and endpoint combinations that the server has requested; it does this by calling the use-protocol-sequence operations. However, the server can remove any of those binding handles from the list before exporting it. This enables a server to export the binding information associated with a subset of its binding handles.

To export object UUIDs, a server application must provide a list of object UUIDs for the RPC objects it offers. The server can generate these object UUIDs itself or obtain them from some application-specific source such as an object-UUID database. All object UUIDs in a given server entry are associated with every interface UUID and server address in the entry.

Figure 13-2 illustrates how server binding handles in the application code refer to server binding information in the runtime, which is exported to the name service.

Figure 13–2. Exporting Server Binding Information



A server entry must belong exclusively to a server running on a given host. If there are identical, interchangeable instances of a server on the host, they can share a single set of server entries. However, if clients need to distinguish between coexisting instances

of a server (for example, when each offers a different RPC object), each instance requires its own server entry.

Note: CDS databases are subject to access control. To access entries in a CDS database, you need access control list (ACL) permissions. Depending on the NSI operation, you need ACL permissions to the parent directory, the CDS object entry, or both. If you need ACL permissions, see your CDS administrator.

The ACL permissions are as follows:

- To create an entry, you need **insert** permission to the parent directory.
- To read an entry, you need **read** permission to the CDS object entry.
- To write to an entry, you need **write** permission to the CDS object entry.
- To delete an entry, you need **delete** permission either to the CDS object entry or to the parent directory.
- To test an entry, you need either **test** permission or **read** permission to the CDS object entry.

Note that **write** permission does not imply **read** permission.

13.2.7 Listening for Calls

When a server is ready to accept remote procedure calls, it initiates listening, specifying the maximum number of calls it can execute concurrently; it does this by calling the **rpc_server_listen()** routine. If a server allows concurrent calls, its remote procedures are responsible for concurrency control. If executing a set of remote procedures concurrently requires concurrency control and a server lacks this control, the server must allow only one call at a time.

Under normal circumstances, the **rpc_server_listen()** routine does not return but the RPC runtime continues listening for new remote procedure calls to the server's registered interfaces until one of the following events occurs:

- Any of the server's procedures makes a local management call to stop a server from listening for future remote procedure calls.

- For applications whose servers enable clients to stop servers from listening, a client makes a remote management call to stop a server from listening for future remote procedure calls.

On receipt of a stop listening request, the RPC runtime stops accepting new remote procedure calls for all registered interfaces. However, currently executing calls are allowed to complete. After all executing calls complete, the listen operation stops listening and returns control to the server. Servers should unregister endpoints after they stop listening.

13.3 How Clients Find Servers

A client runtime can obtain server binding information from a namespace. Alternatively, a client can obtain server binding information in string format from an application-specific source such as a file. Runtime routines enable client applications to obtain server binding handles that refer to server binding information obtained from either source.

13.3.1 Searching a Namespace

To obtain binding information from a namespace, a client can do one of the following:

- The client must call the import routines **rpc_ns_binding_import_begin()**, **rpc_ns_binding_import_next()**, and **rpc_ns_binding_import_done()** to obtain a binding handle for a compatible server.
- The client must call the lookup routines **rpc_ns_binding_lookup_begin()**, **rpc_ns_binding_lookup_next()**, and **rpc_ns_binding_lookup_done()** to obtain a list of binding handles for a compatible server. Select a binding handle from the list by calling either of the following:
  - — The NSI select routine **rpc_ns_binding_select()**, which selects a binding handle at random
  - — A user-defined select routine, which implements an application-specific selection algorithm

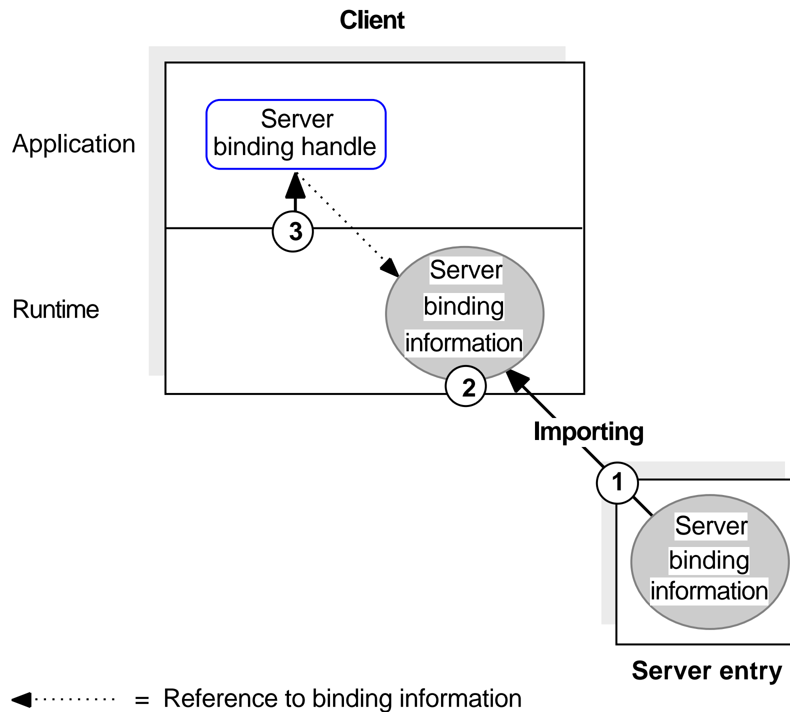
- The client must use the automatic method of binding management to make the client stub transparently manage binding information.

  In this case, the application code lacks any calls to the NSI interface. However, the automatic method does require the client to identify the directory service entry at which to begin the search for binding information. The client must specify the starting entry name as the value of the NSI-defined **RPC_DEFAULT_ENTRY** environment variable.

An NSI import or lookup operation searches server entries for a compatible server. On finding such a server entry, the search operation copies the server binding information associated with the requested interface and an object UUID. The search operation then creates a randomly ordered list of server binding handles to refer to the potential bindings represented by the binding information.

Figure 13-3 illustrates the use of a server binding handle to refer to server binding information selected by an import operation.

Figure 13–3. Importing Server Binding Information



The callouts in the figure refer to the following operations:

1. The import operation looks up binding information of a server that is compatible with the client.

   The import operation finds a server entry based on the specified interface identifier, and then looks at the list of object UUIDs. If the importing client specifies a non-nil object UUID, the import operation looks for and returns that object UUID. If the client specifies the nil object UUID and the server entry contains any object UUIDs, the import operation selects and returns one UUID at random. If the entry lacks any object UUIDs, the import operation returns the nil UUID.

2. The import operation fetches the compatible binding information and creates a binding handle for each potential binding represented in the binding information.

3. The import operation then selects a binding handle at random and passes it to the client application.

13.3.2 Using String Bindings to Obtain Binding Information

To use a string binding, a client starts with either an existing string binding or with the components of the binding information. Do *not* hardcode string bindings into application code. Rather, specify them at runtime using a command argument, environment variable, file, or other means. The simplest way to specify a string binding is for a user to supply a string binding manually to a client. However, this manual approach is awkward for users who must know how to obtain and manipulate the string bindings. Also, if binding information changes, the users are responsible for updating any string bindings used by their clients. Reducing manual intervention in the use of string bindings requires that an application provide its own mechanisms for storing, maintaining, and accessing binding information. In contrast, a directory service such as CDS provides these mechanisms automatically to applications that store binding information in a namespace.

Regardless of how a client obtains a string binding, before establishing a binding, the client must ask the RPC runtime for a binding handle that refers to the server binding information depicted in the string binding. The client converts the string binding into a server binding handle by calling the **rpc_binding_from_string_binding()** routine.

The following pseudocode lists the calls for composing a string binding and for using it to obtain a server binding handle:

```
rpc_string_binding_compose(...);

rpc_binding_from_string_binding(...);
 .
 .
 .
rpc_string_free(...);
```

Chapter 14

RPC and Other DCE Components

This chapter discusses aspects of the internal behavior of remote procedure calls that are significant for advanced RPC programmers, including the following topics:

- Threads of execution in RPC applications
- Authenticated remote procedure calls
- Using the Name Service Interface

DCE RPC is a fully integrated part of the distributed computing environment. The communications capabilities of DCE RPC are used by clients and servers of other DCE components. In turn, RPC uses services provided by DCE Threads, the DCE Security Service, and the DCE Cell Directory Service.

A thread is a single sequential flow of control with one point of execution on a single processor at any instant. Multiple threads can coexist in a single process. DCE RPC uses threads internally for its own operations. DCE RPC also provides an environment where RPC applications can use thread services.

The DCE RPC runtime provides RPC applications with a programming interface to the security service. The RPC authentication interface enables RPC clients and servers

to mutually authenticate (that is, prove the identity of) each other. An authenticated remote procedure call provides client authorization information and authentication information to servers. Authorization information includes the credentials a client has and the identities a client is associated with at the time of a call. By comparing client authorization information to access control lists, a server can find out whether a client is eligible to use a requested remote procedure. Client authentication information identifies a client to a server.

To help RPC clients find RPC servers, RPC applications typically use a namespace. A namespace is a collection of information about applications, systems, and any other relevant computing resources. A namespace is maintained by a directory service such as CDS. DCE RPC provides a Name Service Interface (NSI) that is independent of any particular directory service.

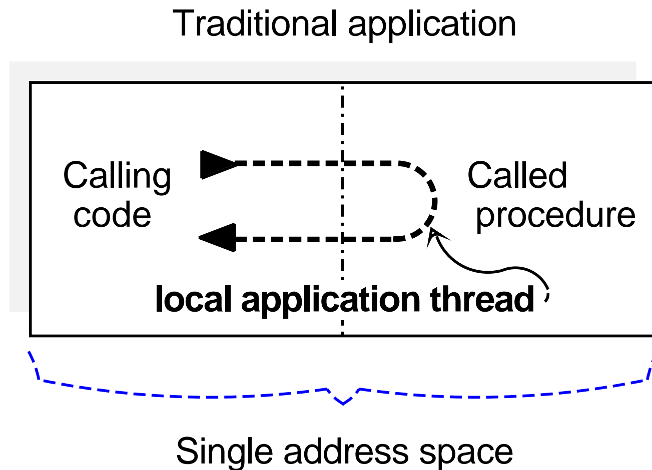
NSI communicates with supported directory services for both RPC applications and the RPC control program. NSI insulates RPC applications from the intricacies of using a directory service. An RPC server uses NSI to store information about itself in a namespace, and a client uses NSI to access information about a server that meets the client's requirements for a specific RPC interface and object, among other things. The client uses this information to establish a relationship, known as a *binding*, with the server.

14.1 Threads of Execution in RPC Applications

Each remote procedure call occurs in an execution context called a *thread*. A thread is a single sequential flow of control with one point of execution on a single processor at any instant. A thread created and managed by application code is an *application thread*.

Traditional processing occurs exclusively within local application threads. Local application threads execute within the confines of one address space on a local system and pass control exclusively among local code segments, as illustrated in Figure 14-1.

Figure 14–1. Local Application Thread During a Procedure Call



RPC applications also use application threads to issue both remote procedure calls and runtime calls, as follows:

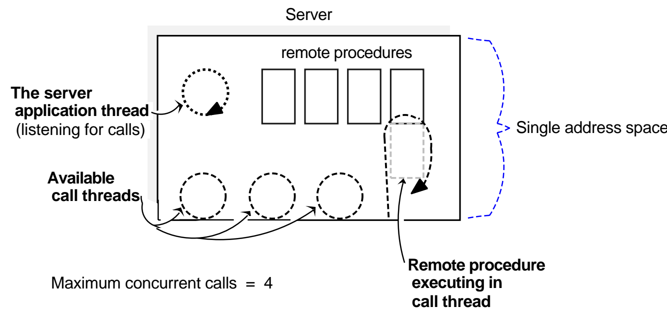
- An RPC client contains one or more client application threads; that is, a thread that executes client application code that makes one or more remote procedure calls.
- A DCE RPC server uses one server application thread to execute the server application code that listens for incoming calls.

In addition, for executing called remote procedures, an RPC server uses one or more call threads that the RPC runtime provides. As part of initiating listening, the server application thread specifies the maximum number of concurrent calls it will execute. The maximum number of call threads in multithreaded applications depends on the design of the application. The RPC runtime creates the same number of call threads in the server process.

The number of call threads is significant to application code. When using only one call execution thread, application code does not have to protect itself against concurrent resource use. When using more than one call thread, application code must protect itself against concurrent resource use.

Figure 14-2 shows a multithreaded server with a maximum of four concurrently executing calls. Of the four call threads for the server, only one is currently in use; the other three threads are available for executing calls.

Figure 14–2. Server Application Thread and Multiple Call Threads

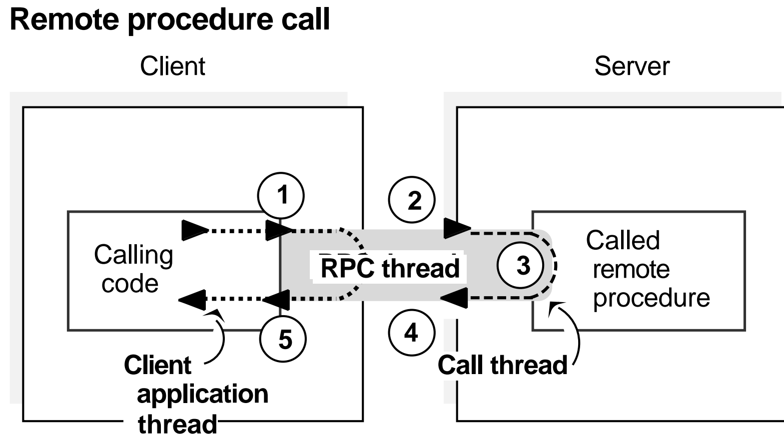


14.1.1 Remote Procedure Call Threads

In distributed processing, a call extends to and from client and server address spaces. Therefore, when a client application thread calls a remote procedure, it becomes part of a logical thread of execution known as an *RPC thread* . An RPC thread is a logical construct that encompasses the various phases of a remote procedure call as it extends across actual threads of execution and the network. After making a remote procedure call, the calling client application thread becomes part of the RPC thread. Usually, the RPC thread maintains execution control until the call returns.

The RPC thread of a successful remote procedure call moves through the execution phases illustrated in Figure 14-3.

Figure 14–3. Execution Phases of an RPC Thread

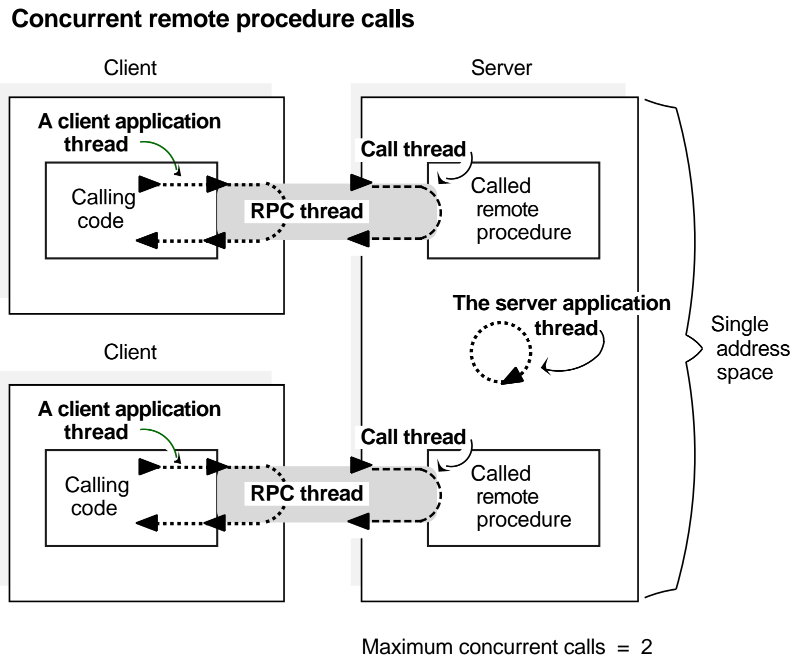


The execution phases of an RPC thread in the preceding figure include the following operations:

1. The RPC thread begins in the client process, as a client application thread makes a remote procedure call to its stub; at this point, the client thread becomes part of the RPC thread.
2. The RPC thread extends across the network to the server address space.
3. The RPC thread extends into a call thread, where the remote procedure executes. While a called remote procedure is executing, the call thread becomes part of the RPC thread. When the call finishes executing, the call thread ceases being part of the RPC thread.
4. The RPC thread then retracts across the network to the client.
5. When the RPC thread arrives at the calling client application thread, the remote procedure call returns any call results and the client application thread ceases to be part of the RPC thread.

Figure 14-4 shows a server executing remote procedures in its two call threads, while the server application thread listens.

Figure 14–4. Concurrent Call Threads Executing in Shared Address Space



Note: Although a remote procedure can be viewed logically as executing within the exclusive control of an RPC thread, some parallel activity does occur in both the client and server.

An RPC server can concurrently execute as many remote procedure calls as it has call threads. When a server is using all of its call threads, the server application thread continues listening for incoming remote procedure calls. While waiting for a call thread to become available, DCE RPC server runtimes can queue incoming calls. Queuing incoming calls avoids remote procedure calls failing during short-term congestion. The queue capacity for incoming calls is implementation dependent; most implementations offer a small queue capacity. The queuing of incoming calls is discussed in Chapter 17, under the topic of the routing of incoming calls.

14.1.2 Cancels

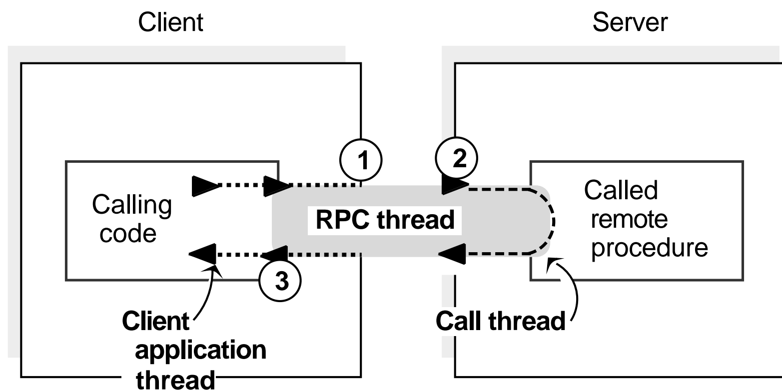
DCE RPC uses and supports the synchronous cancel capability provided by POSIX threads (pthreads). A *cancel* is a mechanism by which a thread informs another thread (the canceled thread) to terminate as soon as possible. Cancels operate on the RPC thread exactly as they would on a local thread, except for an application-specified, cancel-timeout period. A cancel-timeout period is an optional value that limits the amount of time the canceled RPC thread has before it releases control.

During a remote procedure call, if its thread is canceled and the cancel-timeout period expires before the call returns, the calling thread regains control and the call is orphaned at the server. An orphaned call may continue to execute in the call thread. However, the call thread is no longer part of the RPC thread, and the orphaned call is unable to return results to the client.

A client application thread can cancel any other client application thread in the same process (it is possible, but unlikely, for a thread to cancel itself.) While executing as part of an RPC thread, a call thread can be canceled only by a client application thread.

A cancel goes through several phases. Figure 14-5 shows where each of these phases occur.

Figure 14–5. Phases of a Cancel in an RPC Thread



The phases of a cancel in the preceding figure include the following:

1. A cancel that becomes pending at the client application thread at the start of or during a remote procedure call becomes pending for the entire RPC thread. Thus, while still part of the RPC thread, the call thread also has this cancel pending.
2. If the call thread of an RPC thread makes a cancelable call when cancels are not deferred and a cancel is pending, the cancel exception is raised.
3. The RPC thread returns to the canceled client application thread with one of the following outcomes:
   - If a cancel exception has not been taken, the RPC thread returns normal call results (output arguments, return value, or both) with a pending cancel.
   - If the remote procedure is using an exception handler, a cancel exception can be handled. The procedure resumes, and the RPC thread returns normal call results without pending any cancel.
   - If the remote procedure failed to handle a raised cancel exception, the RPC thread returns with the cancel exception still raised. This is returned as a fault.
   - If the cancel-timeout period expires, the RPC thread returns either a cancel-timeout exception or status code, depending on how the application sets up its error handling. This is true for all cases where any abnormal termination is returned.

14.1.3 Multithreaded RPC Applications

DCE RPC provides an environment for RPC applications that create multiple application threads (multithreaded applications). The application threads of a multithreaded application share a common address space and much of the common environment. If a multithreaded application must be thread-safe (guarantee that multiple threads can execute simultaneously and correctly), the application is responsible for its own concurrency control. Concurrency control involves programming techniques such as controlling access to code that can share a data structure or other resource to prevent conflicting overlapping access by separate threads.

A multithreaded RPC application can have diverse activities going on simultaneously. A multithreaded client can make concurrent remote procedure calls and a multithreaded server can handle concurrent remote procedure calls. Using multiple threads allows an RPC client or server to support local application threads that

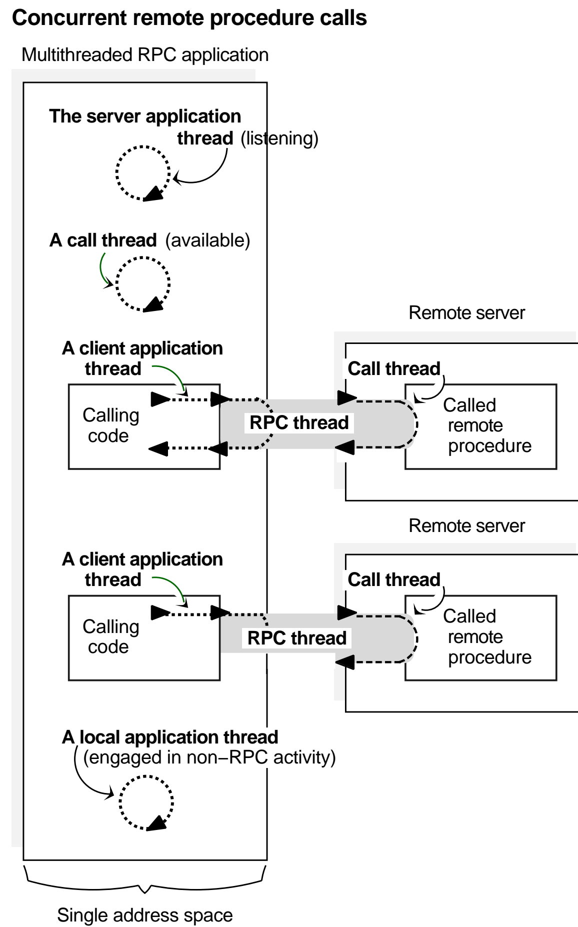
continue processing independently of remote procedure calls. Also, multithreading enables the server application thread and the client application threads of an RPC application to share a single address space as a joint client/server instance. A multithreaded RPC application can also create local application threads that are uninvolved in the RPC activity of the application.

Figure 14-6 shows an address space where application threads are executing concurrently.

The application threads in Figure 14-6 are performing the following activities:

- The server application thread is listening for calls.
- A call thread is available to execute an incoming remote procedure call.
- One client application thread has separated from an RPC thread and another is currently part of an RPC thread.
- A local application thread is engaging in non-RPC activity.

Figure 14–6. A Multithreaded RPC Application Acting as Both Server and Client



14.2 Security and RPC: Using Authenticated Remote Procedure Calls

DCE RPC supports authenticated communications between clients and servers. Authenticated RPC works with the authentication and authorization services provided by the DCE Security Service.

On the application level, a server makes itself available for authenticated communications by registering its principal name and the authentication service that it supports with the RPC runtime. The server principal name is the name used to identify the server as a principal to the registry service provided by the security service. In practice, this name is usually the same as the name that the server uses to register itself with the DCE Directory Service.

A client must establish the authentication service, protection level, and authorization service that it wishes to use in its communications with a server. The client identifies the intended server by means of the principal name that the server has registered with the RPC runtime. Once the required authentication, protection, and authorization parameters have been established for the server binding handle, the client issues remote procedure calls to the server as it normally does.

The security service, in conjunction with the RPC runtime, assumes responsibility for the following:

- Authenticating the client and server in accordance with the requested authentication service
- Applying the requested level of protection to communications between the client and server
- Providing client authorization data to the server in a form determined by the requested authorization service

Note: For a detailed discussion of authentication within the context of DCE security, refer to Chapter 24 of this guide.

14.2.1 Authentication

When a client establishes authenticated RPC, it must indicate the authentication service that it wants to use. The possible values are the following:

rpc_c_authn_none
No authentication

rpc_c_authn_dce_secret
DCE shared-secret key authentication

rpc_c_authn_dce_public
DCE public key authentication

rpc_c_authn_default
DCE default authentication service

The value **rpc_c_authn_none** is used to turn off authentication already established for a binding handle. The default authentication is DCE shared-secret (also known as private key) authentication.

Before a client and server can engage in authenticated RPC, they must ‘‘agree’’ on which authentication service to use. Specifically, the server must register the ‘‘agreed on’’ authentication service with the RPC runtime, along with the server’s principal name. For its part, the client must select the same service for the server’s binding handle. The client indicates the appropriate server by supplying the server’s principal name. If the client does not know the server’s name, it can use the **rpc_mgmt_inq_server_princ_name()** routine to determine the name.

14.2.1.1 Cross-Cell Authentication

A client can engage in authenticated RPC with a target server that is in the client’s cell or in a foreign cell. In the case of cross-cell authentication, DCE security performs the necessary additional steps on behalf of the client.

To establish authenticated RPC with a foreign server, a client must supply the fully qualified principal name of the server. A fully qualified name includes the name of the cell as well as the name of the principal and takes the following form:

/ . . . / *cell_name* / *principal_name*

14.2.1.2 Protection Levels

When a client establishes authenticated RPC, it can specify the level of protection to be applied to its communications with the server. The protection level determines how much of client/server messages are encrypted. As a rule, the more restrictive the protection level, the greater the impact on performance. Different levels are provided so that applications can control the protection versus performance tradeoffs.

Note that the protection level is entirely a client responsibility. When a server registers its supported authentication service with the RPC runtime, it does not specify any protection information for that service. However, the server can include the protection level used for a particular operation when deciding if the caller is authorized to perform the operation.

Authenticated RPC supports the following protection levels:

rpc_c_protect_level_default
Uses the default protection level for the specified authentication service.

rpc_c_protect_level_none
There is no protection level.

rpc_c_protect_level_connect
Performs protection only when the client establishes a relationship with the server. This level performs an encrypted handshake when the client first communicates with the server. Encryption or decryption is not performed on the data sent between the client and server. The fact that the handshake succeeds indicates that the client is active on the network.

rpc_c_protect_level_call
Performs protection only at the beginning of each remote procedure call when the server receives the request. This level attaches a verifier to each client call and server response.

This level does not apply to remote procedure calls made over a connection-based protocol sequence; that is, **ncacn_ip_tcp**. If this level is specified and the binding handle uses a connection-based protocol sequence, the routine uses the **rpc_c_protect_level_pkt** level instead.

rpc_c_protect_level_pkt
Ensures that all data received is from the expected client. This level attaches a verifier to each message.

rpc_c_protect_level_pkt_integrity
Ensures and verifies that none of the data transferred between client and server has been modified. This level computes a cryptographic checksum of each message to verify that none of the data transferred between the client and server has been modified in transit.

This is the highest protection level that is guaranteed to be present in the RPC runtime.

rpc_c_protect_level_pkt_privacy
Performs protection as specified by all of the previous levels and also encrypts each remote procedure call argument and return values. This level encrypts all user data in each call.

This is the highest protection level, but it may not be available in the RPC runtime.

If a client wants to use the default protection level but does not know what this level is, it can use the **rpc_mgmt_inq_dflt_protect_level()** routine to determine what the default level is.

14.2.2 Authorization

Authorization is the process of checking a client's permissions to an object that is controlled by the server. Access checking is entirely a server responsibility and involves matching the client's credentials against the permissions associated with the object. A client's credentials consist of the principal ID and group memberships contained in the client's network login context.

Authenticated RPC supports the following options for making client authorization information available to servers for access checking:

rpc_c_authz_none
No authorization information is provided to the server, usually because the server does not perform access checking.

rpc_c_authz_name
Only the client principal name is provided to the server. The server can then perform authorization based on the provided name. This form of authorization is sometimes referred to as *name-based* authorization.

rpc_c_authz_dce
The client's credentials (DCE Privilege Attribute Certificate or PAC) is provided to the server with each remote procedure call that is made using the binding parameter. The server performs authorization by using the client credentials. Generally, access is checked against DCE ACLs.

When a client establishes authenticated RPC, it must indicate which authorization option it wants to use.

It is the server's responsibility to implement the type of authorization appropriate for the objects that it controls. When the server calls **rpc_binding_inq_auth_caller()** to return information about an authenticated client, it gets back either the client's principal name or a pointer to the data structure that contains the client's credentials. The value that is returned depends on which type of authorization the client specified on its call to establish authenticated RPC with that server.

Each server is responsible for implementing its own access checking by means of ACL managers. When a server receives a client request for an object, the server invokes the ACL manager appropriate for that type of object and passes the manager the client's authorization data. The manager compares the client authorization data to the permissions associated with the object and either refuses or permits the requested operation. In the case of certified (PAC-based) authorization, servers must implement access checking by using the ACL facility provided by the DCE Security Service.

An ACL management API (**dce_acl***) is also available.

14.2.2.1 Name-Based Authorization

Name-based authorization (**rpc_c_authz_name**) provides a server with the client's principal name. The server call to **rpc_binding_inq_auth_caller()** retrieves the name from the binding handle associated with the client and returns it as a character string.

It is not recommended that names be used for authorization. To perform access checking using client principal names, the names must be stored in the access lists

associated with the protected objects. Each time a name is changed, the change must be propagated through all the access lists in which the name is defined.

14.2.2.2 DCE Authorization

DCE authorization (**rpc_c_authz_dce**) provides a server with the client's credentials.

Credentials offer a trusted mechanism for conveying client authorization data to authenticated servers. The security service generates a client's credentials in a tamper-proof manner. When a server receives a client credentials, it knows that the credentials has been certified by DCE security.

Credentials are designed to be used with the DCE ACL facility. The ACL facility provides an editor and a set of API routines that support the implementation of access control lists and the managers to control them.

14.2.3 Authenticated RPC Routines

Authenticated RPC is implemented as a set of related RPC routines. Some of the routines are for use by clients, some are for use by servers and their managers, and some are for use by both clients and servers. The authenticated RPC routines are as follows:

rpc_binding_set_auth_info()
A client calls this routine to establish an authentication service, protection level, and authorization service for a server binding handle. The client identifies the server by supplying the server's principal name. The RPC runtime, in conjunction with the security service, applies the authentication service and protection level to all subsequent remote procedure calls made using the binding handle.

rpc_binding_inq_auth_info()
A client calls this routine to return the authentication service, protection level, and authorization service that are in effect for a specified server binding handle. This routine also returns the principal name of the server associated with the binding handle.

rpc_mgmt_inq_dflt_protect_level()
A client or a server calls this routine to learn the default protection level that is in force for a given authentication service.

rpc_mgmt_inq_server_princ_name()
A client, a server, or a server manager can call this routine to return the principal name that a server has registered with the RPC runtime via the **rpc_server_register_auth_info()** routine. A client can identify the desired server by supplying a server binding handle and the authentication service associated with the registered principal name.

rpc_server_register_auth_info()
A server calls this routine to register an authentication service that it wants to support and the server principal name to be associated with the registered service. The server can also optionally supply the address of a key retrieval routine to be called by the security service as part of the client authentication process. The routine is a user-supplied function whose purpose is to provide the server's key to the DCE security runtime.

Note that the server registers only an authentication service. It does not establish a protection level or an authorization service. These are the responsibilities of the client.

rpc_binding_inq_auth_caller()
A server calls this routine to return the authentication service, protection level, and authorization service that is associated with the binding handle of an authenticated client. This call also returns the server principal name specified by the client on its call to **rpc_binding_set_auth_info()**.

rpc_mgmt_set_authorization_fn()
A server calls this routine to establish a user-supplied authorization function to validate remote client calls to the server's management routines. For example, the user function can call **rpc_binding_inq_auth_caller()** to return authentication and authorization information about the calling client. The RPC runtime calls the user-supplied function whenever it receives a client request to execute one of the following server management routines:

- **rpc_mgmt_inq_if_ids()**
- **rpc_mgmt_inq_server_princ_name()**
- **rpc_mgmt_inq_stats()**

- **rpc_mgmt_is_server_listening()**
- **rpc_mgmt_stop_server_listening()**

When an unauthenticated client calls a server that has specified authentication, the RPC runtime will not perform any authentication, and *the call will reach the application manager code*. It is up to the manager to decide how to deal with the unauthenticated call.

Typically, servers and clients establish authentication as follows:

- The server specifies an authentication service for a principal identity under which it runs by calling **rpc_server_register_auth_info()**. The authentication service is specified by the *authn_svc* parameter of this call. Currently, servers may specify either DCE secret key authentication (by supplying either **rpc_c_authn_dce_secret** or **rpc_c_authn_default**) or no authentication (by supplying **rpc_c_authn_none**). The specified authentication service will be used *if it is also requested by the client*.
- The client sets authentication for a binding handle by calling **rpc_binding_set_auth_info()**. The choices are also currently either DCE secret key or no authentication. Client calls made on the binding handle attempt to use the specified authentication service.
- The server manager code calls **rpc_binding_inq_auth_caller()** to extract any authorization information from the client binding for the call.

14.2.4 Using RPC Within a Single Thread

The default behavior for an application client is to be single-threaded. This means that only one thread, the main thread, exists in the client process. All application and RPC runtime execution takes place within this single thread. This behavior applies only to clients that use the User Datagram Protocol (UDP). If another protocol sequence is used for RPC transport, the RPC runtime will spawn several threads and revert to multithreaded behavior.

Single-threaded behavior, compared to multithreaded client behavior, provides several benefits to application developers:

- Debugging is easier. Using advanced thread-aware debuggers and following code execution through multiple thread context switches are unnecessary. The same

debugging techniques and tools used to debug standard applications can be used to debug an RPC client.

- Usage of system resources is lower. The DCE Threads runtime is not initialized in single-threaded mode. This means startup time will be faster, less memory will be used, and performance will improve because context switching does not take place.
- Linking libraries that are not thread-safe into DCE applications is less dangerous. Some third-party libraries depend on default behavior from certain operating system functions. However, in a multithreaded process this behavior is defined differently. Examples of this include signal handling, I/O, and **fork**, and **exec** functions. When an application client is single-threaded, the default behavior for these functions is guaranteed, and without risk when using libraries that are not thread-safe.

If any application-level threads are created in the RPC client, the single-threaded process immediately reverts to multithreaded behavior. This means that both the RPC runtime and DCE Threads runtime will be initialized and create several runtime-level threads, and the benefits described for a single-threaded client will no longer apply. Once the client becomes multithreaded, it remains so even if all of the user-level threads have terminated.

Existing applications can take advantage of single-threaded mode without requiring changes to the code. As long as the client is using the UDP protocol sequence and has not performed a **pthread_create** call, single-threaded behavior automatically remains; applications can continue to make pthread API calls and remain in single-threaded mode. If, for example, the application creates mutex variables, and even locks or unlocks these variables, these calls will behave correctly and not cause the process to become multithreaded. However, after the first **pthread_create** call takes place in the client application, it becomes multithreaded and all previously initialized pthreads primitives will function as expected in a multithreaded environment.

To implement single-threaded behavior, the DCE Threads library performs its initialization in two phases:

- Phase 1 occurs when the first pthread API call is made. This initializes mutexes, condition variables, and attributes.
- Phase 2 occurs when the first **pthread_create** call is made. This initializes the remaining DCE Threads functionality, including thread management, context switching, the creation of a null background thread, and all of the multithreaded

operating system behavior as described in the chapter on multithreaded programming.

14.3 Directory Services and RPC: Using the Namespace

This section discusses how the DCE RPC NSI configures directory service entries and how RPC applications can use those entries. The following topics are included:

- Directory service entries defined by NSI

  Describes the kinds of directory service entries NSI defines.

- Searching the namespace

  Describes how the namespace is searched when a client requests binding information.

- Strategies for using directory service entries

  Outlines strategies for using each kind of entry.

- The service model

  Describes the service model for defining RPC servers and introduces NSI usage models intended to guide application developers in assessing how to best use NSI for a given application.

- The resource model

  Describes the resource model for defining RPC servers.

14.3.1 NSI Directory Service Entries

To store information about RPC servers, interfaces, and objects, NSI defines the following directory service entries in the namespace: server entries, groups, and profiles. These directory service entries are CDS objects.

- A server entry is a directory service entry that stores binding information and object UUIDs for an RPC server.
- A group is a directory service entry that corresponds to one or more RPC servers that offer one or more RPC interfaces, type of RPC object, or both in common.

- A profile is a directory service entry that defines search paths in a namespace for a server that offers a particular RPC interface and object.

The use of server entries, groups, and profiles determines how clients view servers. A server describes itself to its clients by exporting binding information associated with interfaces and objects to one or more server entries. A group corresponds to servers that offer a given interface, service, or object. Profiles enable clients to access alternative directory service entries when searching for an interface or object. Used together, groups and profiles offer sophisticated ways for RPC applications to maintain and use directory service data.

14.3.1.1 NSI Attributes

Usually, the distinct server entries, groups, and profiles concepts are adequate for using NSI. However, the way NSI stores RPC information allows you to combine server entries, groups, and profiles into a single directory service entry. To store information about RPC applications in a directory service entry, the RPC directory service interface defines several RPC-specific directory service attributes, or NSI attributes. NSI attributes contain information about RPC applications in a directory service entry. The NSI attributes are as follows:

- NSI binding attribute

  The binding attribute stores binding information and interface identifiers (interface UUID and version numbers) exported to the server entry. This attribute identifies a directory service entry as a server entry.

- NSI object attribute

  The object attribute stores a list of one or more object UUIDs. Whenever a server exports any object UUIDs to a server entry, the server entry contains an object attribute as well as a binding attribute. When a client imports from that entry, the import operation returns an object UUID from the list stored in the object attribute.

- NSI group attribute

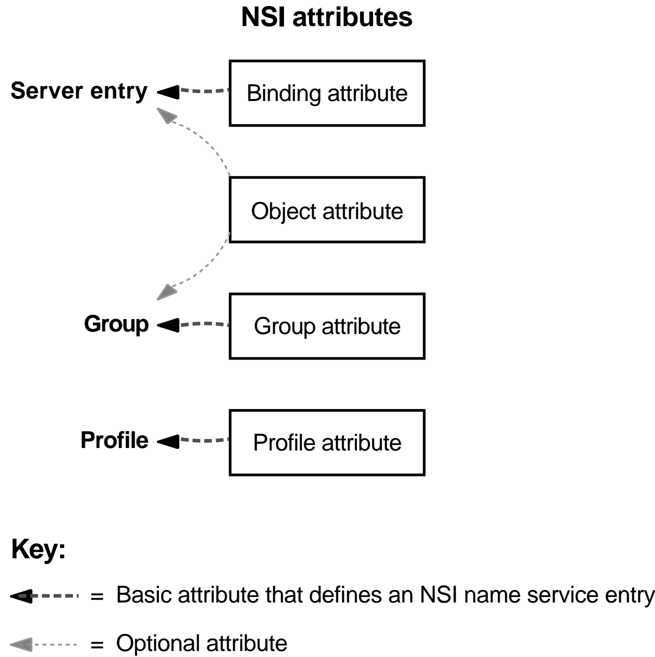
  The group attribute stores the entry names of the members of a single group. This attribute identifies a directory service entry as an RPC group.

- NSI profile attribute

The profile attribute stores a set of profile elements. This attribute identifies a directory service entry as an RPC profile.

Figure 14-7 represents the correspondence between NSI attributes and the different directory service entries: server entries, groups, and profiles.

Figure 14–7. NSI Attributes



Any directory service entry can contain any combination of the four NSI attributes. However, to facilitate administrating directory service entries, avoid creating binding, group, and profile attributes in the same entry. Instead, use distinct directory service entries for server entries, groups, and profiles. The object attribute, in contrast, is designed as an adjunct to another NSI attribute, especially the binding attribute.

When implementing the resource model or when used to distinguish server instances, a server entry contains an object attribute as well as a binding attribute. On finding a server entry whose binding attribute contains compatible binding information, an NSI search operation also looks in the entry for an object attribute. For groups whose

membership is selected according to a shared object or set of objects, it may be useful to export those objects to the group. In this case, the directory service entry of the group contains both group and object attributes. For reading the object UUIDs in the NSI object attribute in any directory service entry, NSI provides a set of object inquiry operations, called using the **rpc_ns_entry_object_inq_**{**begin**,**next**,**done**}**()** routines.

Using separate entries facilitates administration of the namespace; for example, by enabling entry names to specifically describe their contents. Keeping server entries, profiles, and groups separate allows clear references to each of them.

Note: In addition to any NSI attributes, a directory service entry contains other kinds of directory service attributes. Every entry in a namespace contains standard attributes created by the directory service. NSI operations rely on some standard attributes to identify and use an entry.

14.3.1.2 Structure of Entry Names

Each entry in a namespace is identified by a unique global name comprising a cell name and a cell-relative name.

A cell is a group of users, systems, and resources that share common DCE services. A cell configuration includes at least one cell directory server and one security server. A cell's size can range from one system to thousands of systems. A host is assigned to its cell by a DCE configuration file. For information on cells, see the *DCE 1.2.2 Administration Guide*.

The following is an example of a global name:

/.../C=US/O=uw/OU=MadCity/LandS/anthro/Stats_host_2

The parts of a global name are as follows:

- Cell name (using X.500 name syntax):

  /.../C=US/O=uw/OU=MadCity

The symbol **/...** begins a cell name. The letters before the = (equal signs) are abbreviations for Country (**C**), Organization (**O**), and Organization Unit (**OU**). For entries in the local cell, the cell name can be represented by a **/.:** prefix, in place of the actual cell name; for example:

/.:/LandS/anthro/Stats_host_2

The / (slash) to the right of the cell name represents the root of the cell directory (the cell root).

For NSI operations on entries in the local cell, you can omit the cell name.

- Cell-relative name (using DCE name syntax):

  Each directory service entry requires a cell-relative name, which contains a directory pathname and a leaf name.

  — A directory pathname follows the cell name and indicates the hierarchical relationship of the entry to the cell root.

  The directory pathname contains the names of any subdirectories in the path; each subdirectory name begins with a / (slash), as follows: /*sub-dir-a-name*/*sub-dir-b-name*/*sub-dir-c-name*

  Directory pathnames are created by directory service administrators. If an appropriate directory pathname does not exist, ask your directory service administrator to extend an existing pathname or create a new pathname. In a directory pathname, the name of a subdirectory should reflect its relationship to its parent directory (the directory that contains the subdirectory).

  — A leaf name identifies the specific entry.

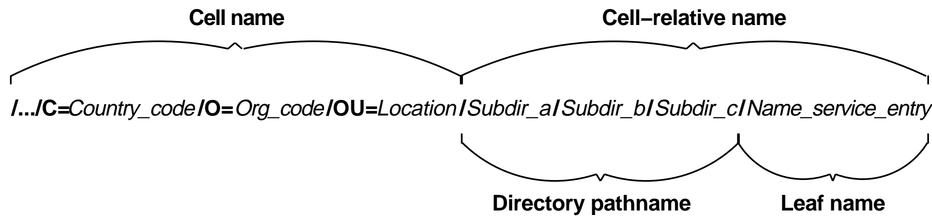
  The leaf name constitutes the right-hand part of a global name, beginning with the rightmost / (slash).

  For example, **/.:/LandS/anthro/Cal_host_4**, where **/.:/** represents the cell name, **/LandS/anthro** is the directory pathname, and **/Cal_host_4** is the leaf name. If the directory service entry is located at the cell root, the leaf name directly follows the cell name; for example, **/.:/cell-profile** .

  Note: When NSI is used with CDS, the cell-relative name is a CDS name.

Figure 14-8 shows the parts of a global name.

Figure 14–8. Parts of a Global Name



14.3.1.3 Server Entries

NSI enables any RPC server with the necessary directory service permissions to create and maintain its own server entries in the namespace. A server can use as many server entries as it needs to advertise combinations of its RPC interfaces and objects.

Each server entry must correspond to a single server (or a group of interchangeable server instances) on a given system. Interchangeable server instances are instances of the same server running on the same system that offer the same RPC objects (if any). Only interchangeable server instances can share a server entry.

Each server entry must contain binding information. Every combination of protocol sequence and network addressing information represents a potential binding. The network addressing information can contain a network address, but lacks an endpoint, making the address partially bound.

A server entry can also contain a list of object UUIDs exported by the server. Each of the object UUIDs corresponds to an object offered by the server. In a given server entry, each interface identifier is associated with every object UUID, but with only the binding information exported with the interface.

Figure 14-9 represents a server entry. This server entry was created by two calls to the **rpc_ns_binding_export()** routine. The first call created the first column of the top half of the figure. The routine's *binding_vec* parameter had three elements, each of which is paired with the routine's *if_handle* parameter. The vertical ellipsis points under the last box indicate that more elements in the routine's *binding_vec* parameter would have resulted in more interface UUID/binding information pairs in the first column.

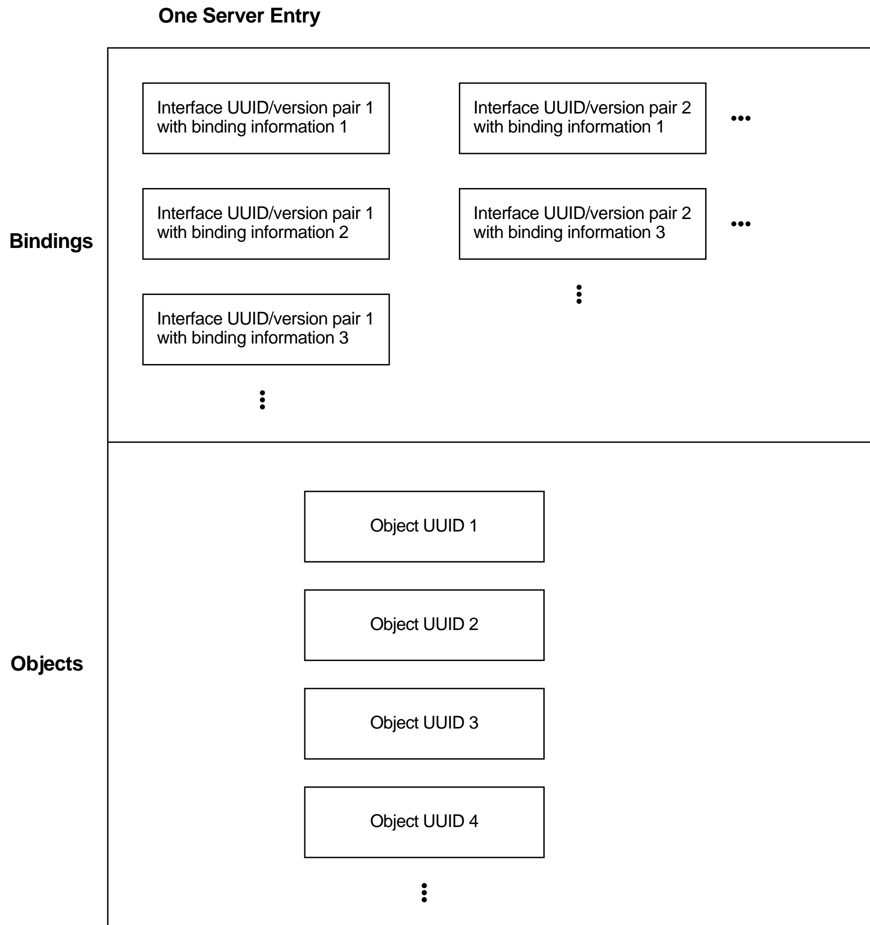
Similarly, the second call to the **rpc_ns_binding_export()** routine created the second column of the top half of the figure. The routine's *binding_vec* parameter had two elements, each of which is paired with the routine's *if_handle* parameter. For example, the first element could have contained binding information with the *ncacn_ip_tcp* protocol sequence, and the second element could have contained binding information with the **ncadg_ip_udp** protocol sequence. As in the first column, more elements in the routine's *binding_vec* parameter would have resulted in more interface UUID/ binding information pairs.

Third and subsequent calls to the **rpc_ns_binding_export()** routine would create more columns; the two pairs of horizontal ellipsis points indicate this expansion.

Finally, note that the **rpc_ns_binding_export()** routine optionally takes a vector of object UUIDs. The four object UUIDs in the bottom half of the figure came from the two calls to the routine, or from another call to the routine with no interface UUID/ version and with no binding information, but with object UUIDs. The object UUIDs are associated with no particular binding. Instead, they are associated with all the bindings. Third and subsequent calls to the routine could create more object UUIDs; the vertical ellipsis points indicate this expansion.

Note: To distinguish among RPC objects when using the CDS ACL editor, export the RPC objects to separate directory service entries.

Figure 14–9. Possible Information in a Server Entry



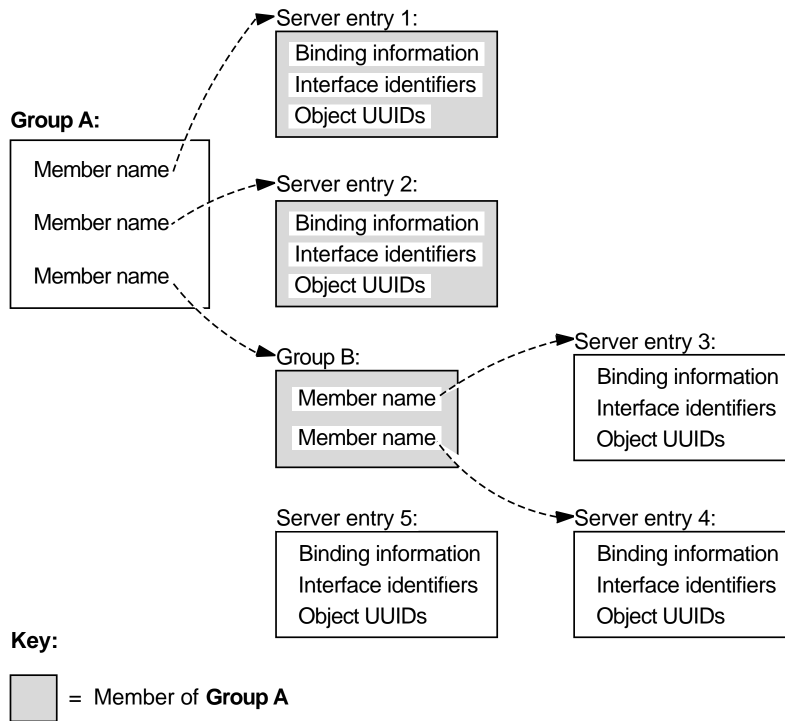
14.3.1.4 Groups

Administrators or users of RPC applications can organize searches of a namespace for binding information by having clients use an RPC group as the starting point for NSI search operations. A group provides NSI search operations (**import_next** or **lookup_next** operations) with access to the server entries of different servers that

offer a common RPC interface or object. A group contains names of one or more server entries, other groups, or both. Since a group can contain group names, groups can be nested. Each server entry or group named in a group is a member of the group. A group's members must offer one or more RPC interfaces, the type of RPC object, or both in common.

Figure 14-10 shows an example of the kinds of members a group can contain and how those members correspond to database entries.

Figure 14–10. Possible Mappings of a Group



The members of Group A are Server Entry 1, Server Entry 2, and Group B. The members of the nested group, Group B, are Server Entry 3 and Server Entry 4. An additional server entry that advertises the common interface or object, Server Entry 5, is omitted from either group.

14.3.1.5 Profiles

Administrators or users of RPC applications can organize searches of a namespace for binding information by having clients use an RPC profile as the starting point for NSI search operations. A profile is an entry in a namespace that contains a collection of profile elements. A profile element is a database record that corresponds to a single RPC interface and that refers to a server entry, group, or profile. Each profile element contains the following information:

- Interface identifier

  This field is the key to the profile. The interface identifier consists of the interface UUID and the interface version numbers.

- Member name

  The entry name of one of the following kinds of directory service entries:

  — A server entry for a server offering the requested RPC interface

  — A group corresponding to the requested RPC interface

  — A profile

- Priority value

  The priority value (0 is the highest priority; 7 is the lowest priority) is designated by the creator of a profile element to help determine the order for using the element NSI search operations to select among like-priority elements at random.

- Annotation string

  The annotation string enables you to identify the purpose of the profile element. The annotation can be any textual information; for example, an interface name associated with the interface identifier or a description of a service or resource associated with a group.

  Unlike the interface identifier field, the annotation string is not a search key.

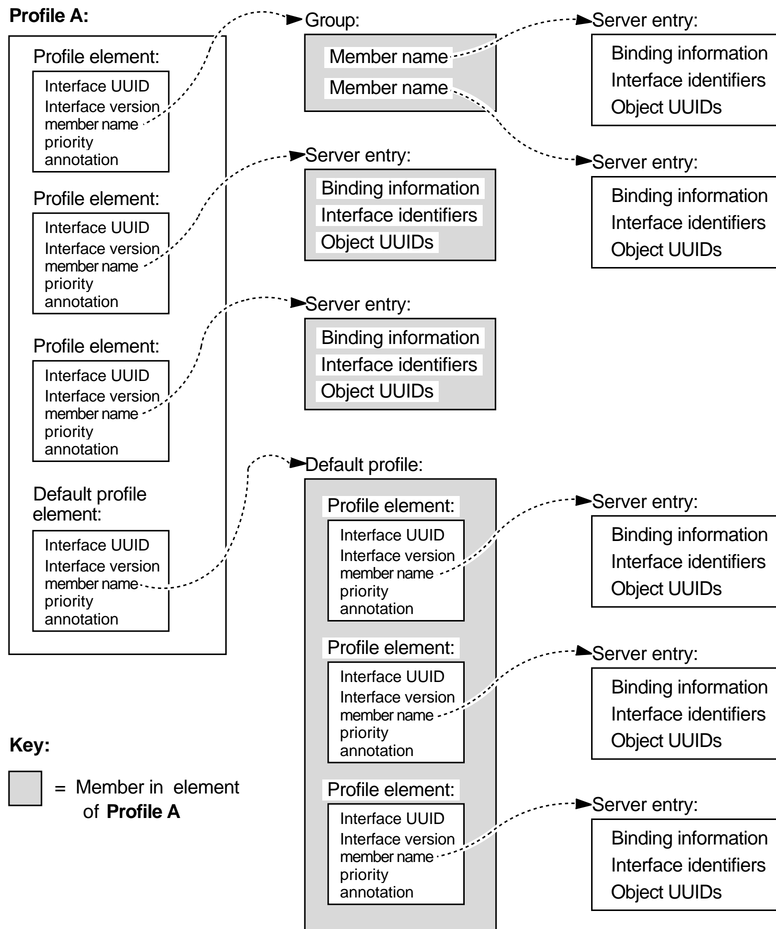
Optionally, a profile can contain one default profile element. A default profile element is the element that an NSI search operation uses when a search using the other elements of a profile finds no compatible binding information; for example, when the current profile lacks any element corresponding to the requested interface. A default profile element contains the nil interface identifier, a priority of 0, the entry name of a default profile, and an optional annotation.

A default profile is a backup profile, referred to by a default profile element in another profile. A profile designated as a default profile should be a comprehensive profile maintained by an administrator for a major set of users, such as the members of an organization or the owners of computer accounts on a local area network (LAN).

A default profile must not create circular dependencies between profiles; for example, when a public profile refers to an application's profile, the application's profile must not specify that public profile as a default profile.

Figure 14-11 shows an example of the kinds of elements a profile can contain and how those elements correspond to database entries.

Figure 14–11. Possible Mappings of a Profile



NSI search operations use a profile to construct an NSI search path. When an NSI search operation reads a profile, the operation dynamically constructs its NSI search path from the set of elements that correspond to a common RPC interface.

A profile element is used only once per NSI search path. The construction of NSI search paths depends partly on the priority rankings of the elements. A search operation uses higher-priority elements before lower-priority elements. Elements of equal priority are used in random order, permitting some variation in the NSI search

paths between searches for a given interface. If nondefault profile elements do not satisfy a search, the search path extends to the default profile element, if any.

Profiles meet the needs of particular individuals, systems, LANs, sites, organizations, and so forth, with minimal configuration management. The administrator of a profile can set up NSI search paths that reflect the preferences of the profile's user or users. The profile administrator can set up profile elements that refer (directly or indirectly) to only a subset of the server entries that offer a given RPC interface. Also, the administrator can assign different search priorities to the elements for an interface.

14.3.1.6 Guidelines for Constructing Names of Directory Service Entries

A global name includes both a cell name and a cell-relative name composed of a directory pathname and a leaf name. The cell name is assigned to a cell root at its creation. When you specify only a cell-relative name to an NSI operation, NSI automatically expands the name into a global name by inserting the local cell name. When returning the name of a directory service entry, a group member, or a member in a profile element, NSI operations return global names.

The directory pathname and leaf name uniquely identify a directory service entry. The leaf name should somehow describe the entry; for example, by identifying its owner or its contents. The remainder of this section contains guidelines for choosing leaf names.

Note: Directory pathnames and leaf names are case sensitive.

Use the following guidelines for constructing names:

- Naming a server entry

  For a server entry that advertises an RPC interface or service offered by a server, the leaf name must distinguish the entry from the equivalent entries of other servers. When a single server instance runs on a host, you can ensure a unique name by combining the name of the service, interface (from the interface definition), or the system name for the server's host system.

  For example, consider two servers, one offering a calendar service on host **JULES**, and one on host **VERNE**.

The server on **JULES** uses the following leaf name:

calendar_JULES

The server on **VERNE** uses the following leaf name:

calendar_VERNE

For servers that perform tasks on or for a specific system, an alternative approach is to create server entries in a system-specific host directory within the namespace. Each host directory takes the name of the host to which it corresponds. Because the directory name identifies the system, the leaf name of the server entry name does not need to include the host name, for example:

/.:/LandS/host_1/Process_control

To construct names for the server entries used by distinctive server instances on a single host, you can construct unique server entry names by combining the following information: the name of the server's service, interface, or object; the system name of the server's host system; and a reusable instance identifier such as an integer.

For example, the following leaf names distinguish two instances of a calendar service on the **JULES** system:

calendar_JULES_01

calendar_JULES_02

Avoid automatically generating entry names for the server entries of server instances; for example, by using unique data such as a timestamp (**calendar_verne_15OCT91_21:25:32**) or a process identifier (**calendar_jules_208004D6**). When a server incorporates such unique data into its server entry names, each server instance creates a separate server entry, causing many server entries. When a server instance stops running, it leaves an

obsolete server entry that is not reused. The creation of a new entry whenever a server instance starts may impair performance.

A server can use multiple server entries to advertise different combinations of interfaces and objects. For example, a server can create a separate server entry for a specific object, and the associated interfaces. The name of such a server entry should correspond to a well-known name for the object. For example, consider a server that offers a horticulture bulletin board known to users as **horticulture_bb**. The server exports the **horticulture_bb** object, binding information, and the associated bulletin-board interface to a server entry whose leaf name identifies the object, as follows:

horticulture_bb

Note: An RPC server that uses RPC authentication can choose identical names for its principal name and its server entry. Use of identical names permits a client that calls the **rpc_binding_set_auth_info()** routine to automatically determine a server's principal name. (The client will assume the principal name to be the same as the server's entry name.) If a server uses different principal and server entry names, users must explicitly supply the principal name. For an explanation of principal names, see Part 5 of this guide.

• Naming a group

The leaf name of a group should indicate the interface, service, or object that determines membership in the group. For example, for a group whose members are selected because they advertise an interface named **Statistics**, the following is an effective leaf name:

Statistics

For a group whose members advertise laser printer print queues as objects, the following is an effective leaf name:

laser-printer

• Naming a profile

The leaf name of a profile should indicate the profile users; for example, for a profile that serves the members of an accounting department, the following is an effective leaf name:

accounting_profile

The following text describes the NSI **begin**, **next**, and **done** operations. NSI accesses a variety of search and inquire operations that read NSI attributes in directory service entries. An NSI attribute is an RPC-defined attribute of a directory service entry used by the DCE RPC directory service interface. An NSI attribute stores one of the following: binding information, object UUIDs, a group, or a profile. Reading information from any attribute involves an equivalent set of search or inquire operations; that is, an integral set of **begin**, **next**, and **done** operations. An RPC application uses these operations as follows:

1. The application creates a directory service handle (a reference to the context of the ensuing series of **next** operations) by calling an NSI **begin** operation.
2. The application calls the NSI **next** operation corresponding to the **begin** operation one or more times. Each **next** operation returns another value or list of values from the target RPC directory service attribute. For example, an **import_next** operation returns binding information from a binding attribute and an object from an object attribute.
3. The application deletes the directory service handle by calling the corresponding NSI **done** operation.

Note: Search and inquire operations are also accessible interactively from within the RPC control program.

Table 14-1 lists the NSI **next** operations used by RPC applications.

Table 14–1. NSI next Operations

Search Operation	**Attributes Traversed**
rpc_ns_binding_import_next()	Searches for binding and object attributes of a compatible server; reads any NSI attribute in a search path. Returns a binding handle that refers to a potential binding for a compatible server, and also to a single object UUID.
rpc_ns_binding_lookup_next()	Searches for binding and object attributes of a compatible server; reads any NSI attribute in a search path. Returns a list of binding handles, each of which refers to a potential binding for a compatible server, and also to a single object UUID. The same object UUID is associated with each potential binding. Note that, after calling the **lookup_next** operation, the client must select one binding handle from the list. To select a binding handle at random, the client can call the NSI binding select routine **rpc_ns_binding_select()**. For an alternative selection algorithm, the client can define and call its own application-specific select algorithm.
Inquire Operation	**Attributes Traversed**
rpc_ns_group_mbr_inq_next()	Reads a group attribute and returns a member name.
rpc_ns_profile_elt_inq_next()	Reads a profile attribute and returns the fields of a profile element.

14.3.1.7 Selecting the Starting Entry

When searching a namespace for an RPC interface and object, a client supplies the name of the directory service entry where the search begins. The entry can be a server entry, group, or profile. Generally, an NSI search starts with a group or profile. The group or profile defines a search path that ends at a server entry containing the requested interface identifier, object UUID, and compatible binding information.

A user may know in advance what server instance to use. In this case, starting with a server entry for the server instance is appropriate.

14.3.1.8 Environment Variables

DCE RPC provides predefined environment variables that a client can use for NSI operations. An environment variable is a variable that stores information, such as a name, about a particular environment. The NSI interface provides two environment variables, **RPC_DEFAULT_ENTRY** and **RPC_DEFAULT_ENTRY_SYNTAX**, which are described in the *DCE 1.2.2 Application Development Reference*. Used together, these environment variables identify an entry name and indicate its syntax.

When a client searches for binding information, the search starts with a specific entry name. Optionally, a client can specify this entry name as the value of the **RPC_DEFAULT_ENTRY** variable. A client can also specify the name syntax of the starting entry as the value of the **RPC_DEFAULT_ENTRY_SYNTAX** variable; the default name syntax is **dce**.

Note: The **dce** name syntax is the only syntax currently supported by CDS. However, NSI is independent of any specific directory service and depending on your vendor, may support one or more alternative directory services that use different name syntaxes.

14.3.2 Searching the Namespace for Binding Information

Searching the namespace for binding information requires that a client specify a starting point for the search. A client can start with a specific server entry. However, this is a limiting approach because the client is restricted to using one server. To

avoid this, a client can start searching with a group or a profile instead of with a server entry. Searches that start with a profile or a group should encounter the server entry of a compatible server. If such an entry is not encountered, a search operation returns the **rpc_s_no_more_bindings** status code to the client. When calling the routines **rpc_ns_binding_import_next()** or **rpc_ns_binding_lookup_next()**, a client must track whether the routine returns this status code.

14.3.2.1 The **import_next** and **lookup_next** Search Algorithm

The NSI search operations (**import_next** and **lookup_next**) traverse one or more entries in the namespace when searching for compatible binding information. In each directory service entry, these operations ignore non-RPC attributes and process the NSI attributes in the following order:

1. Binding attribute (and object attribute, if present)
2. Group attribute
3. Profile attribute

If an NSI search path includes a group attribute, the search path can encompass every entry named as a group member. If a search path includes a profile attribute, the search path can encompass every entry named as the member of a profile element that contains the target interface identifier. A search finishes only when it finds a server entry containing compatible binding information and the nonnil object UUID, if requested. Search operations take the following steps when traversing a directory service entry:

Step 1: Binding attribute

In each entry, the search operation starts by searching for a compatible interface identifier in the binding attribute, if present.

The absence of a binding attribute or of any compatible interface identifier causes the search operation to go directly to step 2.

The presence of any compatible interface identifier indicates that compatible potential bindings may exist in the binding attribute. At this point, object UUIDs may impact the search, as follows:

- If the client specified the nil object UUID, object UUIDs do not affect the success or failure of the search. The search returns compatible binding information for one or more potential bindings.
- If the client specified a nonnil object UUID, the search reads the object attribute, if present, to look for the requested object UUID. This search for an object UUID has one of the following outcomes:
  - — On finding the specified object UUID, the search returns the object UUID along with compatible binding information for one or more potential bindings.
  - — If a requested object UUID is absent, the search continues to step 2.

Note: If a search involves a series of **import_next** or **lookup_next** operations, a subsequent next operation resumes the search at the point in the search path where the preceding operation left off.

Step 2: Group attribute

If the binding attribute does not lead to compatible binding information or if a series of **import_next** or **lookup_next** operations exhausts the compatible binding information, the search continues by reading the group attribute, if present; if the directory service entry lacks a group attribute, the search goes directly to step 3.

The search operation selects a member of the group at random, goes to the entry of that member, and resumes the search at step 1. Unless a group member leads the search to compatible binding information, the search looks at all the members of the group, one by one in random order, until none remain.

Step 3: Profile attribute

If the binding and group attributes do not lead to compatible binding information, the search continues by reading the profile attribute, if present; if the directory service entry lacks a profile attribute, the search fails.

The search operation identifies all the profile elements containing the requested interface identifier and searches them in the order of their priority, beginning with the 0 (zero) priority elements. Profile elements

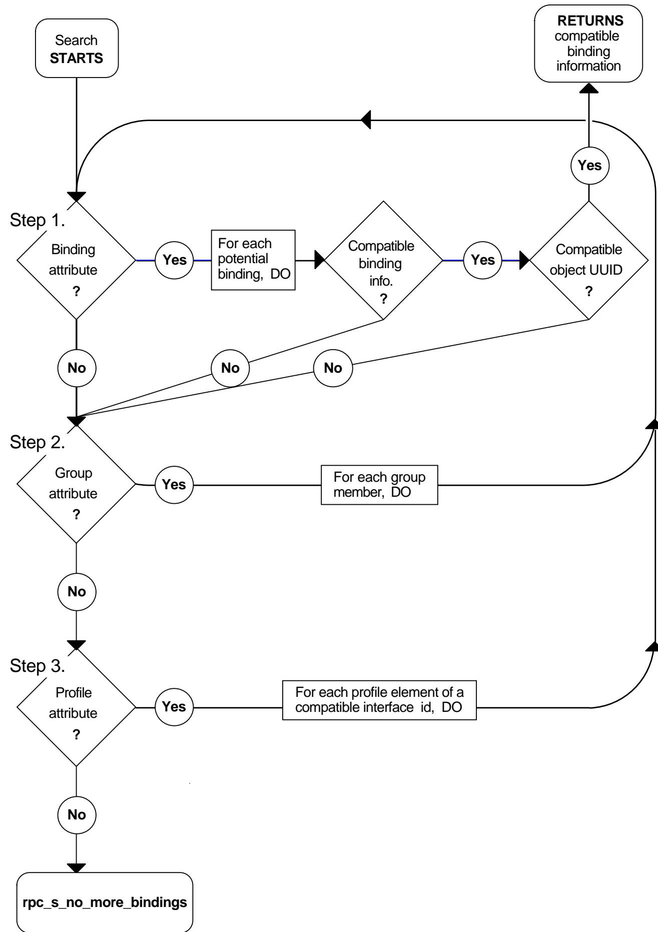
of a given priority are searched in random order. For the selected profile element, the search reads the member name and goes to the corresponding directory service entry. There, the search resumes at step 1. Unless a profile element leads the search to compatible binding information, the search eventually looks at all the profile elements with the requested interface identifier, one by one, until none remain.

If the starting entry does not contain NSI attributes, or if none of the steps satisfies the search, the search operation returns the status code **rpc_s_no_more_bindings** to the client.

Note: The inquire next (**inq_next**) operations for objects, groups, or profiles look at only the entry specified in its corresponding inquire begin (**inq_begin**) operation. The search ignores nested groups or nested profiles.

Figure 14-12 illustrates the three steps of the **import_next** and **lookup_next** search operations.

Figure 14–12. The import_next, lookup_next Search Algorithm in a Single Entry



14.3.2.2 Examples of Searching for Server Entries

This subsection provides several examples of how the NSI **import_next** and **lookup_next** operations search for binding information associated with a given RPC interface and object in a namespace.

The examples in this guide use the following conventions:

- To simplify the following examples, each member name is represented by a leaf name preceded by the symbol that represents the local cell (**/.:**). For example, the full global name of the group for the **Bulletin_board_interface** is as follows:

  /.../C=US/O=uw/OU=MadCity/LandS/bb_grp

  The abridged name is **/.:/LandS/bb_grp**.

- Except for the nil interface UUID of the default profile, the examples avoid string representations of actual UUIDs. Instead, the examples represent a UUID as a value consisting of the name of the interface and the string *if-uuid* or of the name of the object and the string *object-uuid*; for example:

  calendar-if-uuid`,1.0`

  laser-printer-object-uuid

- Profile elements in the examples are organized as follows (annotations are not displayed):

  interface-identifier member-name priority

  For example,

  ```
  2fac8900-31f8-11ca-b331-08002b13d56d,1.0 /.:/LandS/C_host_7  0
  ```

  which, in the following examples, is represented as follows:

  calendar-if-uuid`,1.0    /.:/LandS/C_host_7   0`

Note: The priority is a value of 0 to 7, with 0 having the highest search priority and 7 having the lowest priority.

The first two examples begin with the personal profile of a user, Esther Rose, whose user name is **esther_r** and whose profile has the leaf name of **esther_r_profile**. To use this profile, Esther must specify its entry name to the client. Usually, a client either uses the predefined RPC environment variable **RPC_DEFAULT_ENTRY** or prompts for an entry name. For a client to use **RPC_DEFAULT_ENTRY**, the client or user must have already set the variable to a directory service entry.

The following example illustrates six profile elements from the individual user profile used in the first two examples. The six elements include five nondefault elements for some frequently used interfaces and a default profile element. Each profile element is displayed on three lines, but in an actual profile all the fields occupy a single record. The fields are the interface identifier (interface UUID and version numbers), member name, priority, and annotation.

```
/.:/LandS/anthro/esther_r_profile contents:

ec1eeb60-5943-11c9-a309-08002b102989,1.0
   /.../C=US/O=uw/OU=MadCity/LandS/Cal_host_7
   0  Calendar_interface_V1.0

ec1eeb60-5943-11c9-a309-08002b102989,2.0
   /.../C=US/O=uw/OU=MadCity/LandS/Cal_host_4
   1  Calendar_interface_V2.0

62251ddd-51ed-11ca-852c-08002b1bb4f6,2.0
   /.../C=US/O=uw/OU=MadCity/bb_grp
   0  Bulletin_board_interface_V2.0

62251ddd-51ed-11ca-852c-08002b1bb4f6,2.1
   /.../C=US/O=uw/OU=MadCity/bb_grp
   1  Bulletin_board_interface_V2.1

9e18d295-51ec-11ca-9cc0-08002b1bb4f5,1.0
   /.../C=US/O=uw/OU=MadCity/LandS/anthro/Zork_host_2
   0  Zork_interface_V1.0
```

```
00000000-0000-0000-0000-000000000000,0.0
   /.../C=US/O=uw/OU=MadCity/cell-profile
   0  Default_profile_element
```

14.3.2.2.1 Example 1: Importing for an Interface with Multiple Versions

Target Interface: Calendar V2.0

1. The search for binding information associated with Calendar V2.0 starts with the entry **esther_r_profile**:

```
/.../C=US/O=uw/OU=MadCity/LandS/anthro/esther_r_profile contents:

   calendar-if-uuid,1.0    /.:/LandS/C_host_7    0
   calendar-if-uuid,2.0    /.:/LandS/C_host_4    1

   bulletin_board-if-uuid,2.0    /.:/LandS/bb_grp    2
   bulletin_board-if-uuid,2.1    /.:/LandS/bb_grp    3

   Zork-if-uuid,1.0    /.:/Eng/Zork_host_2    0
   00000000-0000-0000-0000-000000000000,0.0    /.:/cell-profile    0
```

   The search operation examines only the two profile elements that refer to the Calendar interface:

   a. The operation rejects the first profile element for the interface because it refers to the wrong version numbers.

   b. In the next profile element, the operation finds the correct version numbers (**2.0**). The search proceeds to the associated server entry, **/.:/LandS/Cal_host_4**.

2. The search ends with the indicated server entry, where the binding information requested by the client resides:

```
/.:/LandS/Cal_host_4 contents:
    calendar-if-uuid,2.0

    binding-information
```

14.3.2.2.2 Example 2: Using a Default Profile for Importing an Interface

Target Interface: Statistics V1.0

1. The search for binding information associated with Statistics V1.0 starts with the entry **esther_r_profile**. But the profile lacks any elements for the interface. Thus the search reaches the default profile element, which provides the entry name for the default profile, **/.:/cell-profile**:

```
/.:/LandS/anthro/esther_r_profile contents:

    calendar-if-uuid,1.0    /.:/LandS/C_host_7    0
    calendar-if-uuid,2.0    /.:/LandS/C_host_4    1

    bulletin_board-if-uuid,2.0    /.:/LandS/bb_grp    2
    bulletin_board-if-uuid,2.1    /.:/LandS/bb_grp    3

    Zork-if-uuid,1.0    /.:/Eng/Zork_host_2    0
    00000000-0000-0000-0000-000000000000,0.0    /.:/cell-profile    0
```

2. The search continues to the indicated default profile, **/.:/cell-profile**, which contains a profile element for the requested Statistics V1.0 interface:

```
/.:/LandS/cell-profile contents:
  .
  .
  .
  Statistics-if-uuid,1.0    /.:/LandS/Stats_host_6    0
  .
  .
```

.

3. The search ends at the indicated server entry, **/.:/LandS/Stats_host_6**, where a server address for the requested interface resides:

```
/.:/LandS/Stats_host_6 contents:

    Statistics-if-uuid,1.0

    binding-information
```

14.3.2.2.3 Example 3: Importing an Interface and an Object

Target Interface: Print Server V2.1

Target Object: Laser Printer Print Queue

1. The search starts with the entry **/.:/Bldg/Print_queue_grp**, which contains the entry names of several server entries that advertise the **Print_server** interface and the object UUID of a given **Laser_printer** print queue. The search begins by randomly selecting a member name. In this instance, the search selects the name **/.:/Bldg/Print_server_host_3**:

```
/.:/Bldg/Print_queue_grp contents:

    /.:/Bldg/Print_server_host_3
    /.:/Bldg/Print_server_host_7
    /.:/Bldg/Print_server_host_9
```

2. The search continues with the **/.:/Bldg/Print_server_host_3** entry. There, it finds the requested Version 2.1 of the **Print_server** interface. However, the search continues because the entry lacks the object UUID of the requested **Laser_printer** queue:

/.:/Bldg/Print_server_host_3 contents:

print_server-if-uuid,2.1

binding-information

line_printer_queue-object-uuid

3. The search goes back to the previous entry, which was **/.:/Bldg/Print_queue_grp**, to select another entry name; in this instance **/.:/Bldg/Print_server_host_9**:

```
/.:/Bldg/Print_queue_grp contents:

   /.:/Bldg/Print_server_host_3
   /.:/Bldg/Print_server_host_7
   /.:/Bldg/Print_server_host_9
```

4. The search selects the **/.:/Bldg/Print_server_host_9** entry. This entry contains both a server address for the requested Version 2.1 of the interface and the requested object UUID of the **Laser_printer** queue:

/.:/Bldg/Print_server_host_9 contents:

print_server-if-uuid, 2.1

binding-information

laser_printer_queue-object-uuid

The search returns binding information from this entry to the client.

14.3.2.3 Expiration Age of a Local Copy of Directory Service Data

To prevent accessing a namespace unnecessarily, previously requested directory service data is sometimes stored on the system where the request originated. A local copy of

directory service data is not automatically updated at each request. Automatic updating of the local copy occurs only when it exceeds its expiration age. The expiration age is the amount of time that a local copy of directory service data from an NSI attribute can remain unchanged before a request from an RPC application for the attribute requires updating of the local copy. When an RPC application begins running, the RPC runtime randomly specifies a value between 8 and 12 hours as the default expiration age for that instance of the application. Most applications use only this default expiration age, which is global to the application.

An expiration age is used by an NSI next operation, which reads data from directory service attributes. For a given search or inquire operation, you can override the default expiration age by calling the routine **rpc_ns_mgmt_handle_set_exp_age()** after the operation's begin routine. Note that specifying a low default age will result in increased network updates among the name servers in your cell. This will adversely affect the performance of all network traffic. Therefore, use the default whenever possible. If you must override the default age, specify a number that is high enough to avoid frequent updates of local data.

An NSI next operation usually starts by looking for a local copy of the attribute data being requested by an application. In the absence of a local copy, the NSI next operation creates one with fresh attribute data from the namespace. If a local copy already exists, the operation compares its actual age to the expiration age used by the application. If the actual age exceeds the expiration age, the operation automatically tries to update the local copy with fresh attribute data. If updating is impossible, the old local data remains in place and the NSI next operation fails, returning the **rpc_s_name_service_unavailable** status code.

14.3.3 Strategies for Using Directory Service Entries

When developing an RPC application, decide how an application will use the namespace and design your application accordingly. The following subsections discuss issues associated with how servers use different types of directory service entries.

14.3.3.1 Using Server Entries

An application requires separate server entries for servers on different hosts. For example, if a server offering the calendar service runs on two hosts, **JULES** and **VERNE**, one server entry is necessary for the server on **JULES** and another is necessary for the server on **VERNE**.

Each server entry requires a unique cell-relative entry name. If a server adheres to a simple and consistent arrangement of server entries, you may be able to use server initialization code to automatically generate a name for each server entry, and also to ensure that the entry exists. However, some servers will need to obtain the entry name of a server entry from an external source such as a command-line argument or a local database belonging to the application.

Note: Applications that obtain entry names and UUIDs as command-line arguments should accept user-defined values that represent them as an alternative to accepting the actual names.

Some applications, such as a process-control application, require only one server instance per system. Many applications, however, can accommodate multiple server instances on a system. When multiple instances of a server run simultaneously on a single system, all instances on a host can use a single server entry, every instance can use separate server entries, or the instances can be classified into subsets with a separate server entry. A client importing from a shared server entry cannot distinguish among the server instances that export to the entry. Therefore, the recommended strategy for a server on a given system depends on which server instances are viewed by clients as interchangeable entities and which are viewed as unique entities, as follows:

- Interchangeable server instances

  When clients consider all the server instances on a host as equivalent alternatives, all of the instances can (and should) share a server entry. For example, multiple instances of the calendar service running on host **JULES** can all export to the **calendar_JULES** entry.

- Unique server instances

  A unique server instance possesses a significant difference from other instances of the same host. Unique server instances require separate server entries. Each server instance must export unique information to its own server entry; this unique information can be either a server-specific, well-known endpoint or an object UUID belonging exclusively to the one server instance.

Before exporting, each server instance must acquire the entry name of its server entry from an external source. When a unique server instance stops running, its server entry becomes available. An available server entry should be reused for a new instance of that server by providing the existing entry's name for a new server instance to use with the export operation. If any existing server entries are unavailable, a new server instance requires a new server entry name.

For a discussion of when a server instance should remove the binding information from its server entry, see the **rpc_ns_binding_unexport(3rpc)** reference page.

14.3.3.2 Using Groups

When a server is first installed on a system, the server or the installer creates one or more server entries for the server. Also, when installing the first instance of the server within a cell, the installer usually creates one or more groups for the application. For any application, the local system and directory service administrators can create site-specific groups whose members are server entries, groups, or both. Typically, a server adds a server entry to at least one group.

Design decisions for defining groups may reflect a number of possible factors. Typical factors that help define effective groups include the proximity of services or resources to clients, the types of any resources offered by servers, the uses of UUIDs, and the types of users that require a specific server.

For example, for a print server, proximity to the clients and the type of supported file formats are both relevant. These factors may affect print servers as follows:

- Proximity

  If the proximity of a server is important to clients, assign servers to groups according to their locations. For example, print servers that are located together can use their own group (for example, print servers in building 1 use the group **bldg_1_print_servers**). Each server instance can add its own entry to the group, or a system administrator can add server entries by using the RPC control program.

  To select randomly among servers in a given location, a client imports using the name of a group that corresponds to those servers (or of a profile that refers to that group).

Note: If proximity is the key factor in selecting among servers, name each server entry for the server's location; for example, **bldg_1_pole_27_print_server**.

- Object types

  When accessing specific classes of resources is important to clients, you can group server instances based on the type of object they offer.

  For servers that advertise resources in server entries, groups often use subsets for server entries according to the resources they advertise. For example, print servers can be grouped according to supported file formats. In this case, an administrator creates a group entry for each file format; for example, **post_printers**, **sixel_printers** , and **ascii_printers**. Each print server entry is a member of one or more groups.

  Users that specify a group for a file format must find the printer that processes the print command. To help the user find the printer, the client can obtain the name of the server entry that supplied the server binding information by calling **rpc_ns_binding_inq_entry_name()**, and then display the name for the user. If the server entry name indicates the location of the print server (for example, **floor_3_room_45A_print_server**), the user can then find the printer.

An application can set up groups according to different factors for different purposes. For example, the print server application can set up groups of neighboring print servers and a group of print servers for each of the file formats. The same server is a member of at least one group of each kind. Clients require users to specify the name of a directory service entry as a command-line argument of remote print commands. The user specifies the name of the appropriate group.

Note: If a user wants a specific print server and knows the name of its server entry, the user can specify that name to the client instead of a group.

14.3.3.3 Using Profiles

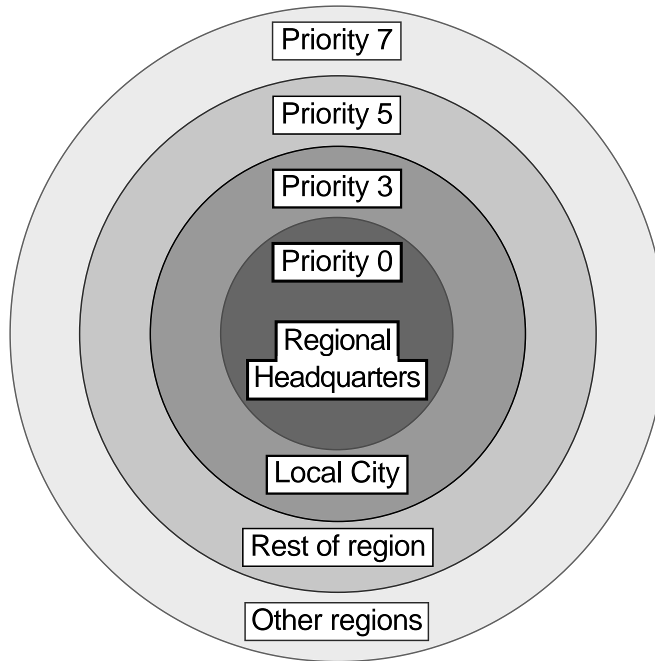
Profiles are tools for managing NSI searches (performed by **import_next** or **lookup_next** operations). Often profiles are set up as public profiles for the users of a particular environment, such as a directory service cell, a system, a specific application, or an organization. For example, the administrator of the local directory service cell should set up a cell profile for all RPC applications that use the cell, and

the administrator of each system in the distributed computing environment should set up a system profile for local servers.

For each application, a directory service administrator or the owner of an application should add profile elements to the public profiles that serve the general user population; for example, a cell profile, a system profile, or a profile of an organization. Each profile element associates a profile member (represented in the member field of an element as the global name of a directory service entry) with an interface identifier, access priority, and optional annotation. A candidate for membership in a cell profile is a group or another profile; for example, a group that refers, directly or indirectly, to the servers of an application installed in the local cell or an application-specific profile.

An application may benefit from an application-specific profile. For example, an administrator at a specific location, such as a company's regional headquarters, can assign priorities to profile elements based on the proximity of servers to the headquarters, as illustrated by Figure 14-13.

Figure 14–13. Priorities Assigned on Proximity of Members



An individual user can have a personalized user profile that contains elements for interfaces the user uses regularly and a default element that specifies a public profile, such as the cell profile, as the default profile. NSI searches use the default profile when a client needs an RPC interface that lacks an element in the user profile.

14.3.4 The Service Model for Defining Servers

The NSI operations accommodate two distinct models for defining servers: the service model and the resource model. These models express different views of how clients use servers and how servers can present themselves in the directory service database. The models are not mutually exclusive, and an application may need to implement both models to meet diverse goals. By evaluating these models before designing an RPC application, you can make informed decisions about whether and how to use object UUIDs, how many server entries to use per server, how to distinguish among instances of a server on a system, whether and how to use groups or profiles or both, and so forth. The two models are the service model and resource model.

The service model views a server exclusively as a distributed service composed of one or more application-defined interfaces that meet a common goal independently of specific resources. The service model is used by applications whose servers offer an identical service and whose clients do not request an RPC resource when importing an interface. Often, with the service model, all the server instances of an application are equivalent and are viewed as interchangeable. However, the service model can accommodate applications that view each server instance as unique. The implications of whether server instances are viewed as interchangeable or unique are significant, so the following subsections address these alternatives separately.

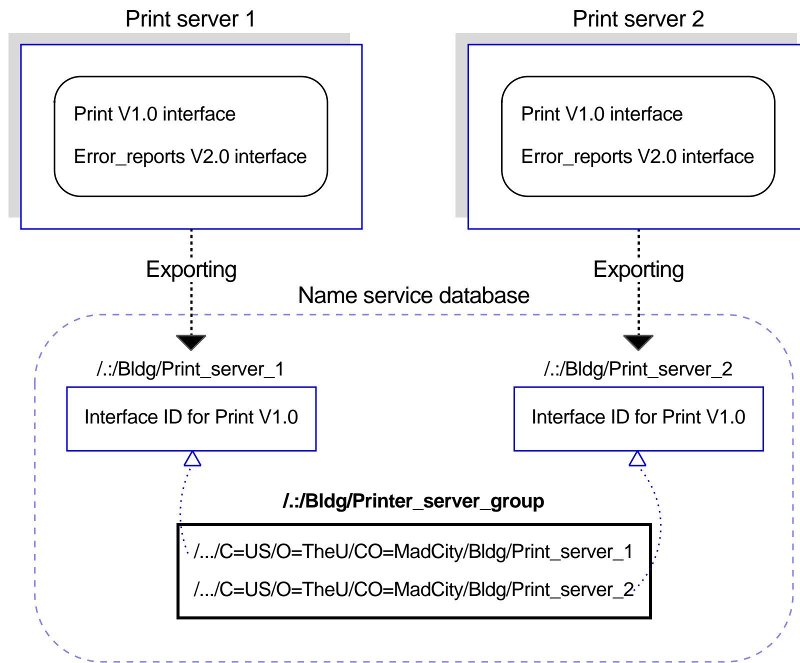
14.3.4.1 Interchangeable Server Instances

With the service model, servers offer an identical service that operates the same way on all host systems. For example, an application that uses the service model is a collection of equivalent print servers that support an identical set of file formats, and that are installed on printers in a single location. The print servers in any location can be segregated from printer servers elsewhere by using a location-specific group.

Figure 14-14 shows interchangeable print servers offering an identical print service on different hosts. To access this service, clients request the Print V1.0 interface and specify the nil object UUID. In this illustration, the starting entry for the NSI search is a group corresponding to local print servers. Note that a client may be able to reach this print server group by starting from a profile or another group.

Note: To simplify the illustrations of the usage models, the contents of server entries are represented without listing any binding information.

Figure 14–14. Service Model: Interchangeable Instances on Two Hosts



Search Requirements

Target interface: Printer V1.0

Target Object: None

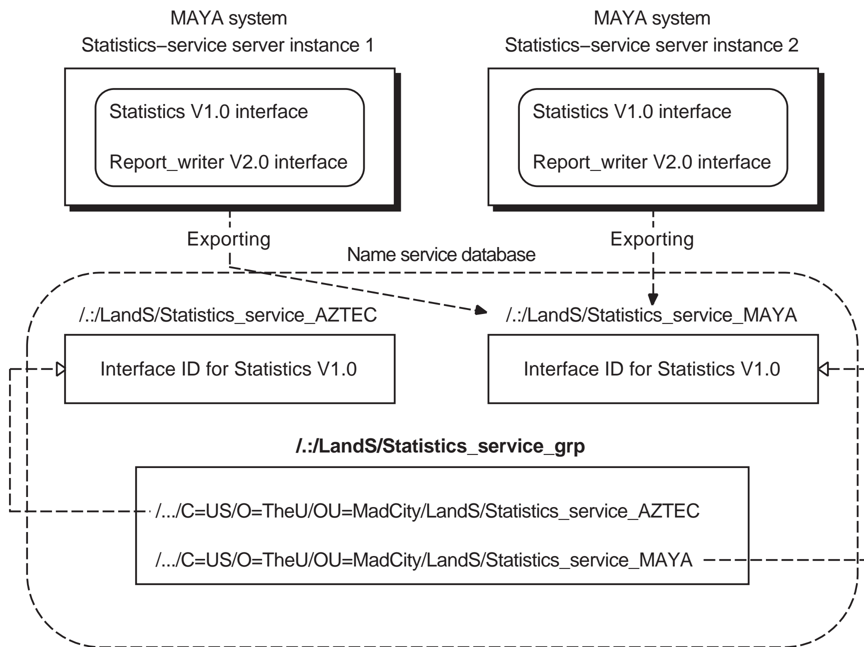
Starting Entry: /.:/Bldg/Print_server_group

Maximum number of traversed entries: 2

Note: The number of entries traversed by a search operation is unrelated to the number of binding handles it returns.

Figure 14-15 shows interchangeable service instances offering an identical statistics service on a single host. To access this service, clients request the Statistics V1.0 interface and specify the nil object UUID. The starting entry for the NSI search is a group corresponding to local servers that offer the service (or a profile that refers to that group).

Figure 14–15. Service Model: Interchangeable Instances on One Host



Search Requirements

Target interface: Statistics V1.0

Target Object: None

Starting Entry: /.:/LandS/Statistics_service_grp

Maximum number of traversed entries: 2

Note that, if an application with interchangeable server instances uses the connectionless RPC protocol, the default behavior of the endpoint map service is to

always return the endpoint from the first map element for that set of server instances. To avoid having all clients using only one of the instances, before making a remote procedure call to the server, each client must inquire for an endpoint. For a random selection, a client calls the **rpc_ep_resolve_binding()** routine. Alternatively, a client can call the **rpc_mgmt_ep_elt_inq_...()** routines to obtain all the map elements for compatible server instances, and then use an application-specific selection algorithm to select one of the returned elements.

14.3.4.2 Distinct Service Instances on a Single Host

With the service model, when multiple server instances on a given host are somehow unique, each instance must export to a separate server entry. The exported binding information must contain one or more instance-specific, well-known endpoints or an instance UUID. Well-known endpoints and instance UUIDs are used under the following circumstances:

- Well-known endpoints

  An instance-specific, well-known endpoint must be provided to a server instance as part of its installation; for example, as a command-line argument. Before calling the export operation, the server instance tells the RPC runtime to use each of its well-known endpoints; it does this by calling **rpc_server_use_protseq_ep()**. The runtime includes these endpoints in the instance's binding information, which the runtime makes available to the instance via a list of server binding handles. The server instance uses this list of binding handles to export its binding information, including the well-known endpoints. The server also uses this list of binding handles to export its well-known endpoint with the local endpoint map; it does this by calling **rpc_ep_register()** or **rpc_ep_register_no_replace()** . Remote calls made using an imported well-known endpoint from a server entry are guaranteed by the RPC runtime to go only to the server instance that exported the endpoint to that entry.

  Note: Only one server instance per system can use a well-known endpoint obtained from a given interface specification.

- Instance UUID

  Create an instance UUID only for a new server entry. Generating a new instance UUID each time a server instance exports to a server entry will result in many instance UUIDs that are difficult to manage and may affect

performance as new instance UUIDs are constantly added to server entries. If a new server instance inherits a currently unused server entry left behind by an earlier instance, before exporting, the new server instance should inquire for an instance UUID in the server entry; this is done by calling the **rpc_ns_entry_object_inq_**{**begin**,**next**,**done**}**()** routines. If the inherited entry contains an instance UUID, the server uses it for an instance UUID, rather than creating and exporting a new instance UUID. If an inherited entry lacks an instance UUID, however, the server must create a UUID and export it to the server entry.

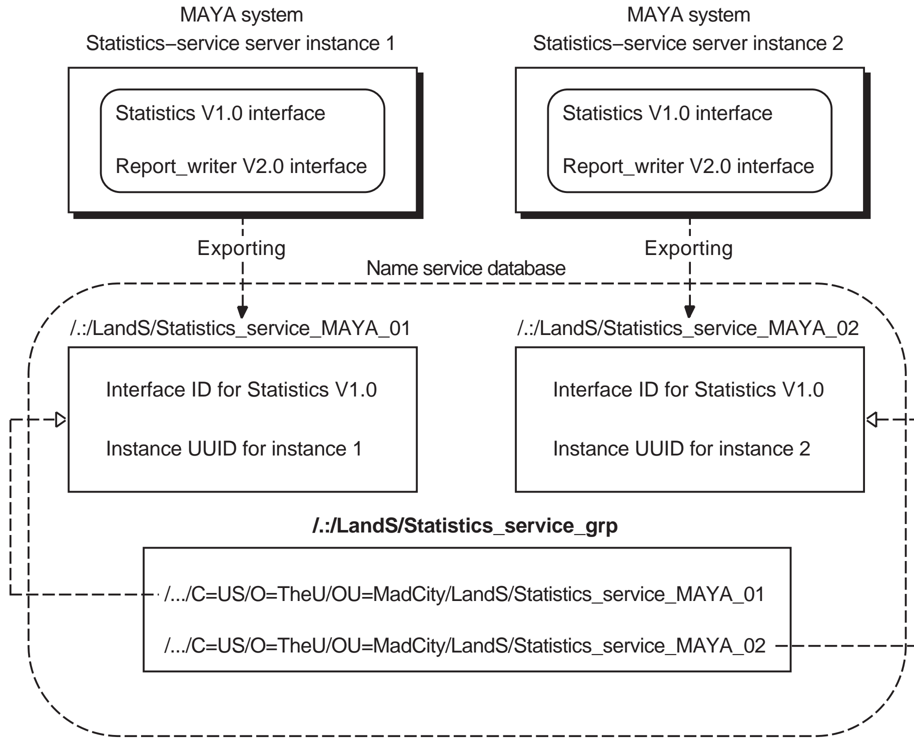
Note that every server instance must register its instance UUID along with its endpoints in the local endpoint map.

Note: Using an instance UUID precludes any other use of object UUIDs for the application.

Figure 14-16 shows distinct instances of a statistics-service server on the same host. Each server instance uses an instance UUID to identify itself to clients. The instance UUID is the only object UUID a server instance exports to its server entry. Starting at the statistics-service group, clients import the statistics interface.

After finding a server entry with compatible binding information for the statistics interface, the import operation returns an instance UUID along with binding information. Every remote procedure call made with that binding information goes to the server instance that exported the instance UUID.

Figure 14–16. Service Model: Distinct Instances on One Host



Search Requirements

Target interface: Statistics V1.0

Target Object: None

Starting Entry: /.:/LandS/Statistics_service_grp

Maximum number of traversed entries: 2

14.3.5 The Resource Model for Defining Servers

The resource model views servers and clients as manipulating resources. A server and its clients use object UUIDs to identify specific resources. With the resource model, any resource an application’s servers and clients manipulate using an object UUID is considered an RPC resource. Typically, an RPC resource is a physical resource such

as a database. However, an RPC resource may be abstract; for example, a print format such as ASCII. Note that an application that uses the resource model for one context may use the service model for another. (See earlier sections for details of the service model.)

Applications use object UUIDs to refer to resources as follows:

1. Servers offer resources by assigning an object UUID to each specific resource.
2. Clients obtain those object UUIDs and use them to learn about a server that offers a given resource.
3. When making a remote procedure call, a client requests a resource by passing its UUID as part of the server binding information.

Each RPC resource or type of resource requires its own object UUID. A calendar server, for example, may require a distinct UUID to identify each calendar.

RPC interfaces can be defined to operate with different types of resources and can be implemented separately for each type; for example, a print server application that supports PostScript, sixel, and ASCII file formats. When using different implementations of an interface (different managers), servers must associate the object UUID of a resource, such as an ASCII file format and its manager, by assigning them a single type UUID. To request the resource, a client specifies its object UUID in the server binding information. When a print server receives the remote procedure call, it looks up the corresponding type UUID and selects the associated manager.

Some RPC resources, such as print queues, belong exclusively to a single server instance. Some can be shared among server instances; for example, a file format or an airline reservation database. For server instances on the same system, sharing a resource means that its object UUID cannot distinguish between the two instances. For a print server, this is unlikely to be a problem, assuming that each printer runs only one instance of the print server. In contrast, an application with a widely accessed database, such as an airline reservation application, may need to ensure that clients can distinguish server instances from each other. An application can distinguish itself by supplying its clients with instance-specific information; for example, a well-known endpoint or an instance UUID.

Note: Multiple server instances that access the same set of resources can introduce concurrency control problems, such as two instances accessing a tape drive at the same time. Also, where the system provides concurrency control, servers

may compete and have to wait for resources such as databases. Dealing with delayed access to shared resources may require an application-specific mechanism, such as queuing access requests.

14.3.5.1 Guidelines for Defining and Using RPC Resources

When developing an RPC application, you need to decide whether to use object UUIDs to identify RPC resources and, if so, what sorts of resources receive UUIDs that servers export to the namespace. When making these decisions, consider the following questions:

- Will users need to select a server entry from the namespace based on what object UUIDs the entry contains (and what the client needs)?

  If yes, then a client must specify an object UUID to the import operation.

- Does the type of resource you are using last for a long time (months or years), so you can advertise object UUIDs efficiently in the namespace?

  The information kept in a namespace should be static or rarely change. For example, print queues are appropriate RPC resources. In contrast, quickly changing information, such as the jobs queued for the printer, owners of the jobs, or the time the job was added to the queue, should not be viewed as RPC resources. Such short-lived data may be viewed as local objects, which are stored and managed at a specific server. Programming with local objects is in the area of regular object-oriented programming and is independent of an application's use of RPC resources.

- Is the number of objects belonging to the type of resource bounded in order to avoid placing high demands on the directory service?

- Will the server implement an interface for different types of a resource, such as different forms of calendar databases or different types of queues?

  If yes, then the server must classify objects into types. For each type, the server generates a nonnil UUID for the type UUID, sets the type UUID for every object of the type, and specifies that type as the manager type when registering the interface. When making a remote procedure call to the interface, a client must supply an object UUID to specify an RPC resource.

- Is control over specific resources an important factor for distinguishing among server instances on a host?

If yes, then each server must generate an object UUID for each of its resources.

For some applications, such as those accessing a database that many people use, shared access to one or more objects may be essential. However, not all objects accommodate such shared access.

14.3.5.2 Using Objects and Groups Together

Servers can associate object UUIDs with a group. Each server exports one or more object UUIDs (without exporting any binding information) to the directory service entry of the group. This involves specifying the NULL interface identifier to the export operation along with the list of object UUIDs. The object UUIDs reside in the directory service entry of the group. If a server stops offering an advertised object, a server must unexport its object UUID from the group entry in order to keep its object list up-to-date.

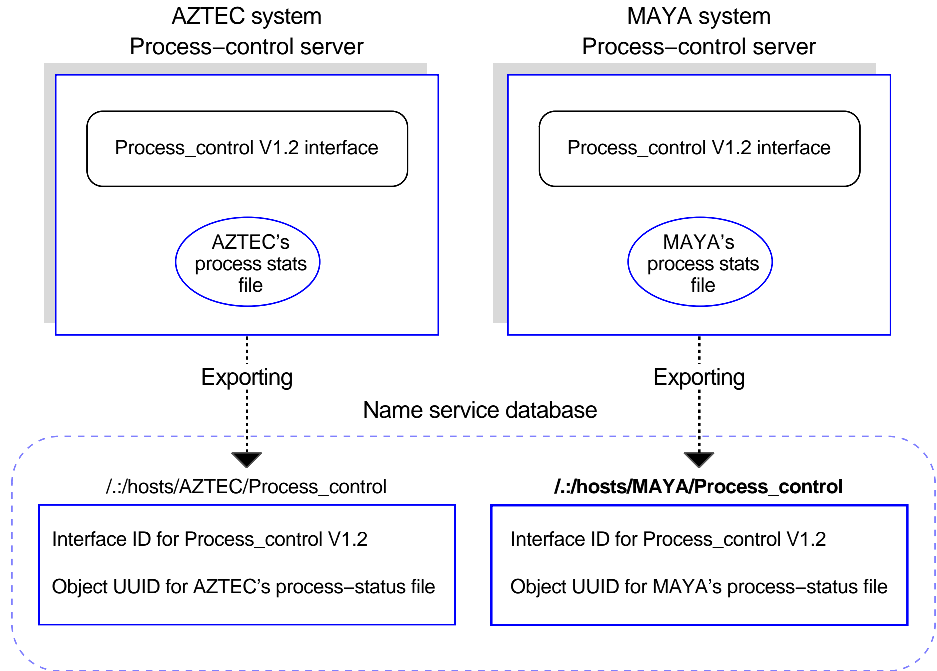
Clients use objects in a group entry as follows:

1. The client inquires for an object UUID from the group entry by calling the **rpc_ns_entry_object_inq_**{**begin** ,**next**,**done**}() routines. This routine selects one object UUID at random and returns it to the client.
2. The client imports binding information for the returned object UUID (and the interface of the called remote procedure), specifying the group for the start of the search.
3. The import operation returns a binding handle that refers to the requested object UUID and binding information for a server that offers the corresponding object.
4. The client issues the remote procedure call by using that binding handle.
5. The server looks up the type of the requested object.
6. The server assigns the remote procedure call to the manager that implements the called remote procedure for that type of object.

14.3.5.3 System-Specific Applications

For some applications, the clients need to import an RPC resource that belongs to a specific system, and the clients can specify a server entry name to learn about a server on that system. For example, a process server that allows clients to monitor and control processes on a remote machine is useful only to that machine. Figure 14-17 illustrates this type of system-specific interpretation of the resource model.

Figure 14–17. Resource Model: A System-Specific Application



Search Requirements

Target interface: Process_control V1.2

Target Object: Process–status file of MAYA system

Starting Entry: /.:/hosts/MAYA/Process_control

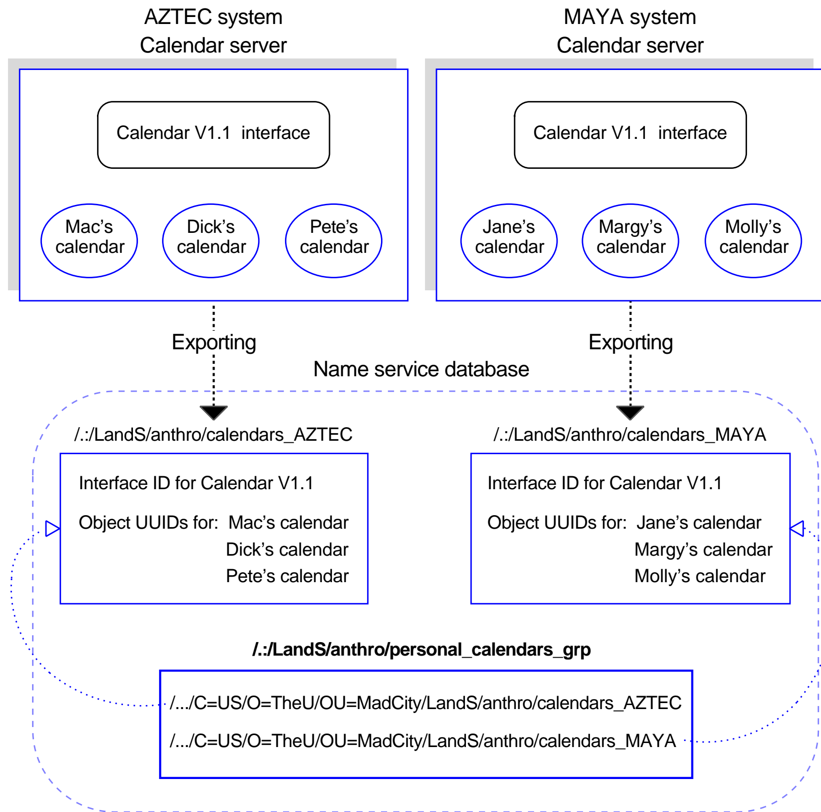
Maximum number of traversed entries: 1

Because clients usually find a system-specific server by specifying its server entry to the import operation, groups are usually not part of the NSI search path for system-specific applications. However, groups are a management tool for such applications. A group containing the names of the server entries of all the current servers can act as an accounting database. Also, a group for the servers on each set of related systems, such as the members of a LAN or an administrative grouping, permits a client to sequentially use the application on every system in the set. An application with system-specific servers should *not* use profiles.

14.3.5.4 Exporting Multiple Object UUIDs to a Single Server Entry

Often a single server offers more than one resource, or it offers several types of resources. In cases where a server instance has a large number of object UUIDs, the application should usually place multiple object UUIDs into a single server entry. Typically, an application places all its object UUIDs into one server entry; however, it may need to segregate them into several server entries according to factors such as object type, location, or who uses the different types of objects. When you are subsetting resources, try to assign each resource to a single set so that its object UUID is exported to only one server entry. Figure 14-18 illustrates a single server entry implementation for each server for the resource model.

Figure 14–18. Resource Model: A Single Server Entry for Each Server



Search Requirements

Target interface: Calendar V1.1

Target Object: A specific personal calendar

Starting Entry: /.:/LandS/anthro/personal_calendars_grp

Maximum number of traversed entries: 3

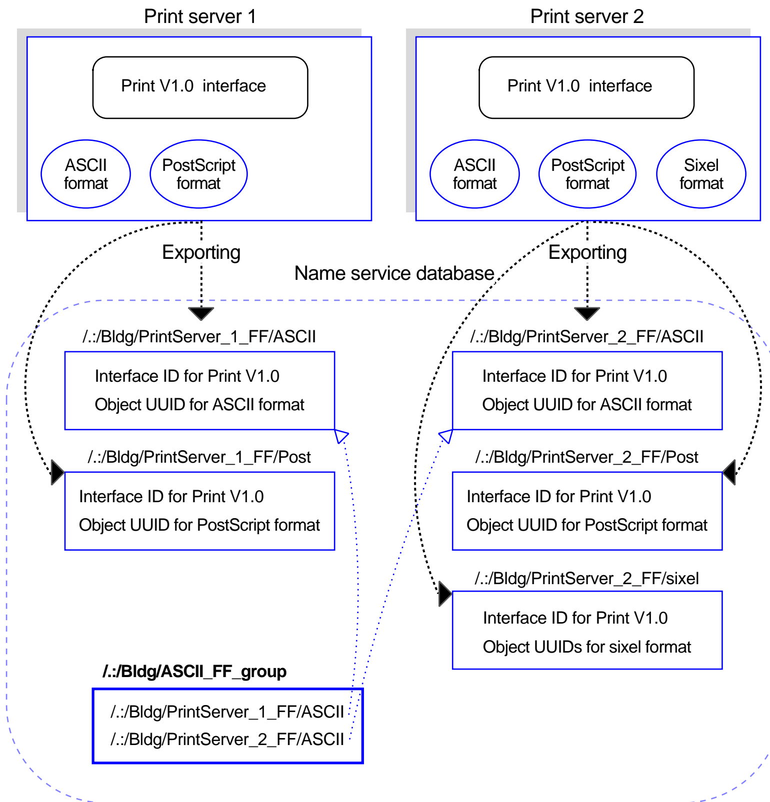
14.3.5.5 Exporting Every Object UUID to a Separate Server Entry

For some applications, exporting each object UUID to a separate server entry is a practical strategy. To avoid excessive demands on directory service resources, however, this strategy requires that the set of objects remain small. Applications with many RPC resources should usually have each server create a single server entry for itself and export the object UUIDs of the resources it offers to that server entry. For example, an application that accesses a different personal calendar for every member of an organization needs to avoid using a separate server entry for each calendar.

For some applications, however, you can use a separate server entry for each object UUID; for example, a print server application that supports a small number of file formats. Each server can create a separate server entry for each supported file format and export its object UUID to that server entry. The server entries for a file format are members of a distinct group.

To import binding information for a server that supports a required file format, a client specifies the nil UUID as the object UUID and the group for that format as the starting entry. The import operation selects a group member at random and goes to the corresponding server entry. Along with binding information, the operation returns the server's object UUID for the requested file format from the server entry. When the client issues a remote procedure call to the server, the imported object UUID correctly identifies the file format the client needs. Figure 14-19 illustrates this use of object UUIDs.

Figure 14–19. Resource Model: A Separate Server Entry for Each Object



Search Requirements

Target interface: Print V1.0

Target Object: ASCII file format (client specifies nil object UUID)

Starting Entry: /.:/Bldg/ASCII_FF_group

Maximum number of traversed entries: 2

Applications that use a separate entry for each object UUID need to use groups cautiously. Keeping groups small when clients are requesting a specific object is essential because an NSI search looks up the group members in random order. Therefore, the members of a group form a localized flat NSI search path rather than the hierarchical path. Flat search paths are inefficient because the average search will look at half the members. Small groups are not a problem. For example, if a group

contains only 4 members, each of whom refers to a server entry that advertises a distinct set of RPC resources, the average number of server entries accessed in each search is 2 entries and the maximum is only 4. The larger the group, however, the more inefficient the resulting search path. For example, for a group containing 12 members, each of whom refers to a server entry that advertises a distinct set of object UUIDs, the average search accesses 6 entries and some searches access all 12 server entries.

Chapter 15

Developing Applications that Use Distributed Objects

Before you read this chapter and begin developing with distributed objects, first read *DCE 1.2.2 Application Development—Introduction and Style Guide*, chapter 8. This chapter describes how to develop object-oriented, DCE applications that have distributed objects. The chapter introduces C++ features of the Interface Definition Language (IDL) that allow direct development of C++ DCE applications. It covers the following topics:

- IDL and the class hierarchy of a DCE application
- Servers that manage distributed objects
- Clients that use distributed objects
- Multiple interfaces and interface inheritance
- Integrating C and C++ clients and servers
- Using objects from class libraries as RPC parameters

15.1 IDL and the Class Hierarchy of a DCE Application

When you develop a DCE application, be it object oriented or otherwise, you begin by creating an interface definition file. This file specifies the operations (with necessary data structures) available for a client to call, all of which a server of this interface must implement.

Although IDL resembles the C programming language, it is intended to be language independent. This means that the applications that are developed could use any programming language that makes sense for them. However, the IDL compiler generates intermediate stub files in either C or C++, two of the most popular languages in use today. We use a particular programming language to take advantage of its features when developing an application. However, an application developed in another language could use mechanisms (such as wrapper routines) that call the routines generated by the IDL compiler.

The **-lang** option of the IDL compiler when used with a **cxx** argument generates C++ intermediate stub files rather than C intermediate stub files. In order to support the generation of C++ stubs, the IDL also needs additional features to give applications developed in C++ a cleaner and more efficient use of the distributed application features of DCE. This section describes how to use these features in interface definitions.

15.1.1 Specifying a C++ Class via an IDL Interface

An IDL interface definition and a C++ class are very similar. An IDL interface definition specifies the data structures and operations that an application needs to use a distributed interface. A C++ class specifies the data structures and functions that an application needs to use a type of object. IDL and the IDL compiler blend together the distributed computing capabilities of an interface definition with the object-oriented features of a C++ class to specify *distributed objects*.

The following example shows an interface definition for a distributed Matrix object:

```
FILE matrix.idl ---------------------------------------------------
[
    uuid(24cb0eda-3eb9-11ce-b1ce-08002bbbf636)
] interface Matrix
{
    /* Create a new 2 by 2 Matrix. This operation requires an ACF */
    /* to tell the stubs this is a creator operation.  */
    Matrix * createMatrix(
 [in] long v11,
 [in] long v12,
 [in] long v21,
 [in] long v22
    );

    /* Create a new Matrix of size rows by columns and return TRUE.*/
    /* If server does not support the size requested, return FALSE  */
    /* and the maximum size in rows and columns that it supports.*/
    /* This operation requires an ACF to tell the stubs this is a    */
    /* static operation.  */
    boolean newMatrix(
 [in, out] long &rows,
 [in, out] long &columns,
 [out] Matrix ** m
    );

    /* The rest of the operations operate on the existing object */
    /* that invokes them (this Matrix).  */

    /* Set a new value in this Matrix. */
    void set(
 [in] long row,
 [in] long col,
 [in] long value
    );

    /* Get a value from this Matrix. */
    long get(
 [in] long row,
 [in] long col
    );
```

```
    /* Return a new Matrix that is the inverse of this Matrix. */
    Matrix * inverse();

    /* Return a new Matrix that is the product of this Matrix */
    /* and m1.*/
    Matrix * multiply(
 [in] Matrix * m1
    );

    /* Return in Matrix m2 the sum of this Matrix and m1. */
    void add(
 [in] Matrix * m1,
 [out] Matrix ** m2
    );

}
```

Interface definitions and C++ classes are both specifications, not implementations. An implementation of the IDL interface definition is a server's manager code, and an instance of the class is an object of that class. The operations of the Matrix interface are described as follows:

createMatrix
: If an interface designer expects clients to create dynamic objects, at least one operation must be a static function that creates a new object. For example, the **createMatrix** operation is intended to be a static member function. Static member functions do not require an existing object before they are called.

newMatrix
: Parameters are typically passed-by-value in C++. Apply the reference operator (**&**) to parameters you want to pass by reference. A reference parameter is required if the function changes the value. In this example, the number of the rows and columns are input but the values change if the function cannot create the Matrix requested.

set
: The **set** operation sets an individual value in an existing Matrix object.

get
: The **get** operation obtains an individual value from an existing Matrix object.

inverse The **inverse** operation returns a new Matrix object that is the inverse of an existing Matrix object.

add The **add** operation does not return a value but has an output parameter that is a new Matrix object. The output is the sum of an existing Matrix object and an input parameter that is a Matrix object.

It is not appropriate to encapsulate data in the definition of a public interface; that would be implementation detail, which does not belong in the interface definition. Therefore, there is no IDL concept of *private* data as there is in C++. However, the base class from which all IDL interface classes are derived does encapsulated binding data and RPC mechanisms.

15.1.2 IDL-Generated Classes as Part of Your Hierarchy

The interface definition is compiled with the following IDL compiler command to generate an intermediate C++ header file, client stub, server stub, and manager class header file:

```
idl -lang cxx matrix.idl
```

The IDL compiler then automatically invokes the local language compiler by default. In this case it invokes the C++ compiler to create binary stub files that are used in the development of clients and servers.

The IDL compiler automatically uses an Attribute Configuration File (ACF) if one is available in its search directories. C++ applications use an ACF to specify features such as static member functions, implementation class names, a lookup function for named or persistent objects, and header files for inclusion in stub files.

Class hierarchies are created by the IDL compiler and made part of the clients and servers. The hierarchies include an RPC base class that encapsulates the distributed nature of objects. An abstract interface class is also created by the IDL compiler and derived from the RPC base class. The interface class includes the data types and nonstatic member functions of the interface definition and is the common interface used by clients and servers. The interface class contains no implementation. Therefore, clients and servers each need to derive implementation classes from the interface class.

Clients have an **idl**-generated implementation class generated for them, called a *proxy class*. Servers have an **idl**-generated class generated for them called a *manager class*.

Server developers must implement the manager class functions by either modifying the generated manager class header file or deriving an application-specific class from the manager class. The manager class name generated by the IDL compiler is a combination of the interface name and **Mgr**. For example, the manager class for our **Matrix** interface is **MatrixMgr**. The generated class is placed in a header file with a name created from the combination the interface file name and the **_mgr** suffix. For example, **matrix_mgr.h**.

If you decide to implement the manager by modify the generated manager class, you want to be sure that any subsequent invocation of the IDL compiler does not overwrite your manager class code. Use the **-no_cxxmgr** option with the IDL compiler command to suppress generating a manager class.

```
idl -lang cxx -no_cxxmgr  matrix.idl
```

15.2 Servers that Manage Distributed Objects

An application creates local objects for its own internal use. Servers must manage these application-specific objects, just as any application does. In addition, distributed object servers must manage two other basic kinds of objects for their clients: *distributed dynamic objects* and *distributed named objects*. The following subsections cover a number of programming tasks and topics of interest to server developers. The basic programming tasks server developers typically perform include the following:

1. Implementing dynamic objects for clients, if needed
2. Implementing static member functions, if any
3. If clients can pass local objects in calls to the server, linking in both server and client stubs so that manager functions automatically access parameters that are client-local objects

Other topics of interest to server developers include naming objects, dynamically creating named or persistent objects with a lookup function, and using the DCE backing store for persistent objects.

15.2.1 Initializing Object-Oriented Servers

DCE servers consist of two major portions of code: *initialization code* and *manager code*. All servers must perform some initialization prior to providing services and objects. In addition to initialization code, the server also has manager code that implements each interface that a server supports. The manager code contains the implementation of both the static and nonstatic member functions (or methods).

In an object-oriented development environment, there would generally be a server class with each server being an instance of that class. Although interesting and important for object-oriented applications, the design and implementation of such an environment is beyond the scope of this chapter. However, there are a few issues to consider when initializing C++ servers, as follows:

- Server Registration

  Servers are automatically registered by server stubs, so if your code calls the **rpc_server_register_if()** routine, you will get a warning indicating the server is already registered.

- Entry point vectors (EPVs) and C++ function tables

  When a C++ application is compiled, a function table is automatically generated for each class. The EPV mechanism in DCE is necessary for languages that do not supply such a feature, such as C. Use NULL (the default EPV) for C++ applications.

- Named and persistent objects

  Your server may need to create persistent or long-lived named objects before the server begins servicing client requests. Naming objects is described later in this chapter.

- Exceptions

  DCE supplies exception handling macros such as **TRY,CATCH**, and **FINALLY** for use in distributed applications. You should use DCE's macros in your applications instead of the standard C++ macros to be sure exceptions are propagated properly from servers to clients.

See the first chapter of the *DCE 1.2.2 Application Development—Introduction and Style Guide* for the typical steps DCE requires to initialize a server. The following subsections describe features needed in manager code, the code responsible for a server's specific implementations of the interfaces supported.

15.2.2 Implementing Distributed-Dynamic Objects

After the server has been initialized and is listening for calls, one obvious question arises: How does the server create distributed objects? The server creates objects locally, just as they are created in typical C++ applications, by allocating variables of the class types or by dynamically creating them with the C++ **new** operator, as shown in the following example:

```
// m1 is allocated as a variable of class Matrix
Matrix m1;
// m2 is a pointer variable of class Matrix allocated with "new"
Matrix *m2 = new MatrixMgr(0, 0, 0, 0);
```

However, clients have no way to use these objects since they are only local and not yet available as distributed objects.

For distributed dynamic objects, the server needs a way to know when a client requests that the server create a dynamic object. This is done by using an ACF to associate an appropriate interface operation with the server's implemented manager class. You must then write manager code that turns server-local objects into distributed dynamic objects.

When you compile the interface definition file to create the interface header file and server stub, you use an ACF to customize how your application code uses the interface, as shown in the following:

```
/* FILE NAME: matrix.acf */
/* This file defines some attributes for the Matrix interface */
interface Matrix
{
 /* include header files generated into the server stub */
 [sstub] include "matrix_mgr";

 /* createMatrix should be mapped as a creator function.       */
 /* The MatrixMgr is a class derived from the interface class. */
 [cxx_new(MatrixMgr)] createMatrix();
 .
```

```
.
.
```

[sstub] include

Use the **include** statement with the **sstub** attribute to make the IDL compiler include specific header files in the server stub. In this example, this is required so that the stub has a declaration of the manager class.

[cxx_new(MatrixMgr)] createMatrix();

Use the **cxx_new** attribute with the name of the implemented manager class (**MatrixMgr**) as an argument, and apply it to the interface operation that is intended to create a dynamic object, **createMatrix.** The manager class can be the **idl**-generated one, as in this example, or it can be one you derived from the generated manager class.

The following C++ code shows examples of constructor and destructor functions you write for the manager class (**MatrixMgr**):

```
 .
 .
 .
// Constructor
MatrixMgr::MatrixMgr(idl_long_int v1, idl_long_int v2,
                     idl_long_int v3, idl_long_int v4)
{
 d[0][0] = v1;
 d[0][1] = v2;
 d[1][0] = v3;
 d[1][1] = v4;
}

// Destructor for a 2x2 Matrix.
// In this application, the destructor does nothing.
MatrixMgr::~MatrixMgr(void)
{
 return;
}
```

MatrixMgr::MatrixMgr

In the trivial case, a constructor automatically initializes the object allocated by the C++ new operator. For this application, the constructor simply fills in the data structure with the values sent in the remote procedure call. In more realistic applications, the C++ constructor may have to perform additional work. C++ allows you to define constructor functions that contain application-specific code that is automatically called immediately after the object is created.

MatrixMgr::~MatrixMgr

In addition to a constructor, C++ allows you to define destructor code that is called to do application-specific cleanup just prior to the release of storage for the object. In this example, the destructor is a dummy function that has no special code and does nothing.

When a client initiates the creation of a dynamic object, the server receives a remote procedure call request for the **createMatrix** function. This causes the server stub to call the C++ constructor for the specified manager class (in this example **MatrixMgr**), which creates a new object on the server. When this happens, the DCE runtime stores information about the object in a table that also associates the object with the requesting client. No other clients have access to a dynamic object unless the originating client gives an object reference to another client. The runtime uses reference counting to keep track of how many clients know about the object. When a client deletes the object, the reference count on the server is reduced. The object on the server is deleted only when the reference count reaches zero, which indicates that there are no more clients with references to the object.

15.2.3 Implementing Static Member Functions

Static member functions are specified in the interface definition or with an ACF. Those operations of an interface that the designer knows should be static have the **static** keyword before the operation in the interface definition file. For example, the **newMatrix** operation of the Matrix interface is designed to work without an invoking Matrix, so it could have been specified in the interface definition as a static member function as follows:

```
interface Matrix
 .
 .
 .
 static boolean newMatrix(...);
```

The IDL compiler automatically compiles this kind of operation as a static member function in both the server and client stubs. Depending on how a developer wants to implement the interface, it may be undesirable to commit to a static function. For example, the **CreateMatrix()** function described in the previous section could have been specified as static in the interface, but it would prevent the server developer from directly using the built-in constructor feature of C++ to implement an object creator function. Therefore, to give maximum flexibility to both client and server developers, the static keyword can be left off the operation and then specified as needed in an ACF file.

Of course, creating new objects is just one thing a static member function can do, and so any number of other static member functions may be specified in the interface to do whatever application-specific work is required.

The Matrix interface declares the following operations:

```
   Matrix * createMatrix(
 [in] long  v11,
 [in] long  v12,
 [in] long  v21,
 [in] long  v22
    );

    boolean newMatrix(
 [in, out] long   &rows,
 [in, out] long   &columns,
 [out]     Matrix ** m
    );
```

The IDL compiler requires an ACF to implement these as static member functions. A sample server ACF contains the following:

```
/* FILE NAME: matrix.acf */
/* This file defines some attributes for the Matrix interface */

interface Matrix
{
 /* include header files generated into the server stub */
 [sstub] include "matrix_mgr";

 /* createMatrix should be mapped as a creator function.       */
 /* The MatrixMgr is a class derived from the interface class. */
 [cxx_new(MatrixMgr)] createMatrix();

     /* newMatrix should be mapped as a static member function. */
 [cxx_static] newMatrix();
}
```

[sstub] include

Use the **include** statement with the **sstub** attribute to make the IDL compiler include specific header files in the server stub. In this example, this is required so that the stub has a declaration of the manager class.

[cxx_new(MatrixMgr)] createMatrix();

Use the **cxx_new** attribute with the name of the implemented manager class (**MatrixMgr**) as an argument, and apply it to the interface operation that is intended to create a dynamic object, **createMatrix**. This feature is described in the previous section.

[cxx_static] newMatrix;

Apply the **cxx_static** attribute to the names of all interface operations you intend to implement as static member functions.

To complete the story of a static function, the following is an example of one trivial implementation of the **newMatrix** function. The code implements only a 2 by 2 Matrix. If a client inputs values other than **2** for **rows** or **columns**, the values are changed to **2**, and **FALSE** is returned.

```
// Implementation of the static member function declared with an ACF
idl_boolean
Matrix::newMatrix(idl_long_int &rows, idl_long_int &columns, Matrix **m)
{
```

```
 if(rows != 2 && columns != 2) //implementing only a 2 by 2 Matrix
 {
     rows = columns = 2;
     *m = 0;
     return FALSE;
 }
 else
 {
     *m = new MatrixMgr(0, 0, 0, 0);
     return TRUE;
 }
}
```

The **cxx_static** attribute can also take an argument that represents a new name to use for the function. This may be necessary in your application if it needs to distinguish between remote and local versions of a static member function. In any case, to minimize changes to your code modules, it is a good idea to keep the implementation of static functions in files separate from the nonstatic member functions (the rest of the manager code). The following section describes a common example of when to use an argument for the **cxx_static** attribute.

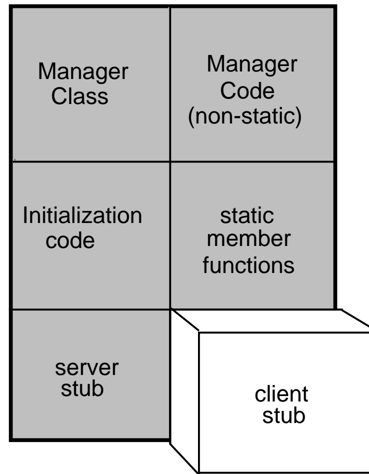
15.2.4 When Function Parameters Are Remote Objects

With distributed applications, especially with distributed objects, the distinction between a client and server is not determined so much by a program on a specific machine as it is by a state the program is currently in. Thus a program can be both a client and a server, depending on its purposes. For example, it is possible that, when a client object uses a function that has another object as an input parameter (our **add()** function, for example), the input could easily be an object that is local to the client. When the server is executing the **add()** function, it needs a way to transparently access the input object that is now remote to the server (but local to the client).

A server accesses client objects by linking in the client stub in addition to the server stub. When an object is remote to the server, information in the binding from a client is used automatically by the server stub during unmarshalling to create an object reference (a proxy) and make remote calls back to the client to access the object there. Server code itself does not have to do any special calls.

The following figure illustrates a brief review of all the code modules a typical server needs. The server stub for each interface and initialization code are required to access DCE's distributed environment. Each interface requires a manager class, manager code, and static member functions to implement them. Each interface with input object parameters should include the client stub in order for the server stub to access client-local objects.

Figure 15–1. Servers Need the Client Stub to Access Client-Local Objects



Making this work includes one other step besides linking in a client stub. If there are any static member functions in the interface class, linking together a client and server stub will produce a C++ compiler error due to a name conflict in the server and client stub versions of the function. You use the **cxx_static** attribute in an ACF to rename the server's local version of the static functions. An example of such an ACF is as follows:

```
/* FILE NAME: matrix.acf */

interface Matrix
{
 /* include files generated into the server stub */
 [sstub] include "matrix_mgr", "staticfunc";
```

```
 /* createMatrix should be mapped as a creator function.  The  */
 /* argument represents the class that implements the interface.*/
 [cxx_new(MatrixMgr)] createMatrix();

 /* newMatrix should be mapped as a static member function. */
 [cxx_static(LocalMatrix)] newMatrix();
}
```

The **LocalMatrix** argument to the **cxx_static** attribute is the name for this server's local implementation of the function, and the **newMatrix** name refers to the remote (in this case, the client stub) function.

The **include** statement is needed with the **sstub** attribute to include header files that contain declarations needed by the server stub only. In this example, the **matrix_mgr.h** file contains the server's manager class declaration, and the **staticfunc.h** file contains the declaration of the renamed static function, **LocalMatrix**. The **staticfunc.h** header file is as follows:

```
// FILE NAME: staticfunc.h
// This file declares the function(s) to call
// when invoking local versions of an interface's static functions.
// The prototype signatures should match that of the remote versions.

idl_boolean LocalMatrix(idl_long_int, idl_long_int, Matrix **m);
```

Note: Servers will work without including the client stub and renaming the local version of the static functions. However, if a client ever uses a member function with an object parameter that is remote to the server, a runtime error occurs. If this happens, the server raises an exception (**rpc_x_no_client_stub**) to propagate back to the client that indicates the client stub is not included in the server.

15.2.5 Naming Objects

This section explains how to do the following for named objects:

- Register named objects

  The built-in **register_named_object()** function uses the name service and endpoint map to name and advertise an object.

- Place object names in name service directly

  The name service can be used to advertise objects for which an instance has not yet been created.

- Dynamically create instances of named or persistent objects

  The server's runtime can automatically call a lookup function to create objects it supports but does not yet have an instance created.

15.2.5.1 Registering Named Objects

DCE RPC supplies every interface class with a member function, **register_named_object()**, to do all that is required to register named objects. The following example shows how a server might create an object and then register it as a named object. The server first creates an object by using the **new** operator. Then the server calls the **register_named_object** function to register the object's name, universal unique identifier (UUID), and its server binding information with the name service. The function also registers the object's UUID and binding information with the host's endpoint map, and it updates the runtime's object table.

```
 .
 .
 .
 // Create an object on the server.
Matrix *  matrix = new MatrixMgr(1, 1, 1, 1);
 matrix->register_named_object((unsigned_char_t *) \
          "/.:/MatrixObject");
 .
 .
 .
```

The **register_named_object()** function greatly simplifies your work, but you need to be aware of the information it uses and generates. The following lists the approximate order of events that occur when an object invokes this function:

1. A name service entry is created if one is not already there, using the name in the first argument of the function.

2. If the named object does not already have a UUID associated with it in the name service, one is created.

3. The server's binding information is associated with the name service entry.

4. All interfaces supported by the object are also registered with the name service.

5. The object UUID is associated with the server's location on the host by registering endpoints in the host's endpoint map.

   The function has an optional second argument of type **boolean**. The default value is **TRUE**, which means this is the*only* server on this host that services this interface. (In C++, using no argument is the same as using the default value for the argument.) If the default value is used, values in the endpoint map are updated.

   If the second argument to the function is **FALSE**, this is not the only server this host has that services this interface. In this case, the **register_named_object()** function adds server binding information to the endpoint map (rather than updating the endpoint map) so clients can find any of the servers. See the **rpc_ep_register_no_replace(3rpc)** reference page for more on this topic.

6. Finally, an object table maintained by the server's RPC runtime is updated so that requests for specific objects are directed to the correct member function invocation. Even though creating the object in the first place registers it with the runtime's object table, some information (such as the object's UUID) may need to be updated.

15.2.5.2 Placing an Object's Name Directly in the Name Service

Consider the following situations:

- Suppose you want a server to just advertise the named objects it supports and not use resources to create them until they are needed. As described in the previous section, an object must be created before it can register itself with the **register_named_object()** function.

- Suppose you want to use a known UUID to represent a named object. If the name does not already exist in the name service, a new UUID is generated via the **register_named_object()** call on the fly. This may be fine for many applications, but, for some, manipulating objects only by their name service names may be cumbersome and inflexible.

If you wish to place a named object in the name service and at the same time use a consistent, stable, and well-known UUID for a named object, you first associate the UUID with the named object in the name service *prior to* using the **register_named_object()** function. There are typically two ways to place object names in the name service:

- Prior to server startup, you can create or update a named object entry by using **dcecp** with the **rpcentry** object and its export operation.
- Your server can create or update a named object entry by using **rpc_ns_binding_export()** during server initialization.

The following example shows a script of **dcecp** commands and arguments to execute on the server's host to export an object's name and then show the data exported to the entry:

```
dcecp -c rpcentry export /.:/objects/IdentityMatrix
 -interface {24cb0eba-3eb9-11ce-b1ce-08002bbbf636   0.0} \
 -binding   {ncacn_ip_tcp `hostname`} \
 -binding   {ncadg_ip_udp `hostname`} \
 -object    {dcea4900-65ba-11cd-bb34-08002b3d8412}
dcecp -c rpcentry show /.:/objects/IdentityMatrix
```

Attributes and arguments are as follows:

/.:/objects/IdentityMatrix
: The object name.

-interface ...
: The interface's UUID and version numbers from the interface definition header.

-binding *ncacn_ip_tcp* ` **hostname** ` \
: Binding information including a protocol sequence and the host's name (generated with the **hostname** command).

-object ...
: The object UUID desired.

Whether you call **dcecp**'s **rpcentry export** operation or the **rpc_ns_binding_export()** routine, the first call automatically creates the entry in the name service and each additional call adds binding information to the entry.

15.2.5.3 Dynamically Creating Named or Persistent Objects

If there are potentially thousands of persistent objects, you may want your application to conserve resources and not register all of them at server startup. Servers may defer creating objects until a client makes a request to use one.

The server's runtime maintains a table of all its objects. The server gets a request from a client on an object that is uniquely identified by an object UUID (from the binding handle), and the object table maps object UUIDs to each object's address in the server's address space. The server's object table is a C++ class containing the following information:

- Object UUIDs
- Interface UUIDs
- Object addresses

If the runtime cannot find the UUID of the object requested, an exception is raised on the server to propagate to the client unless a user-defined *object lookup function* exists. If the lookup function does exist, the runtime automatically executes it. The lookup function is created by the server developer to create the object and, if required, register it as a named object. If the lookup function cannot create an object for the specified UUID, it should return a 0, which causes the runtime to raise an exception (**rpc_x_object_not_found**).

After the named object is registered, the object table contains the new object UUID, so subsequent attempts to use the object do not invoke the lookup function again. Alternatively, the lookup function can maintain its own object map. By not registering with the runtime, subsequent operations will invoke the lookup function. This allows the developer to use the lookup function to maintain complete control over the existence of the object.

A lookup function name is specified using an ACF when the interface is compiled. The following example is a portion of an ACF that specifies a lookup function:

```
[
 cxx_lookup(object_lookup)
]
interface Matrix
{
 [sstub] include "matrix_mgr", "lookup";
 .
 .
 .
```

cxx_lookup(object_lookup)
To specify a lookup function use the **cxx_lookup** attribute with the name of the lookup function (in this case, **object_lookup**) as an argument. A lookup function is interface-wide, so it is defined in the ACF header.

[sstub] include
Use the include statement with the **sstub** attribute to make the IDL compiler include implementation-specific header files in the server stub. The **matrix_mgr.h** header file contains the manager class and the **lookup.h** file contains a declaration of the lookup function you create.

The following example shows the declaration of the **object_lookup** function in the **lookup.h** header file:

```
//FILE NAME: lookup.h
//This file declares the lookup function used
// for server management of object lookup.

Matrix *object_lookup(uuid_t *);
```

A lookup function has the following signature requirements:

- The lookup function returns a pointer to the interface class (**Matrix ***).
- The function name matches the one declared in the ACF (**object_lookup**).
- There is one input parameter pointer of type **uuid_t**.

An implementation of the **object_lookup()** function is shown in the following section.

15.2.5.4 Storing and Retrieving Persistent Objects

DCE provides a convenient database storage facility called the backing store, that lets you store and retrieve objects in a system-independent manner. The following implementation of a lookup function shows how to use a backing store database to lookup an object.

```
// FILE NAME: lookup.cxx
// This file contains the server lookup callout function
// specified by the [cxx_lookup] attribute in an ACF. It is called
// whenever an object cannot be found within the DCE runtime.

extern "C" {
#include <dce/dce.h>  // standard DCE header file
#include <dce/dbif.h> // backing store facility header file
}
#include "matrix_mgr.h"
#include <check_status.h>
#include "backing.h" // IDL generated header file
//
// This function performs the server management of object lookups.
// If the uuid_t parameter identifies one of the persistent objects,
// this function creates and returns the object.
//



Matrix *
object_lookup(uuid_t *key)
{
   dce_db_handle_t db_h;
   backing_data_s_t data;
   int    found;
   unsigned32  status;
   Matrix  *matrix;

   //
   // Lookup the UUID's in a backing store database
   // and get the data.
```

```
   //
   dce_db_open(
    "backing.store",
        0,
        db_c_index_by_uuid | db_c_readonly,
        (dce_db_convert_func_t) backing_data_convert,
        &db_h,
        &status
        );

   dce_db_fetch_by_uuid(
        db_h,
        key,
        (void *) &data,
        &status
        );
   if (status != rpc_s_ok)
        found = 0;
   else
        found = 1;

   dce_db_close(&db_h, &status);

   if (!found)
        return 0;

   // Found the object's data so create an instance of it.
  matrix = new MatrixMgr(data.v00, data.v01, data.v10, data.v11);

   // register the object so clients can find it directly
   // and the server won't have to look it up again.
   matrix->register_named_object((unsigned_char_t *) data.name);

   return matrix;
}
```

The example is described as follows:

dce_db_open()

Applications that have persistent objects commonly store in a database the information necessary to regenerate the object. In this example, the data is stored in a backing store data file (**backing.store**). The argument **db_c_index_by_uuid | db_c_readonly** indicates the file is opened for read-only access and to be indexed by UUID. The argument **backing_data_convert** is the function (defined in the backing interface) that the backing store facility uses to store or retrieve the data. A record for this database is also defined in the backing interface to contain the entry name and values for a two-by-two matrix. The backing interface is in the file **backing.idl**, and looks as follows:

```
[
uuid(3e9400dc-0895-11cf-abec-08002b39f4b8)
] interface backing
{
        import "dce/database.idl";

        /* Data: object name (for CDS) and values       */
        /* for 2-by-2 matrix                             */
        typedef struct backing_data_s_t {
                [string] char name[100];
                int v00;
                int v01;
                int v10;
                int v11;
        } backing_data_s_t;

        /* conversion function declaration */
        void backing_data_convert(
                [in] handle_t                        h,
                [in,out] backing_data_s_t        *data,
                [in,out] error_status_t                *st
        );
}
```

dce_db_fetch_by_uuid()

This DCE routine obtains the data for the object represented by the key UUID.

matrix = new MatrixMgr(data.v00, data.v01, data.v10, data.v11);
An instance of the persistent object is created for this server. Note that each server of the object would have its own implementation and instance of the object.

register_named_object((unsigned_char_t *) data.name);
This function registers the object's name, UUID, and its server binding information with the cell's name service. It also registers the object's UUID and binding information with the host's endpoint map. Finally, this routine updates the runtime object table. As an option for more specific control, you can choose not to call this function and implement your own object table instead.

return(0); If the object was not found, return a 0 value. This will cause the server to raise an exception (**rpc_x_object_not_found**).

The **backing.idl** file is compiled with the following ACF:

```
interface backing
{
        [encode,decode] backing_data_convert(
                [comm_status] st
        );
}
```

The application must also declare the database conversion function as shown in the following **backing.cxx** file:

```
#include "backing.h"

extern "C" {

void
backing_data_convert(
        idl_es_handle_t                h,
        backing_data_s_t        *data
) {
}
```

```
}
```

For more on how to use the backing store facility, see the chapter, *The DCE Backing Store*.

15.3 Clients That Use Distributed Objects

This section describes how to write object-oriented DCE clients. The subsections describe how to do the following:

- Create remote, dynamic objects
- Create both local and remote instances of the same class
- Call functions that intermix the use of local and remote objects
- Bind to named objects by using names stored in the name service
- Bind to named objects by using their UUID identifiers. This method uses your local name service hierarchy to begin the namespace search.
- Bypass the name service to bind to objects by using binding information

15.3.1 Creating Remote-Dynamic Objects

In C++ we create new objects dynamically by calling the **new** operator for the class. This works to creates local objects, but how do clients create remote dynamic objects? In order for a client to create dynamic objects, at least one static object creator operation must be defined in an interface to create its objects. Remember that a static member function does not have to be invoked by an existing object, and thus it is appropriate as a way to create new objects. The operation can be declared to return a new object as a return value or an output parameter. Object creator functions are declared as static in either of two ways:

- In the IDL file explicitly by using the **static** keyword
- In an ACF by using the **cxx_static** (or **cxx_new**) attribute

The following example is an ACF that specifies object creator member functions for the Matrix interface:

```
/* FILE NAME: matrix.acf              */
/* This file defines some attributes for a simple client   */
/* of the Matrix interface. */

interface Matrix
{
        /* createMatrix needs to be mapped as a creator function    */
        [cxx_static] createMatrix();

        /* newMatrix needs to be mapped as a static member function */
        [cxx_static] newMatrix();
}
```

When the interface is compiled with this ACF, the IDL compiler generates a proxy class for the client in which these operations are declared as static member functions. The proxy class is our client's interface to DCE, and it is DCE's mechanisms that let clients interact with objects in the distributed environment.

In some ACFs, static object creator functions may be specified with the **cxx_new** attribute instead of **cxx_static**, and both the attributes may include an argument. These differences do not affect the client stub and are significant only for server stubs.

The following example shows how a client calls the Matrix interface's static member functions:

```
#include "matrix.h"                // IDL generated header file
#include printmatrix.h

void
main()
{
        Matrix        *m1;

        cout << "Creating dynamic objects:" << endl;
```

```
// Create a remote Matrix object on a server using an
// object creator function.
m1 = Matrix::createMatrix(1, 2, 3, 4);
cout << "m1 created by an object creator function:" << endl;
print(m1);
delete m1;

// Create a remote Matrix object on a server using
// a static member function.
idl_boolean result = Matrix::newMatrix(2, 2, &m1);
if(result)
{
    print(m1);
    delete m1;
}
.
.
.
```

#include "matrix.h"
The interface class and proxy class are defined in the **matrix.h** header file generated by the IDL compiler.

Matrix *m1;
Object references are declared as pointers to an interface class. The interface class is an abstract class, and C++ does not allow you to create instances of it. However, pointers to abstract classes are allowed. When a remote object is created for one of these object references, the client stub actually creates a proxy class object on the client.

m1 = Matrix::createMatrix(...)
Object creator functions are invoked using the interface class name (Matrix) with the standard C++ scope operator (::). This function creates a remote Matrix object on a server and returns a reference to the remote object.

print(m1); After a dynamic object is created, the application uses it just like any local object. This function is an application-specific inline function to display a Matrix. It is defined in the **printmatrix.h** header file and uses the Matrix interface's **get()** function.

delete m1; Remote dynamic objects are deleted with the standard C++ **delete** operator, just like local objects. However, for the remote object, an RPC is sent to it to decrement the reference count. If no other clients have a reference to it, the object is also deleted from the server's address space. Client applications should take care to delete all dynamic objects prior to exiting. Otherwise, the object remains in the server's address space wasting resources. Dynamic objects are created for the use of the invoking client. This means that servers cannot give a different client a reference to a dynamic object. However, the client could behave as a server and give a copy of the object reference to another client. For this reason, a reference count is maintained on the server for objects.

... = Matrix::newMatrix(2, 2, &m1)
Static member functions are invoked using the interface class name (Matrix) with the standard C++ scope operator (**::**). This function is also an object creator function that creates a remote Matrix object on a server.

15.3.2 Creating Client-Local Objects

The client code in the previous section showed only the case in which a class of objects is remote. However, many client applications also need to create and use local objects of the same class. The significant difference is that the local object is not created by way of a remote procedure call as is the remote object. The interface class generated by the IDL compiler from the interface definition is an abstract class. This means that another class must be derived from it to create and manipulate objects. The client stub has a proxy class automatically defined for remote objects, but your client application must define a local implementation class so that your client can create and manipulate local interface objects.

Do the following to create and use local versions of interface objects:

1. Derive a local class from the interface class to implement the client-local objects. This class is just like a manager class used in server development: in fact, this example uses the same manager class as the server.

2. Write the local code that implements the interface class. Our example uses the same manager code implementation as for the server. You implement the manager class by adding the code to the manager header file generated by the IDL compiler,

or by deriving a new class from the manager class and implementing those functions.

3. Link the local class and local implementation code into your client application.

The following sample code shows how a client creates a local Matrix object:

```
#include "matrix.h"  // IDL generated header file

#include "matrix_mgr.h"  // local class implementation
 .
 .
 .
 Matrix  *mlocal;
 // Create a local Matrix object in this program
 mlocal = new MatrixMgr(4, 3, 2, 1);
 cout << "mlocal created:" << endl;
 print(mlocal);
        .
        .
        .
```

#include "matrix_mgr.h"
: To implement client-local objects, the application includes a local manager class that is derived from the interface class. Local code is also linked to the application that implements the client-local objects.

mlocal = new MatrixMgr(...)
: Clients create a local object by using the C++ **new** operator on the local manager class defined in the **matrix_mgr.h** header file.

15.3.3 Location Transparency of Local and Remote Objects

The previous sections showed separate cases of how to create objects that are either remote or local. However, many applications use a mixture of remote and local objects. For example, a presentation application can link in a video clip from another system (remote), or it can embed a copy of the video clip into the presentation itself (local). After the objects are created, we want the distinction to be as transparent as possible

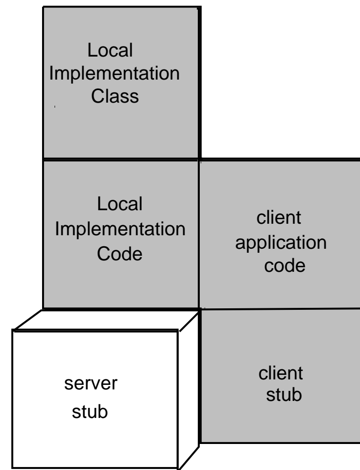
to simplify application code. In DCE, you can also intermix local and remote objects in function calls without needing to keep track of which is which.

To prepare your application to handle both local and remote objects simultaneously, do the following development steps:

1. Use the **cxx_static** ACF attribute to rename local versions of static functions.
2. Use the IDL compiler to produce both the client and server stub code.
3. Link into your client the client stub, server stub, and local object implementation code.

To accomplish this, you develop the client as if you are producing both a client and a server simultaneously. The only real difference is that you do not need any server initialization code. This means that your application includes the **idl**-generated manager class header and server stub, and manager implementation code for each interface. (See the following figure.) A client uses the client stub to produce and use remote objects. The client uses the server code to produce and use client-local objects of the interface class. This makes more sense when you think about server development: the manager class and code implement distributed objects of the interface class that are *local* to the server, so it helps to think local implementation code rather than server implementation code when we use server stubs, manager classes, and manager code in a client. If your application fails to use the server stub, the exception **rpc_x_no_server_stub** is raised by the client if your application tries to use local objects.

Figure 15–2. Clients Use the Server Stub



The IDL compiler requires an ACF such as the following when a client uses both remote and local objects:

```
/* FILE NAME: matrix.acf */

interface Matrix
{
        /* include files generated into the server stub */
        [sstub] include "matrix_mgr", "staticfunc";

        /* createMatrix must be mapped as a creator member function.  */
        /* The argument MatrixMgr names the class that implements the */
        /* interface for the server stub.                             */
        [cxx_new(MatrixMgr)] createMatrix();

        /* The "newMatrix" name represents the remote version of the  */
        /* function that is used by either the client application or  */
        /* the server stub.                                           */
        [cxx_static(LocalMatrix)] newMatrix();
}
```

[sstub] include

The **include** statement causes the IDL compiler to include header files in stubs. Data structures and definitions in code that are required by stubs need to be included in this way. This example applies the **sstub** attribute to specify the inclusion of **matrix_mgr.h** and **staticfunc.h** files in the server stub only. The **matrix_mgr.h** file contains the definition of the client-local manager class. This class defines the implementation of the interface and is derived from the interface class. The file **staticfunc.h** contains declarations of static member functions for the interface. In this example, there is only one static member function: **LocalMatrix()**.

[cxx_new(MatrixMgr)] createMatrix();

The **cxx_new** attribute specifies that a static member function of the interface is an object creator function. An argument (in this case, **MatrixMgr**) is needed to name the manager class, the class derived from the interface class to implement local interface objects. For the client stub, the argument is ignored and the function **createMatrix()** is generated as a static member function. The client application uses this function to create a remote interface object. For the server stub (or, in this case, the client-local implementation), the **MatrixMgr** argument represents the manager class name defined in a header file previously specified in the ACF with the **include** statement. The application uses the **new** operator on the **MatrixMgr** class to create a local interface object.

[cxx_static(LocalMatrix)] newMatrix();

The **cxx_static** attribute specifies the interface's static member functions. All static member functions need to have this attribute (unless you use the **static** keyword in the interface definition to specify the function as static). An argument is required to avoid name conflicts between the local and remote versions of the function when both client and server stubs are linked together in the same application. For the client stub, the argument is ignored and the client application calls **newMatrix()** for remote access to the interface. For the client-local (server) stub, the argument is used to name the function, and the application calls **LocalMatrix()** for local access to the interface.

The following example shows client code to create and use both remote and local objects from an interface class:

```
#include "matrix_mgr.h"
#include "printmatrix.h" // print() macro

void
main()
{
   idl_long_int d1, d2, d3, d4;
   Matrix         *mremote, *mlocal, *mr, *ml;

   d1 = 1; d2 = 2; d3 = 3; d4 = 4;

   cout << "Creating dynamic objects:" << endl;

   // Create a remote Matrix object on a server
   mremote = Matrix::createMatrix(d1, d2, d3, d4);
   cout << "mremote created:" << endl;
   print(mremote);

   // Create a local Matrix object in this program
   mlocal = new MatrixMgr(d4, d3, d2, d1);
   cout << "mlocal created:" << endl;
   print(mlocal);

   // Create another object from a local and remote one.
   // Whether the new matrix is local or remote depends on whether
   // the invoking object is local or remote.

   // create another remote Matrix while accessing a local object
   mremote->add(mlocal, &mr);
   cout << "mr is remote. It's the sum of mremote and mlocal:" << endl;
   print(mr);

   // create another local Matrix while accessing a remote object
   mlocal->add(mremote, &ml);
   cout << "ml is local. It is the sum of mlocal and mremote:" << endl;
   print(mr);

   // Applications should ALWAYS delete remote dynamic objects when
   // through, otherwise, the server will waste resources maintaining
   // them.
```

```
   delete mremote, mlocal, mr, ml;

   cout << "Client exiting" << endl;

   return;
}
```

Matrix *mremote, *mlocal, *mr, *ml;
Local and remote object references are both defined as pointers to the interface class. Depending on how an object is created, polymorphism causes the invocation of a client stub function for remote objects or the locally defined function for local objects.

mremote = Matrix::createMatrix(d1, d2, d3, d4);

mlocal = new MatrixMgr(d4, d3, d2, d1);
Clients call a static creator function to create a remote object on a server and use the C++ **new** operator to create a local object.

mremote->add(mlocal, &mr);
A client can use remote and local objects together. In this example, a local object (**mlocal**) is added to the invoking remote object (**mremote**) to create a new remote object (**mr**) that is the sum of the two.

mlocal->add(mremote, &ml);
In this example, a remote object (**mremote**) is added to the invoking local object (**mlocal**) to create a new local object (**ml**). Whether the resulting object is local or remote depends on the invoking object.

delete mremote, mlocal, mr, ml;
Clients use the C++ **delete** operator to delete both local and remote objects. If a client does not delete local objects prior to exiting, no real harm is done since all the memory for the application is released. However, clients should always delete remote objects when finished with them because the servers maintain them even after the client has exited.

15.3.4 Finding Known Remote Objects

Servers can register objects with the name service, such as the Cell Directory Service (CDS). Such objects are termed named objects. When an interface is compiled, the

IDL compiler generates an overloaded **bind()** operation that allows a client to bind to a named object in several ways. These include the following:

- Bind by an object's name
- Bind by an object's UUID
- Bind by a binding handle

An *overloaded* operation's argument list and functionality varies depending on which argument is used. The **bind()** operation of an interface is a static operation that returns a typed interface pointer. A zero is returned upon failure to locate and bind to the object.

15.3.4.1 Binding to Named Objects By Name

To bind to a named object by its CDS name, the argument provided to the **bind()** operation should be an **unsigned_char_t** pointer that specifies the name of the registered object in the CDS hierarchy. For example, the following code fragment uses a CDS name to create a local object proxy in the client application bound to a remote object:

```
Matrix m;

cout << "Binding to objects by name stored in CDS:" << endl;
m = Matrix::bind((unsigned_char_t *) "/.:/objects/identityMatrix");
if (m) {
        print (m);
} else {
        cerr << Cant bind to named object << endl;
}
```

In order for this to work, a server must have registered the object in CDS by calling the **register_named_object()** function.

15.3.4.2 Binding to Named Objects by UUID

To bind to a named object by its object ID, the argument provided to the **bind()** operation should be a **uuid_t** reference. The argument specifies the UUID of the registered object in the CDS hierarchy. The DCE environment variable **RPC_DEFAULT_ENTRY** must be set to indicate where the search for the object is to begin in the CDS name space. For example, the following code fragment uses an object's UUID to create a local object proxy in the client application bound to the remote object:

```
const char *UUID = "f063cf5a-c5c8-11ce-8a4b-08002be415b2";
Matrix        *m; // interface pointer
uuid_t        u; // uuid of named object
unsigned32    status; // error status

// get a uuid from string format
uuid_from_string ((unsigned_char_t *) UUID, &u, &status);
if (status !=uuid_s_ok) {
        // handle error case
}
// bind to a named object by uuid
m = Matrix::bind(u);
if (m) {
        print (m);
} else {
        cerr << Cannot bind to named object << endl;
}
```

15.3.4.3 Binding Explicitly to Known Objects

To bind to an object explicitly by its binding handle, the argument provided to the **bind()** operation should be a server binding handle of type **rpc_binding_handle_t**. Note that this method does not use CDS at all. For example, the following code fragment uses a binding handle to create a local object proxy in the client application bound to a remote object:

```
const char *UUID = "f063cf5a-c5c8-11ce-8a4b-08002be415b2";
const char *PROT = "ncacn_ip_tcp";
const char *HOST = "16.01.02.03";
const char *ENDP = "4041";

Matrix   *m;    // interface pointer
unsigned_char_t  *string_binding; // string binding
rpc_binding_handle_t binding_handle; // binding handle
unsigned32   status;  // error status

// build a string binding from the various components
rpc_string_binding_compose(
          (unsigned_char_t *) UUID, // object uuid
          (unsigned_char_t *) PROT, // protocol sequence
          (unsigned_char_t *) HOST, // host address
          (unsigned_char_t *) ENDP, // transport endpoint
          NULL,   // network options
          &string_binding,
          &status
);
if (status != rpc_s_ok) {
 // handle error case
}

// convert a string binding into a binding handle
rpc_binding_from_string_binding(
        string_binding,
        &binding_handle,
        &status
);
if (status != rpc_s_ok) {
        // handle error case
}

m = Matrix::bind(binding_handle);
if (m) {
        print(m);
} else {
        cerr << "Cannot bind to named object" << endl;
}
```

rpc_string_binding_compose()
This RPC API routine combines string components of binding information into a single string representation of a binding.

rpc_binding_from_string_binding()
This RPC API routine creates a binding handle from a string representation of a binding handle.

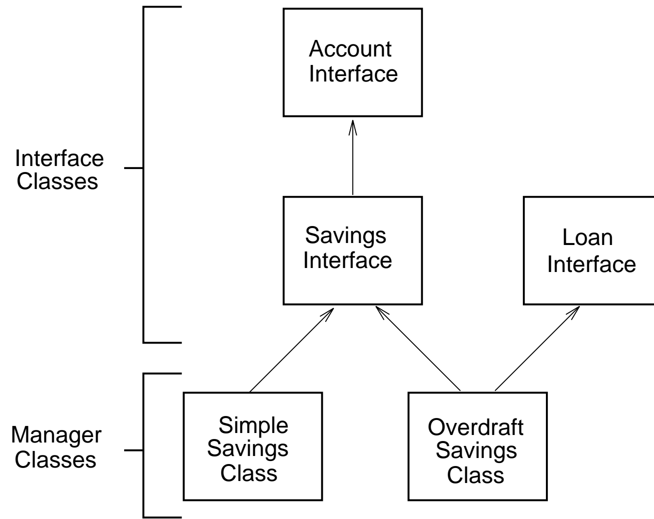
m= Matrix::bind(binding_handle);
The **bind()** operation when used with a binding handle parameter binds to the object specified by the object's UUID and specific server binding information.

15.4 Multiple Interfaces and Interface Inheritance

Objects in useful applications are organized into groups (using classes) and hierarchies in order for people to more easily develop and maintain them. For the same reason, you use more than one IDL interface to logically group the objects and functionality of your applications. In addition, you can organize your interfaces into hierarchies that take advantage of the inheritance capabilities of C++ classes.

This discussion uses a traditional savings account example, as shown in the class hierarchy diagram of the following figure. First there is a high-level *Account* interface and then a *Savings* interface derived from the *Account* interface. The *Account* interface is specified separately from the *Savings* interface for the basic operations all accounts might have and to show how interface inheritance works. With this scheme, we can easily specify other kinds of accounts by using additional interfaces. (For example, we could also have a *Checking* interface.) Our example also has a separate *Loan* interface to show how to combine interfaces in applications. In the implementation of these interfaces, we derive a simple savings account class (**simpleSave**) from the savings interface, and we derive an overdraft-protected savings account class (**overdraft**) from both the savings and the loan interfaces.

Figure 15–3. Multiple Interfaces and Inheritance



The Account interface contains the most basic operations for accounts, including one to obtain the account's balance, one to make deposits, and one to make withdrawals. This interface definition is as follows:

```
[
uuid(b3896a1c-8ee2-11ce-badc-08002b2bf322)
] interface Account
{
    double getAccountBalance();

    double deposit( /* Value returned is the balance. */
                [in] double amt
    );

    double withdraw(/* Value returned is actual amount withdrawn */
                [in] double amt
    );
}
```

Use the inheritance operator, **:**, in an interface definition to specify *interface inheritance.* In the following example, the Savings interface *inherits* operations from the Account interface. (Depending on your perspective, you can also say the Savings interface *is derived from* the Account interface.) When an interface inherits another, it also uses the **import** statement to be sure the operations and any data types of the inherited interface are available to the derived interface. The Savings interface definition is as follows:

```
[
    uuid(b388ab7c-8ee2-11ce-badc-08002b2bf322)
]   interface Savings : Account
{
        import "account.idl";

        static Savings * openSimple(
                [in] double   amt
        );

        static Savings * openOverdraft(
                [in] double   amt
        );

        double getSavingsBalance();

        void   setInterestRate(
                [in] double rate
        );

        void   addInterest();
}
```

The **openSimple()** and **openOverdraft()** static operations are object creator operations used to create new accounts on a server. Notice that the Account interface has no creator operations specified. This means that clients cannot create an Account object directly, but servers of course can. The non-static operations for the Savings interface include one to get the savings account balance (**getSavingsBalance()**), one to set the interest rate (**setInterestRate()**), and one to add the interest to the balance of the account (**addInterest()**)

In this application, we have decided that our server implements the overdraft account with a Loan interface. (Note we could have chosen to implement it in another way, and without an additional interface.) The Loan interface is not derived from another interface and is shown in the following example:

```
[
    uuid(912ef43d-8ee2-11ce-a54e-08002b2bf322)
]
interface Loan
{
    static Loan * openLoan(
        [in]  double   amt,
        [in]  double   rate,
        [in]  long     months,
        [out] double   &payment
    );

    double getLoanBalance();

    void payment(
        [in] double amt
    );

    double recalculateLoan( /* returns payment amount required */
        [in]  double   rate,
        [in]  long     months
    );
}
```

The **openLoan()** operation is a static object creator operation to create a loan object. The **getLoanBalance()** operation gets the current balance of the loan and the **payment()** operation is used to make a payment on the loan. The **recalculateLoan()** operation sets new terms for the loan and returns the new monthly payment required.

There are no special techniques to follow in server initialization code except be sure that whatever is required for an individual interface is done for each interface your application uses. For example, the initialization code must be sure to register the endpoints for all interfaces.

15.4.1 Implementing Multiple Managers

Our implementation derives a simple savings account manager class (**simpleSave**) from the Savings interface class. Since the Savings interface is derived from the Account interface, all nonstatic operations in both interfaces must be declared in the manager class and defined in the manager code. Of course, additional functions and data types (such as constructors and destructors) can also be declared to specifically implement the interface.

Our implementation also derives an **overdraft** manager class for an overdraft type of savings account. The overdraft account has characteristics of both a savings account and a loan and demonstrates *multiple interface inheritance*. It is defined to have multiple inheritance by being derived from both the Savings and Loan interface classes.

Note: Applications can create C++ classes that inherit from multiple interface classes, but interface classes cannot inherit from multiple interfaces.

The following code shows the overdraft manager class and its implementation. This example has the manager implementation included within the class definition header file itself, rather than in separate C++ code. C++ allows you to combine implementation as part of the C++ class declarations. This is common practice when the implementation code for each member function is small.

```
#ifndef overdraft_i_h
#define overdraft_i_h
#include <iostream.h>
#include "savings.h"
#include "loan.h"

class overdraft : public Savings, public Loan {
    public:
        overdraft(idl_long_float amt)
        {
            balance = amt;
        }
        ~overdraft(void)
        {
                return;
```

```
        }
        idl_long_float getBalance()
        {
            return balance;
        }
//////////////// Member Functions from all interfaces ////////////////
        idl_long_float deposit(idl_long_float amt)
        {
                balance += amt;
                return balance;
        }
        void payment(idl_long_float amt)
        {
                balance += amt;
        }
        idl_long_float withdraw(idl_long_float amt)
        {
                balance -= amt;
                return amt;
        }
        void setInterestRate(idl_long_float r)
        {
                rate = r/loanTerm;
        }
        void addInterest()
        {
                balance += (balance * rate);
        }
       idl_long_float recalculateLoan(idl_long_float r, idl_long_int m)
        {
                if(balance < 0)
                    {
                    loanRate = r;
                    loanTerm = m;
                    return abs(balance) / loanTerm;
                    }
                else
                    return 0;
        }
        idl_long_float getAccountBalance()
```

```
        {
                return getBalance();
        }
        idl_long_float getSavingsBalance()
        {
                return getBalance();
        }
        idl_long_float getLoanBalance()
        {
                static idl_long_float loanBalance;
                if(balance < 0)
                  loanBalance = abs(balance);
                else
                  loanBalance = 0;
                return loanBalance;
        }
private:
    idl_long_float balance  = 0; //loan is automatic if negative balance
    idl_long_float rate     = 0.02; //2%
    idl_long_float loanRate = 0.15; //15%
    idl_long_int   loanTerm = 12;   //12 months
};
```

The manager class must declare all the nonstatic functions of all its inherited interfaces. These include all nonstatic operations defined in all three interfaces, including the Account, Savings, and Loan interfaces. Be sure to define the operation signatures exactly as they are declared in each **idl**-generated header file, or else the C++ compiler may not interpret the function as an implementation but rather as a new function. If this occurs, the class is interpreted as an abstract class, which means that your application cannot create instances of the manager class.

For this example, refer to the **savings_mgr.h** and **loan_mgr.h** header files generated by the IDL compiler to find the signatures of all the functions required. For example, the **deposit()**, **withdraw()**, and **getAccountBalance()** functions are from the Account interface but are redeclared in the derived Savings interface. The **payment()**, **recalculateLoan()**, and **getLoanBalance()** functions are declared in the Loan interface. The **setInterestRate()**,**addInterest()**, and **getSavingsBalance()** are declared in the Savings interface.

The static function implementations for the Savings and the Loan interface classes are not shown here but include **openSimple()**, **openOverdraft()**, and **openLoan()**.

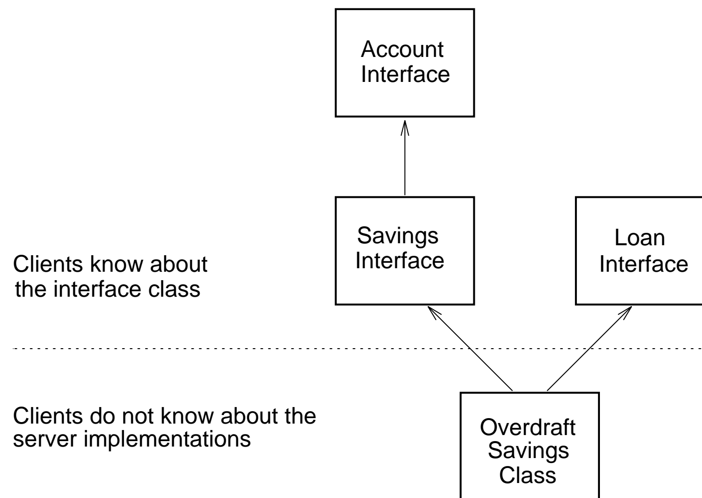
15.4.2 Using Objects that Support Multiple Interfaces

When clients use objects whose interfaces are independent from each other, no special coding is required beyond the conventions described earlier: you just create, use, and delete objects for each interface. The most interesting circumstances involving multiple interfaces are those in which an object itself supports more than one interface.

15.4.2.1 Binding by Object Reference to Use a Different Interface

We defined our overdraft savings account to be derived from two different interfaces (see the following figure). However, the client does not have any knowledge of how a server implements the overdraft account. The client does have a way to create an overdraft account by calling the static function **openOverdraft()**, but that is defined in the Savings interface which has no access to the Loan interface. So how does an overdraft object inquire about its loan balance by using the Loan interface's **getLoanBalance()**member function, when the object reference is to the Savings interface? We obviously cannot simply create another object reference to the Loan interface and expect the two different object references to both refer to the same overdraft object.

Figure 15–4. Clients Do Not Know About Server Implementations



The solution is to use an **idl**-generated member function. When the IDL compiler generates the interface classes, it also generates an additional **bind()** member function that allows the client to easily use other interfaces. The following examples show sample client code that creates and uses a new simple savings account object and an overdraft account object:

```
#include "savings.h"
#include "loan.h"

Account *a  = 0;
Savings *ss = 0;
Savings *od = 0;
Loan    *iLoan  = 0;
```

The interface classes are declared in the header files generated by the IDL compiler as follows:

```
ss = Savings::openSimple(456.12);
od = Savings::openOverdraft(568.19);
```

In this example, the client creates a new simple savings account object on a server by calling the **openSimple()** function. The function creates an object reference to the Savings interface. The client also creates a new overdraft account object on a server by calling the **openOverdraft()** function. This function also creates an object reference to the Savings interface.

A robust server would likely give clients a way to find accounts again later by making the objects named and persistent; but, to simplify our examples, we use only dynamic objects. Therefore, accounts must be recreated each time a client runs.

```
balance = ss::getSavingsBalance();
assert(balance == 456.12);
balance = od::getSavingsBalance();
assert(balance == 568.19);
```

Object references to the Savings interface can call any member functions of the Savings and Account interfaces as follows:

```
iLoan = Loan::bind(od);
```

To use a different interface, clients use the built-in **bind()** member function with an object reference parameter. In this example, the function creates an object reference to the Loan interface, **iLoan**, from the object reference to the Savings interface, **od**:

```
balance = iLoan->getLoanBalance();
cout << "Loan Balance: " << balance << endl;
```

The object can now call any member function of the Loan interface as follows:

```
ss->deposit(20.01);
```

An object reference to one interface can access member functions of its inherited interfaces, as expected. In this example, **ss** is an object reference to a Savings object, but the **deposit()** function is specified in the Account interface:

```
balance = ss->getAccountBalance();
cout << Balance: " << balance << endl;
a = Account::bind(ss);
balance = a->getAccountBalance();
cout << Balance: " << balance << endl;
```

As an aid to debugging, it is a good idea to use the interface in which the operation is declared, even if the inherited operation can be resolved. When the object calls **getAccountBalance()** with a Savings object reference, the function is executed in the client stub for the Savings interface. On the other hand, when the same function is called with an Account object reference, the Account client stub function is executed.

15.4.2.2 Finding Out if an Interface is Supported

One of the most common reasons to find out if an interface is supported is to determine whether or not a new version of an application uses an additional interface. The new clients must check for application compatibility by inquiring as to whether the new interface is supported. Compatibility is easily tested by calling the **idl**-generated **bind()** function with an object reference parameter, as described in the previous section. An interface is not supported if the returned result is 0 (zero). This simple test implies that it is easy to create new versions of applications by adding additional interfaces, rather than running the risk of creating incompatibility by modifying existing interfaces.

The following example shows how to inquire if an interface is supported. Suppose we are told that some servers on our network implemented the overdraft account without using the Loan interface. This would not prevent our clients from creating and using overdraft objects; we would just not have the Loan interface to use to inquire about the status of an overdraft. In this scenario, the client that has the Savings interface could inquire as to whether the object also supports the Loan interface, as in the following:

```
iLoan = Loan::bind(ss);
if(iLoan == 0)
   cout <<"Simple accounts do not support the Loan interface."<< endl;
iLoan = Loan::bind(od);
if(iLoan == 0)
   cout <<
   "This overdraft account doesn't support the Loan interface." << endl;
```

In the first case, attempting to bind a simple savings object to the Loan interface should always return 0 (zero). In the second case, if a zero value is returned, this overdraft object does not support the Loan interface (the Loan interface is not inherited).

15.4.2.3 Multiple Interfaces and Local Objects: a C++ Enhancement

The **bind()** member function that takes an object reference also works for local interfaces and objects. This means that you can use IDL to specify, implement, and test combinations of local interfaces without the overhead of remote procedure calls. You may find this a useful approach when designing, prototyping, and debugging your interfaces and implementations. The steps are as follows:

1. Create your IDL files by using the **uuid** and **local** attributes in the interface headers.
2. Use the IDL compiler with the **-lang cxx** option to compile the interfaces. The IDL compiler generates only the header files for each interface when the interface has the **local** attribute. No stubs are generated.
3. Develop the manager class, manager implementations, and static member functions as you would for typical servers.
4. Create a client that includes the **idl**-generated header files. The client also calls the **idl**-generated **bind()** function that binds by object reference, to switch between local interfaces.
5. Link together the machine object code for the client, manager class, manager code, and static functions.
6. Test the client application program.

15.5 Passing C++ Objects as DCE RPC Parameters

IDL allows the passing of any C language basic or constructed data type as an RPC parameter, mainly through the use of attributes. However, the C++ language makes it much easier and convenient for the programmer to define new types using class

definitions. A C++ application can contain a wealth of class definitions modeled after real world objects, usually in the form of class libraries. The implementation details of a class library definition are hidden from the programmer in favor of a public interface or set of operations to manipulate the class instance. In addition, software vendors are in the business of providing class libraries containing all sorts of class definitions that are ready to use by the application programmer.

As applications move towards the client/server model, and as distributed object technology becomes the vehicle for such a model, RPC must be able to pass C++ objects as parameters efficiently and intrinsically.

When an application is distributed, a number of issues arise that must be dealt with. These issues include the ability of the network to pass large amounts of data, the problem of passing pointers as RPC arguments, and the differences in the representation of a piece of data in the computer's memory that results from different machine architectures. These problems are addressed by DCE implementations adhering to the network data representation (NDR) for data types and the effective use of attributes in the interface definition. However, other problems that are specific to the C++ language include the following:

Data Hiding One advantage of a class definition is that it allows the application designer to model a programming language construct after some real world object and to interact with the construct in a high level fashion. The details of how the construct is built and manipulated should be handled by the designer of the class. The application programmer should be insulated from the class internals and only needs to be aware of the public interface to the object. However, this programming model exposes a fundamental problem when extended to DCE RPC. In passing a parameter to a remote procedure, the DCE runtime library must be able to marshal the RPC parameters over the network on behalf of the caller of the remote operation and unmarshal those parameters and reconstruct the data type on the server side of the application. If users are able to create new and exotic data types, how can the DCE runtime know how to marshal them? It is unreasonable to expect that DCE could be extensible enough to track and know how to marshal new data types as they are created. It is also unreasonable to expect class designers to supply their own support for marshaling objects. This is especially true for data types that are provided as class libraries by outside vendors having no connection at all with DCE.

Inheritance

Inheritance and polymorphism are techniques available with C++ whereby a generic class type is used by an application but the actual object is created from a more specific class type. A classic example of this is a generic class called Shape and a number of specific classes such as Circle, Square and Cylinder that all derive from the Shape class. Shape might have operations such as draw() and rotate() which cause the object to be drawn onto the screen and rotated. The application can have an array of Shape objects and cause each one in turn to be displayed and manipulated. However, the array could be a mix of Circle, Square and Cylinder objects. Each object will know how to draw and rotate itself. For some objects, a function such as rotate() may have no meaning. The polymorphic behavior of the Shape class will forward the draw() operation to the correct specific drawing operation implemented by the object. The rotate() operation behaves similarly for classes that support rotation. And if the object does not support rotation, the Shape class will supply its own rotate implementation which may actually do nothing.

The problem of passing a Shape object is that the DCE runtime may not know what type of shape the object really is. A Shape could have some self-identifying information, but this will often not be the case. Furthermore, if there were some shape identifier, it would need to track new class types as they are introduced into the application. This type of design is not very extensible and contrary to the object oriented methodology.

Lots of data

Another problem with passing a C++ object over the network is fundamental to any RPC argument. As the amount of data needed to be passed over the wire and recreated in the server process increases, the performance of the RPC call will obviously decrease. The decision as to what kinds of operations are remote and what types of data they require is a basic design issue. For example, consider a stack type. If the stack is small then it may be advantageous to pass the entire stack over the wire, recreate it on the server side, allow the server to update it, and then pass it back to the client side so that it reflects any updates the server made to it. The IDL language supports such a paradigm by using an array network type along with other parameters to indicate the array size. However, this paradigm quickly breaks down as the stack size increases. A better way for the server to access a large stack would be to pass a stack reference to the server and allow the server to access the stack by making RPC calls to it.

Two programming methodologies are presented to illustrate how C++ objects can be passed as DCE RPC parameters: data representation and delegation. It is a design choice as to which solution better applies to a specific application problem. By using these methodologies, class libraries can be easily integrated into an application. Both solutions are intended to be handled primarily at the interface definition level so that the application itself can be designed in a normal and natural way while minimizing the issue of distributing the application.

15.5.1 Representation

The DCE IDL compiler supports a feature to allow a network representation of a data type to differ from the representation used by the application. This feature is invoked by using the **represent_as** attribute on a data type in the Attribute Configuration File (ACF). Applying this attribute to an IDL data type allows the network representation of a data type to be isolated within the generated stubs. The programmer is required to supply four conversion routines when using this feature. The function signatures for these four routines are generated by the IDL compiler. Their purpose is to convert an RPC argument from the application presented type to the network type, convert from the network type to the presented type, and to free memory used by the network and presented types. Presumably, a class library designer could supply the four conversion routines along with the IDL generated stub routines as a library. In this way, the application programmer need not be aware of how the data is transmitted across the wire nor that the conversions take place.

For example, consider the C++ String class which is commonly supplied by C++ compiler vendors or easily implemented by the programmer. The IDL compiler has no notion of a String class since it is not a primitive or constructed IDL type. The class definition must be made known to the IDL compiler by using the include directive to include the class definition into the generated header file. But the DCE runtime does not know how to marshal the String type since its internals are hidden and, in fact, could very well differ in its implementation between vendors.

To allow a String type to be passed as an RPC argument, a network type for a String object is defined in the IDL file to be an array of characters with the string attribute applied. An ACF file is then created for the interface to apply the **represent_as** attribute to the network type. The following code fragment is for the IDL file represent an IDL character array as a String class in an application:

```
[ uuid(c5a7c094-c5e3-11ce-bac2-08002be415b2) ]
IText {
        typedef [string,unique] char * net_string; /* 1 */
        static net_string toUpper([in] net_string s); /* 2 */
        static net_string toLower([in] net_string s); /* 3 */
}
```

The following code is an ACF definition for a String type:

```
{
        include "String";     /* 4 */

        typedef [represent_as(String)] net_string; /* 5 */
}
```

The code is described as follows:

1. A net_string is defined to be a unique pointer to a string
2. The static toUpper() operation takes a String argument and returns another one
3. The static toLower() operation takes a String argument and returns another one
4. Include the **String.h** file into the **idl**-generated header file
5. The network type net_string is presented as the C++ String type in the application

Using automatic binding, the client application would invoke the static *toUpper()* operation as follows:

```
String s1("Hello, World"); // create a local String object
String s2 = IText::toUpper(s1); // RPC call returns another
                                // String object
```

Note that a unique attribute is specified for the net_string type. Unique pointers should always be used when the **represent_as** attribute is applied to a pointer type.

The routines to convert between the network type and the presented type are automatically invoked by the DCE runtime during the marshalling and unmarshalling process. The IDL compiler generates a function signature to free the presented data

type. In this example, this routine would be named **net_string_free_local(String *)**. The purpose of this routine is to free the memory occupied by the stack variable in the server stub that represents the RPC parameter. But since the C++ compiler will generate code to delete local stack objects when the server stub routine is exited, this routine should not free its argument.

The **represent_as** attribute is properly used when the data comprising the C++ object can be represented by some primitive or constructed IDL data type. The object's data must be accessible by the application. The overhead involved with using the **represent_as** attribute is the conversion from one type to the other and the freeing of memory.

It may not always be advantageous to use the **represent_as** attribute to pass a C++ object as an RPC parameter. Consider the case presented earlier where a generic Shape class is used in a class hierarchy with the more specific Square, Circle, and Cylinder shapes derived from it. An application may wish to pass a Shape object as an RPC parameter. Using the **represent_as** feature would require the conversion routines to convert from a shape to some NDR structure that can be defined in IDL. However, this is complicated by the fact that one IDL type may not be sufficient to represent all possible shapes. To solve this, a discriminated union of different shape types could be defined. But it is also very possible that the internals of the classes are not exposed to the application. The user may have no knowledge of what data types are needed to represent even the simplest shapes such as a square. Furthermore, as new shapes are introduced into the application, the conversion routines would also require extensions to handle the new shapes. An object oriented application should be extensible without requiring such overhead.

Another drawback to using conversion routines is efficiency. Consider a common C++ Stack class and a distributed implementation of a reverse Polish notation algorithm. The algorithm maintains a stack of operands. When an operator is processed, the required number of operands are popped off the stack, the operation is performed on them, and the result is pushed back onto the stack. For this example, let's assume that the algorithm supports the plus(), minus(), multiply() and divide() binary operations. In order to illustrate the distributed nature of the algorithm, we can further assume that the client reads an equation in reverse Polish notation from standard input and maintains the stack locally, but the binary operations are implemented within a remote server process. Hence, the server process needs access to the same stack as the client. Simply passing the stack to the server process in its entirety would be inefficient since only the top two elements need to be accessed per operation. A large stack would

quickly degrade the performance of the algorithm, especially since the stack would have to be passed as both an input and output parameter.

15.5.2 Delegation

An alternative to passing the stack is to treat the stack as a distributed object and pass a reference to it. The server and client would have access to the single stack in the application and the server could use the stack object reference to push and pop elements. A DCE distributed object requires that there be an interface defined for the object and the object implementation be derived from the generated interface class. If the stack being used is supplied by a third party vendor, it may not be possible to modify its definition to derive it from an IDL generated class. The solution is to create a delegate class for the stack to act as an interface to the actual stack object. A delegate class encapsulates the real object and forwards operation invocations to it. The IDL language has been extended to include the ACF attribute **cxx_delegate** to take advantage of this idiom.

An interface using this attribute will cause the generated interface class to wrap the real object. Only the operations that need to be remote need to be defined in the delegate class interface definition file. The application would then link the delegate server stub with the client. Likewise, the delegate client stub would be linked with the server. The DCE runtime will transparently perform the necessary setup to allow the client application to act as a server for the delegate class. The following example illustrates the use of the **cxx_delegate** attribute with a Stack class definition:

```
[ uuid(0ea74f20-e2dc-11ce-9a8e-08002be415b2) ]
interface IStack     /* 1 */
{
        void push([in] double x);  /* 2 */
        double pop();    /* 3 */
}
```

The ACF definition for delegation of the IStack interface is as follows:

```
[ cxx_delegate(Stack) ]    /* 4 */
interface IStack{
        include "Stack";   /* 5 */
}
```

1. An IStack interface is defined
2. The push() operation pushes an element onto the encapsulated stack
3. The pop() operation pops an element from the encapsulated stack
4. The IStack interface is a delegate for a Stack class
5. include the **Stack.h** file into the IDL generated header file

Using the generated server stub and header file from the above IDL fragment, the client application would instantiate an IStack interface pointer and pass it to the remote procedure as follows:

```
Stack s;  // create a local stack object
IStack *iStack;   // declare an interface pointer to the local stack
iStack = new IStackMgr(&s); // create the interface ptr
                  // using the local stack
```

The **cxx_delegate** attribute causes the IDL generated classes to be built slightly different than a normal interface class. The interface class contains a constructor that takes a pointer to the delegated class instance as an argument and the manager class supplies complete function bodies. The programmer does not need to supply a manager class for an interface using this attribute.

The server application would use the interface pointer to invoke the push() and pop() operations on the client's stack instance. The overhead involved is the remoteness of the push() and pop() operations which are implemented as RPC calls from the server to the client. In this example, the client application would be linked with the IDL generated server stub from the IStack interface and the server application would be linked with the IDL generated client stub from the IStack interface. No extra DCE API calls are required on the part of the client or server stubs. The DCE runtime will handle the necessary overhead to allow the client application to act as a server for the IStack interface.

This idiom is most effectively used when a class type is needed as an RPC argument but the class hierarchy can not be changed by the application or when the overhead of the RPC calls to access the object is outweighed by the combined overhead of converting the object to a network type and the complexity of passing or updating a large amount of data in the RPC call.

15.6 Integrating C and C++ Clients and Servers

This chapter has assumed your clients and servers are both written in C++, and the rest of this guide describes how to write clients and servers that are both written in C. Two fundamental differences between these types of applications are their perception of what interfaces represent and whether clients bind to servers or objects.

For C applications, the model tends to be functionally oriented. The important features are the operations, in which an interface represents a convenient set of operations with associated data structures. Clients bind to servers that support the set of operations and data.

For C++ applications, the model tends to be object oriented. In this model, the important feature is the interface itself, which represent a class of objects. Operations are an integral part of each object, but data structures tend to be hidden in the implementations on the servers and not exposed in the interface. In this model, clients bind to objects that support the interfaces.

This section addresses the intersection of these two models in the following ways:

- Writing C++ clients with a functional approach so that they bind to servers (written in C) rather than to distributed objects
- Writing C clients so that they can bind to distributed objects rather than to servers

15.6.1 Writing a C++ Client for C Servers

Suppose you are writing a C++ client that needs to use an interface definition that has not taken advantage of the IDL C++ features. A logical example is an older interface definition written prior to the introduction of the C++ features of OSF DCE Version 1.2. An older interface is not designed to specify a class of objects and the associated

member functions. This means that servers for older interfaces do not maintain objects in the way described in this chapter (if they maintain objects at all).

This section uses the following simplistic interface for demonstration:

```
[
    uuid(166ab38b-95f9-11ce-9387-08002b2bf322)
]   interface old_interface
{
        double op1();

        void   op2([in] long input);

        void   op3();
}
```

If you simply compile this interface definition for the C++ language and build the C++ client application, the application cannot invoke any of the old interface's member functions because no object can exist on a server. However, static member functions do not require an object in order to invoke them, so the solution is to make the operations of an older interface static member functions.

In order for your C++ client to use an older interface, perform the following steps:

1. Create an ACF for the interface and apply the **cxx_static** attribute to *every* operation of the interface. For example:

   ```
   interface old_interface
   {
           [cxx_static] op1();
           [cxx_static] op2();
           [cxx_static] op3();
   }
   ```

2. Use the IDL compiler with the **-lang cxx** option to compile the interface and generate the header files and C++ stubs. Link the code into your C++ client application as usual.

3. Call the static functions where needed in the C++ client application by using the scope operator (::). For example:

```
#include "old_interface.h"

main()
{
 idl_long_float result;
 idl_long_int input = 1;

 result = old_interface::op1();
 old_interface::op2(input);
 old_interface::op3();
 return 0;
}
```

15.6.2 Writing a C Client for C++ Servers

If you wish, you can develop C language clients that use interfaces written with C++ features. Whenever the interface definition is compiled for C++, C structures, macros, and function prototypes are automatically built into the header file and stubs to give this capability.

For example, the following **get()** operation is defined in the Matrix interface definition:

```
long get(
 long row,
 long col
);
```

The macros generated by the IDL compiler are formed by combining the name of the interface and the name of the operation with an underscore between. For example, to allow a C client to invoke the **get** operation on the interface, the IDL compiler generates the following macro in the header file:

```
Matrix_get(obj, row, col)
```

Since member functions cannot be called in C with an implied object (the C++ *this* object), each member function for the C macros has an additional object argument as the first parameter. The remaining arguments are the same as those specified in the IDL input file.

To obtain the interface pointer using the C mapping, use one of the bind routines generated by the IDL compiler for the C interface. These are also generated in the header file. For example, the Matrix interface supports the following C macros for binding to a remote object:

```
Matrix *Matrix_bind_by_name(unsigned_char_t *name);
Matrix *Matrix_bind_by_uuid(uuid_t * u);
Matrix *Matrix_bind_by_hndl(rpc_binding_handle_t bh);
```

All static member functions of an interface are also supported for C. The macros are formed in a manner similar to the normal member functions (by joining the interface name and the operation name with an underscore), except there is no need for an additional argument to represent a current object. For example, if the Matrix interface supports the **createMatrix()** static operation, the following example C code invokes the operation:

```
/* code fragment showing the use of C macros */
Matrix *m; /* a C structure to represent an interface */
/*
** invoke a static member function to get an interface
** pointer and invoke operations on it.
*/
m = Matrix_createMatrix(1, 2, 3, 4);
if (!m) {
 /* handle error */
} else {
 printf("[%d, %d]\n", Matrix_get(m, 0, 0), Matrix_get(m, 0, 1));
 printf("[%d, %d]\n", Matrix_get(m, 1, 0), Matrix_get(m, 1, 1));
}
```

Chapter 16

Writing Internationalized RPC Applications

An *internationalized* DCE RPC application is one that

- Uses the operating system platform's locale definition functions to establish language-specific and culture-specific conventions for the user and programming environment.
- Isolates all user-visible messages into message catalogs by using the **sams** (symbols and message strings) utility.
- Uses the DCE general-purpose application messaging routines, **dce_msg_** *() and **dce_svc_** * (), to display all program messages.
- Uses DCE RPC-provided or user-defined character and code set evaluation and automatic conversion features to ensure character and code set interoperability during the transfer of international characters in remote procedure calls between RPC clients and servers.

A *locale* defines the subset of a user's environment that depends upon language and cultural conventions. A locale consists of categories; each category controls

specific aspects of some operating system components' behaviors. Categories exist for character classification and case conversion, collation order, date and time formats, numeric nonmonetary formatting, monetary formatting, and formats of informative and diagnostic messages and interactive responses.

The locale also determines the character sets and code sets used in the environment. The syntax and use of a locale definition function depends on the operating system platform in use with DCE. See your operating system programming guide and reference documentation for a description of the system's locale definition functions and locale categories.

The **sams** utility provides DCE services and application programs with a method for defining and cataloging user-visible messages, while the DCE messaging functions allow DCE services and application programs to display messages in a consistent manner. Chapter 3 describes how to develop an application that uses the DCE messaging routines and how to use the **sams** utility to create and generate message catalogs. See the *DCE 1.2.2 Application Development Reference* for a description of DCE messaging routine syntax, and the **sams(1dce)** reference page for a description of **sams** usage.

The remainder of this chapter describes the DCE RPC features for character and code set interoperability in remote procedure calls that are available to programmers who are developing internationalized DCE RPC applications. The first section describes the concepts of character sets, code sets and code set conversion and explains the default character and code set conversion mechanism that the RPC runtime protocol supports for remote procedure calls. The remaining sections describe the execution of a remote procedure call when it uses the DCE RPC features for character and code set interoperability, and explains how to build an RPC application that uses these features.

16.1 Character Sets, Code Sets, and Code Set Conversion

A *character set* is a group of characters, such as the English alphabet, Japanese Kanji, and the European character set. To enable world-wide connectivity, DCE guarantees that a minimum group of characters is supported in DCE. The DCE RPC communications protocol ensures this guarantee by requiring that all DCE RPC clients and servers support the DCE Portable Character Set (PCS). The *DCE 1.2.2 Introduction*

to OSF DCE lists the characters in the DCE PCS. The IDL base type specifiers **char** and **idl_char** identify DCE PCS characters.

A *code set* is a mapping of the members of a character set to specific numeric code values. Examples of code sets include ASCII, JIS X0208 (Japanese Kanji), and ISO 8859-1 (Latin 1). The same character set can be encoded in different code sets; consequently, DCE can contain RPC clients and servers that use the same character set but represent that character set in different numeric encodings. *Code set conversion* is the ability for a DCE RPC client or server to convert character data between different code sets.

The DCE RPC communications protocol, through the NDR transfer syntax, provides automatic code set conversion for DCE PCS characters encoded in two code sets: ASCII and EBCDIC. The RPC communications protocol automatically converts character data declared as **char** or **idl_char** between ASCII and EBCDIC encodings, as necessary, for all DCE RPC clients and servers.

The DCE RPC communications protocol does not provide support for the recognition of characters outside of the DCE PCS, nor does it provide automatic conversion for characters encoded in code sets other than ASCII and EBCDIC.

However, DCE RPC does provide IDL constructs and RPC runtime routines that programmers can use to write RPC applications that exchange nonPCS, or international, character data that is encoded in code sets other than ASCII and EBCDIC. These features provide mechanisms for international character and code set evaluation and automatic code set conversion between RPC clients and servers. Using these features, programmers can design their applications to run in a DCE that supports multiple heterogeneous character sets and code sets.

The next section describes the remote procedure call execution model when the DCE RPC features for character and code set interoperability are used.

16.2 Remote Procedure Call with Character/Code Set Interoperability

Table 11-1 in Chapter 11 illustrates the basic tasks of an RPC application. Table 16-1 shows these basic tasks integrated with the additional tasks required to implement an RPC that provides character and code set interoperability.

Table 16–1. Tasks of an Internationalized RPC Application

	Client Tasks	**Server Tasks**
1.		Set locale.
2.		Select network protocols.
3.		Register RPC interfaces.
4.		Advertise RPC interfaces and objects in the namespace.
5.		Get supported code sets and register them in the namespace.
6.		Listen for calls.
7.	Set locale.	
8.	Establish a character and code set evaluation routine.	
9.	Find compatible servers that offer the procedures.	
10.	**Call the remote procedure**.	
11.	Establish a binding relationship with the server.	
12.	Get code set tags from the binding handle.	
13.	Calculate the buffer size for possible conversion of input arguments from a local to a network code set.	
14.	Convert input arguments from a local to a network code set (if necessary).	
15.	Marshall input arguments	
16.	Transmit arguments to the server's runtime.	
17.		Receive a call.

	Client Tasks	**Server Tasks**
18.		Get code set tags sent from the client.
19.		Calculate the buffer size for possible conversion of input arguments from network to local code set.
20.		Unmarshall input arguments.
21.		Convert input arguments from a network to a local code set (if necessary).
22.		Locate and invoke the called procedure.
23.		**Execute the remote procedure**
24.		Calculate the buffer size for possible conversion of output arguments from a local to network code set
25.		Convert output arguments from a local to a network code set (if necessary).
26.		Marshall output arguments and return value.
27.		Transmit results to the client's runtime.
28.		Remove code set information from namespace on exit.
29.	Receive results.	
30.	Calculate the buffer size for possible conversion of output arguments from a network to a local code set.	
31.	Unmarshall output arguments.	

	Client Tasks	Server Tasks
32.	Convert output arguments from a network to a local code set (if necessary).	
33.	Pass to the calling code the results and return control to it.	

As illustrated in the table, the internationalized RPC execution model consists of the following new steps:

1. Both client and server invoke a platform-dependent function to set their locale during initialization. This step establishes the client's and the server's local character and code set; that is, the character and code set currently in use by processes on the client host and processes on the server host.

2. The server, as part of its initialization phase, calls a DCE RPC routine that retrieves information about code sets support on the server's host. The RPC routine examines the host's locale environment and its code set registry to determine the host's *supported code sets*; that is, code sets for which conversion routines exist that processes on the host can use to convert between code sets, if necessary.

   The code set registry is a per-host file that contains mappings between string names for the supported code sets and their unique identifiers. OSF assigns the unique identifiers for the code sets and DCE licensees, and DCE administrators assign their platform string names for the code sets. The DCE RPC routines for character set and code set interoperability depend upon a code set registry existing on each DCE host. For more information about the code set registry, see the *DCE 1.2.2 Administration Guide—Introduction* and the **csrc(8dce)** reference page.

   The routine returns a list of the supported code sets to the server; the list consists of each code set's unique identifier.

3. The server next calls a new RPC NSI routine to register the supported code sets information in the name service database. Recall that a server can use the NSI to store its *binding information* (information about its interfaces, objects, and addresses) into its own namespace entry, called a *server entry*. The new RPC NSI routine adds the supported code sets information as an attribute that is associated with the server entry, which the server created when it used the NSI export operation to export its binding information into the name service database. Placing the code sets information into the name service database gives RPC clients access to this information.

4. Before it calls the RPC NSI routines that locate a server that offers the desired remote procedure, the client calls a new RPC routine that sets up a character and code sets compatibility evaluation routine.

5. The client calls RPC NSI routines to locate a compatible server. The RPC NSI routines invoke the character and code set compatibility evaluation routine set up by the client to evaluate potential compatible servers for character and code set compatibility with the client.

6. The evaluation routine imports the server's supported code sets information from the name service database, retrieves the client's supported code sets information from the client host, and compares the two. If the client and the server are using the same *local code set*—the code set that processes on the host use to encode character data—then no code set conversion is necessary, and no data loss will result.

   If client and server are using different local code sets, then it is possible that the server is using a different character set than the client. The client does not want to bind to a server that is using a different character set, since significant data loss would result during character data conversion. Consequently, the evaluation routine uses the server's code set information to determine its supported character sets, and rejects servers using incompatible character sets. For example, if a client is using the Japanese Kanji character set (such as JIS0208), the evaluation routine rejects a server that offers the desired remote procedure but which is using the Korean character set (such as KS C 5601).

   If the client and server are character set compatible, and they support a common code set into which one or the other (or both) can convert, the evaluation routine deems the server to be compatible with the client. The NSI import routines return this server's binding information to the client.

7. The client makes the remote procedure call.

8. A client stub is called, with the character data represented in the local form and in the local code set.

9. Before marshalling the input arguments, the client stub calls a new stub support routine that retrieves code set identifying information that the evaluation routine established in the binding handle.

10. The client stub next calls a new stub support routine that determines, based on the code set identifying information, whether the character data needs to be converted to another code set and, if so, whether the buffer that currently holds the character data in the local form and code set is large enough to hold the data once it is

converted. If the routine determines that conversion is necessary and a new buffer is required, it calculates the size of that buffer and returns the value to the client stub.

11. The client stub next calls a new stub support routine that converts, based on the code set identifying information, the character data from the local code set to the appropriate code set to be used to transmit the data over the network to the server (called the *network code set*).
12. The client stub then marshalls the input arguments and transmits them to the server runtime along with code set identifying information.
13. The server stub is called, with the character data represented in the network form (which is always **idl_byte**) and in the network code set.
14. The server stub unmarshalls the input arguments.
15. The server stub next calls a new stub support routine that determines, based on the code set identifying information passed in the client call, whether the character data needs to be converted from the network code set to the server's local code set and, if so, whether the buffer that currently holds the character data in the network format and code set is large enough to hold the data once it is converted. If the routine determines that conversion is necessary and a new buffer is required, it calculates the size of that buffer and returns the value to the server stub.
16. The server stub next calls a new stub support routine that converts, based on the code set identifying information, the character data from the code set used on the network to the server's local code set.
17. The server stub invokes the manager routine to execute the remote procedure.
18. Before marshalling the results of the remote procedure (the output arguments and return values), the server calls a new stub support routine to determine whether conversion from the server's local code set is necessary, based on the code set identifying information it received from the client, and whether or not the buffer currently holding the character data is large enough to accommodate the converted data. If a new buffer is required, the stub support routine calculates the size of this new buffer and returns it to the server stub.
19. The server stub next calls a new stub support routine that converts, based on the code set identifying information from the client, the character data from the server's local code set to the network code set.
20. The server stub marshalls the converted output arguments and transmits them to the client runtime along with code set identifying information.

21. The server initialization procedure also contains a call to a new RPC routine that removes the code set information from the server entry in the name service database if the server exits or is terminated.
22. The client stub is called, with the character data in network format and code set.
23. The client stub unmarshalls the output arguments.
24. The client stub next calls a new stub support routine that determines, based on the code set identifying information passed by the server, whether the character data needs to be converted from the network code set to the client's local code set and, if so, whether the buffer that currently holds the character data in the network format and code set is large enough to hold the data once it is converted. If the routine determines that conversion is necessary and a new buffer is required, it calculates the size of that buffer and returns the value to the client stub.
25. The client stub next calls a new stub support routine that converts, based on the code set identifying information, the character data from the code set used on the network to the client's local code set.
26. The client stub passes the data to the client in the local format and code set.

Note that the stub conversion routines do not implement code set conversion. Instead, they call POSIX compliant **iconv** code set conversion routines, which are part of the local operating system. As a result, if the platform to which DCE is ported does not provide these POSIX conversion routines, DCE applications that run on this platform cannot use the DCE RPC character and code set interoperability features.

16.3 Building an Application for Character and Code Set Interoperability

An application programmer who wishes to design his or her RPC application for character and code set interoperability performs the following steps:

1. Writes the interface definition file (**.idl**) to include constructs that will enable automatic code set conversion during remote procedure execution.
2. Writes an associated attribute configuration file (**.acf**) for the interface that includes ACF attributes that will enable automatic code set conversion during remote procedure execution.

3. Writes the stub support routines that client and server stubs use to carry out automatic code set conversion during a remote procedure call. You can omit this step if you use the stub support routines supplied with DCE.
4. Writes the server code and includes the steps to get the server's supported code sets and export them to the name service database, and to remove them from the name service database upon termination or exit.
5. Writes the client code and includes the steps to set up the character and code set evaluation mechanism.
6. Writes the character and code set compatibility evaluation routine. You can omit this step if you use one of the evaluation routines supplied with DCE.

Note that building an RPC application for character and code set interoperability imposes some restrictions on the application. For example, an application that uses the RPC character and code set interoperability features cannot use customized binding handles. See Chapter 18 for more details on internationalized RPC application restrictions.

The next sections describe the steps just outlined in more detail.

16.3.1 Writing the Interface Definition File

The interface definition file is where the set of remote operations that constitute the interface are defined. The first step in writing an interface definition file that supports automatic code set conversion is to create a special **typedef** that, when used in operation parameters, represents international character data that can be automatically converted, if necessary, before marshalling and unmarshalling at client and server sites.

As described in Chapter 17, the data representation for a **byte** data type is guaranteed not to change when the data is transmitted by the RPC communications protocol. Consequently, the special international character data type defined in the **.idl** is always declared to be a **byte** type so that the RPC protocol will not automatically treat it as a DCE PCS character and convert it between ASCII and EBCDIC.

The second step in writing an interface definition file that supports automatic code set conversion is to define, for each operation that will transmit the special international character data type, a maximum of three operation parameters that will *tag* the international characters being passed in the operation's input and output parameters

with code set identifying information established during the client-server evaluation and binding procedure. These parameters are the following:

- The sending tag, which indicates the code set the client is using for international characters it transmits over the network. The sending tag has the **in** parameter attribute and is applied to international character data declared in the operation's input parameters. If the operation does not specify any international character data as input, then it is not necessary to create this parameter.
- The desired receiving tag, which indicates the code set in which the client prefers to receive international character data sent back from the server as output. The desired receiving tag has the **in** parameter attribute. If the operation does not specify any international character output data, then it is not necessary to create this parameter.
- The receiving tag, which indicates the code set the server is using for international characters it transmits over the network. The receiving tag has the **out** parameter attribute and is applied to international character data declared in the operation's output parameters. If the operation does not specify any international character output data, then it is not necessary to create this parameter.

You must define these code set tag parameters as unsigned long integers or unsigned long integers passed by reference. The receiving tag parameter must be declared as a pointer to the receiving tag unsigned long integer.

When international character data is to be unmarshalled, the client or server stub needs to have received a description of the code set being used before it receives the data. For this reason, the sending tag parameter must occur in an operation's parameter list before any **in** international character data, and the receiving tag parameter must occur in an operation's parameter list before any **out** international character data. The requirement that a tag must be received before the data it relates to is received also means that a customized binding handle cannot include international characters. This is because a binding handle must be the first parameter in a parameter list.

Here is an example **.idl** file for an interface named **cs_test** that uses the special international character type definition and the code set tag parameters for input and output parameters that are fixed arrays of characters from an international character set:

```
[
uuid(b076a320-4d8f-11cd-b453-08000925d3fe),
version(1.0)
]
interface cs_test
{
    const unsigned short SIZE = 100;
    typedef byte net_byte;

    error_status_t cs_fixed_trans (
 [in] handle_t IDL_handle,
 [in] unsigned long stag,
 [in] unsigned long drtag,
 [out] unsigned long *p_rtag,
 [in] net_byte in_string[SIZE],
 [out] net_byte out_string[SIZE]
    );
```

16.3.2 Writing the Attribute Configuration File

The next step in building an RPC application that supports character and code set interoperability is to create an attribute configuration file (**.acf**) to be associated with the **.idl** file. This **.acf** file uses the following attributes:

- The **cs_char** attribute, which associates the local data type that the application code uses to represent international characters in the local code set with the special **typedef** defined in the **.idl** file. This is a required ACF attribute for an RPC application that passes international character data. Chapter 18 provides complete details on how to specify the **cs_char** ACF attribute and the programming restrictions associated with its use.
- The **cs_stag**, **cs_drtag**, and **cs_rtag** attributes, for each operation in the interface that specifies sending tag, desired receiving tag, and/or receiving tag parameters. These ACF attributes declare the tag parameters defined in the corresponding **.idl** file to be special code set tag parameters. Operations defined in the **.idl** file that specify international character in input parameters must use the **cs_stag** attribute. Operations defined in the **.idl** file that specify international character

in output parameters must use the **cs_drtag** and **cs_rtag** attributes. Chapter 19 provides complete details on how to specify the **cs_stag**, **cs_drtag**, and **cs_rtag** ACF attributes.

- The **cs_tag_rtn** attribute, which specifies the name of a routine that the client and server stubs will call to set an operation's code set tag parameters to specific code set values. The **cs_tag_rtn** attribute is an optional ACF attribute for internationalized RPC applications; application developers can use it to provide code set tag transparency for callers of their application's operations. See Chapter 19 for complete details on how to specify the **cs_tag_rtn** attribute. Section 16.3.3.3 provides more information on the role of the tag-setting routine.

Here is the companion **.acf** file for the **cs_test** interface defined in Section 16.3.1:

```
[
explicit_handle
]
interface cs_test
{
    include "dce/codesets_stub";

    typedef [cs_char(cs_byte)] net_byte;

    [comm_status, cs_tag_rtn(rpc_cs_get_tags)] cs_fixed_trans (
 [cs_stag] stag,
 [cs_drtag] drtag,
 [cs_rtag] p_rtag );
```

The ACF for **cs_test** uses the **cs_char** attribute to define **net_byte** as a data type that represents international characters. Note that the local type specified in the **cs_char** attribute definition is **cs_byte**. This local type is analogous to the **byte** type. The ACF for **cs_test** also uses the **cs_tag_rtn** attribute to specify a tag-setting routine.

16.3.3 Writing the Stub Support Routines

When you use the **cs_char** attribute to define an international character data type, you must provide stub support routines that check the buffer storage requirements for character data to be converted and stub support routines that perform the conversions between the local and network code sets. And, if you use the **cs_tag_rtn** attribute, you must provide the routine that sets the code set tag parameters for the operations in the application that transfer international characters.

DCE RPC provides several buffer-sizing routines and one tag-setting routine. You can use the DCE RPC routines, or you can develop your own customized buffer-sizing and tag-setting routines; the choice depends upon your application's requirements. The next sections describe these types of stub support routines in more detail.

16.3.3.1 Buffer-Sizing Routines

Different code sets use different numbers of bytes to encode a single character. Consequently, there is always the possibility that the converted string can be larger than the original string when converting data from one code set to another. The function of the buffer-sizing routines is to calculate the necessary buffer size for code set conversion between local and network code sets and return their findings to the client and server stubs, which call these buffer-sizing routines before marshalling and unmarshalling any international character data. The stubs then allocate a new buffer, if necessary, before calling the code set conversion routines.

You must provide the following buffer-sizing routines for each local type that you define with the **cs_char** attribute:

- *local_type_name* **_net_size()**—Calculates the necessary buffer size for code set conversion from a local code set to a network code set. Client and server stubs call this routine before they marshall any international character data.
- *local_type_name* **_local_size()**—Calculates the necessary buffer size for code set conversion from a network code set to a local code set. Client and server stubs call this routine before they unmarshall any international character data.

You specify the name for the local data type in the *local_type_name* portion of the function name and the appropriate suffix name (**_net_size** or **_local_size**).

DCE RPC provides buffer-sizing routines for the **cs_byte** and **wchar_t** data types. The **cs_byte** data type is equivalent to the **byte** type, while the **wchar_t** data type is a platform-dependent data type whose range of values can represent encodings for all members of the largest international character set that exists within the set of character/ code sets supported on the host.

The DCE RPC buffer-sizing routines are

- **cs_byte_net_size()**—Calculates the necessary buffer size for code set conversion from a local code set to a network code set when the **cs_byte** type has been specified as the local data type in the .**acf** file.
- **cs_byte_local_size()—**Calculates the necessary buffer size for code set conversion from a network code set to a local code set when the **cs_byte** type has been specified as the local data type in the **.acf** file.
- **wchar_t_net_size()—**Calculates the necessary buffer size for code set conversion from a local code set to a network code set when the **wchar_t** data type has been specified as the local data type in the **.acf** file.
- **wchar_t_local_size()**—Calculates the necessary buffer size for code set conversion from a network code set to a local code set when the **wchar_t** data type has been specified as the local data type in the **.acf** file.

If your internationalized RPC application uses either of these data types as the local type in the ACF, it can use these DCE RPC buffer-sizing routines; in order to do so, simply link with the DCE library when compiling your application. The example ACF shown earlier in this chapter uses the **cs_byte** type as the local type. Consequently, the client and server stubs will use the **cs_byte_** buffer-sizing routines. Refer to the **cs_byte_** * **(3rpc)** and **wchar_t_*** **(3rpc)** reference pages for a description of the **cs_byte_** and **wchar_t_** routine signatures and functions.

Applications that use data types other than **cs_byte** or **wchar_t** as their local data types will need to provide their own buffer-sizing routines. User-provided buffer-sizing routines must follow the same signature as the DCE RPC-provided buffer-sizing routines. See the **cs_byte_*(3rpc)** and **wchar_t_** ***(3rpc)** reference pages for a description of the required routine signatures.

16.3.3.2 Code Set Conversion Routines

When RPC clients and servers exchange international character data, the data being exchanged needs to be understood by both client and server. Both client and server need to understand a character set, and both client and server need to understand the way that character set is expressed. Code set conversion provides a way for a character set to be represented in a form that both client and server can understand, given that the client and server are using a compatible character set. (In general, character set conversion is not recommended; it is unlikely that clients and servers would want to map, for example, German characters to Chinese characters due to the data loss that would occur as a result.)

The stub support routines for code set conversion provide the mechanism for the stubs to use to convert between different code sets, given that character set compatibility has been established. The code set conversion routines translate a character set from one encoding to another. Consequently, the code set conversion routines provide the way for a character set to be represented in a form that both client and server can understand.

You must provide the following code set conversion routines for each local type that you define with the **cs_char** attribute:

- *local_type_name* **_to_netcs()**—Converts international character data from a local code set to a network code set. Client and server stubs call this routine before they marshall any international character data.

- *local_type_name* **_from_netcs()**—Converts international character data from a network code set to a local code set. Client and server stubs call this routine before they unmarshall any international character data.

You specify the name for the local data type in the *local_type_name* portion of the function name and the appropriate suffix name (**_to_netcs** or **_from_netcs**).

DCE RPC provides code set conversion routines for the **cs_byte** and **wchar_t** data types. These routines are

- **cs_byte_to_netcs()**—Converts international character data from a local code set to a network code set when the **cs_byte** type has been specified as the local data type in the **.acf** file.

- **cs_byte_from_netcs()**—Converts international character data from a network code set to a local code set when the **cs_byte** type has been specified as the local data type in the **.acf** file.
- **wchar_t_to_netcs()**—Converts international character data from a local code set to a network code set when the **wchar_t** data type has been specified as the local data type in the **.acf** file.
- **wchar_t_from_netcs()**—Converts international character data from a network code set to a local code set when the **wchar_t** data type has been specified as the local data type in the **.acf** file.

If your application uses either of these data types as the local type, it can use these DCE RPC code set conversion routines; in order to do so, simply link with the DCE library when compiling your application. Refer to the **cs_byte_ * (3rpc)** and **wchar_t_* (3rpc)** reference pages for a description of the **cs_byte_** and **wchar_t_** routine signatures and functions.

Applications that use data types other than **cs_byte** or **wchar_t** as their local data types will need to provide their own code set conversion routines. User-provided code set conversion routines must follow the same signature as the DCE RPC-provided code set conversion routines. See the **cs_byte_ *(3rpc)** and **wchar_t_ * (3rpc)** reference pages for a description of the **cs_byte_** and **wchar_t_** routine signatures and functions.

The DCE code set conversion routines depend upon the presence of the XPG4 **iconv** code set conversion facility in the underlying operating system platform. The **iconv** facility consists of the following routines:

- **iconv_open()**—Code conversion allocation function; returns a conversion descriptor that describes a conversion from the code set specified in one string pointer argument to the code set specified in another string pointer argument.
- **iconv()**—Code conversion function; converts the sequence of characters from one code set into a sequence of corresponding characters in another code set.
- **iconv_close()**—Code conversion deallocation function; deallocates the conversion descriptor and all associated resources allocated by the **iconv_open()** function.

Note that the **iconv** facility identifies a code set by a string name. This string name is the name that the local platform uses to refer to the code set. However, all of the stub support routines for automatic code set conversion use the unique identifier assigned to the code set in the code set registry to identify a code set. Before the DCE code

set conversion routines can invoke the **iconv** facility, they must access the code set registry to retrieve the platform-specific string names associated with the local and network code set identifiers.

The DCE code set conversion routines use the **dce_cs_loc_to_rgy()** and **dce_cs_rgy_to_loc()** routines to access the code set registry and translate between code set string names and their corresponding unique identifiers. The *DCE 1.2.2 Application Development Reference* provides a description of these routines' signatures and functions; developers who are writing their own code set conversion routines and who are using the **iconv** facility for conversion may want to use these DCE routines to convert between code set names and identifiers.

16.3.3.3 Tag-Setting Routine

Recall from Section 16.3.1 that operations that specify international characters as input and output parameters declare special code set tag parameters. The purpose of these parameters is to hold the unique identifier for the code set into which the input or output data is to be encoded when it is transferred over the network.

The function of the tag-setting routine is to provide a way to set an operation's code set tag parameters to specific code set values from within the stubs rather than in the application code. The application specifies the name of the tag-setting routine as the argument to the **cs_tag_rtn** ACF attribute; the client and server stubs call this routine when the operation is invoked to set the tag parameters to specific network code set values before they call the stub support routines for buffer-sizing and code set conversion. The stubs use the network code set values returned by the tag-setting routine as input to the buffer-sizing and conversion routines. In turn, these routines compare the network code set values to be used for input and output data to the local code set in use for the data, and determine whether or not new buffer allocation and code set conversion are necessary.

When called from the client stub, the tag-setting routine sets the sending tag parameter to the code set to use for input character data. If the client expects output character data from the server, the routine also sets the desired receiving tag parameter to the code set that the client prefers the server to use for sending back the output data. On the client side, the buffer-sizing routines *local_type_name*_**net_size()** and the code set conversion routines *local_type_name* **_to_netcs()** use the value in the sending tag as the network code set value to use for transmitting the input data. When the

input data arrives at the server side, the server stub uses the sending tag as input to the *local_type_name* **_local_size()** buffer-sizing routine and the *local_type_name* **_from_netcs()** code set conversion routines, which use the value to determine whether or not new buffer allocation and conversion is necessary from the network code set to the local code set.

When called from the server stub, the tag-setting routine sets the receiving tag parameter to the code set to use for transmitting the output character data back to the server. The routine can use the desired receiving tag value as input to determine the most appropriate code set in which to encode output data for the client. On the server side, the buffer-sizing routines *local_type_name*_**net_size()** and the code set conversion routines *local_type_name* **_to_netcs()** use the value in the receiving tag as the network code set value to use for transmitting the output data. When the output data arrives at the client side, the client stub uses the receiving tag as input to the *local_type_name* **_local_size()** buffer-sizing routine and the *local_type_name* **_from_netcs()** code set conversion routines, which use the value to determine whether or not new buffer allocation and conversion is necessary from the network code set to the local code set.

DCE RPC provides one tag-setting routine named **rpc_cs_get_tags()** that applications can use to set code set tag values within the stubs. To use this routine, specify its name as the argument to the **cs_tag_rtn** attribute and link your application with the DCE library. The example ACF for the **cs_test** interface specifies the **rpc_cs_get_tags()** routine.

Note that the **rpc_cs_get_tags()** routine always sets the receiving tag value on the server side to the value that the client specified in the desired receiving tag. See the **rpc_cs_get_tags(3rpc)** reference page for an explanation of this routine's signature and function.

RPC application programmers who are developing their own tag-setting routines can also refer to the **rpc_cs_get_tags(3rpc)** reference page to obtain the required signature for their user-written routine.

The tag-setting routine generally obtains the code set tag values from the binding handle. These values are usually determined by the character and code set evaluation routine invoked during the server binding import process, although they can be explicitly set in the binding handle by using the **rpc_cs_binding_set_tags()** routine. However, applications can design the tag-setting routine to perform evaluation within the stubs rather than in the application (client) code. For example, when called from

the client side, the DCE RPC tag-setting routine **rpc_cs_get_tags()** performs character and code set compatibility evaluation itself if it does not find the tag values in the binding handle. See Section 16.3.6 for more information on deferred evaluation.

16.3.4 Writing the Server Code

A programmer who is developing an RPC server that supports character and code set interoperability needs to add the following steps to the server's initialization functions in addition to the normal initialization functions it carries out for RPC:

- Setting the server's locale
- Establishing the server's supported code sets
- Registering the server's supported code sets in the name service database
- Establishing a cleanup function that removes the server's supported code sets from the name service database on the server's termination or exit.

The next sections explain these steps in detail.

16.3.4.1 Setting the Server's Locale

The server initialization code needs to include a platform-specific routine that sets the locale environment for the server. This step establishes

- The name of the server's local code set.
- The names of the code sets for which converters exist on the host and consequently, into which processes that run on the host can convert if necessary.

An example of a locale-setting function is the POSIX, XPG3, XPG4 **setlocale()** function, which is defined in **locale.h**. The server code should call the locale-setting function as the first step in the initialization code, before calling the DCE RPC routines that register the interface and export the binding information.

The locale-setting function also establishes the value for two platform-specific macros that indicate

- The maximum number of bytes the local code set uses to encode one character.

- The maximum number of bytes that any of the supported code sets on the host will use to encode one character.

On POSIX, XPG3, and XPG4 platforms, these macros are **MB_CUR_MAX** and **MB_LEN_MAX** and are defined in **stdlib.h** and **limits.h**, respectively. The buffer-sizing routines use **MB_CUR_MAX** when calculating the size of a new buffer to hold converted character data.

Note that all hosts that are members of an internationalized DCE cell (that is, a cell that supports internationalized RPC applications) must provide converters that convert between their supported code sets and the ISO 10646 universal code set. The DCE RPC functions for character and code set interoperability use the universal code set as the default intermediate code set into which a client or server can convert if there are no other compatible code sets between them. Section 16.3.6 discusses intermediate code sets in more detail.

16.3.4.2 Establishing the Server's Supported Code Sets

The next step in writing an internationalized RPC server is to add to the server's initialization code a call to the DCE RPC routine **rpc_rgy_get_codesets()**. This routine gets the supported code set names defined in the locale environment and translates those names to their unique identifiers by accessing the code set registry on the host. The server initialization code should call this routine after it has registered the interface and created a server entry for its binding information in the name service database (by calling the DCE RPC NSI binding export routine **rpc_ns_binding_export()**).

The routine returns an array of unique identifiers from the code set registry that correspond to the server's local code set and the code sets into which the server can convert, if necessary; this data structure is called the *code sets array*. The code sets array also contains, for each code set, the maximum number of bytes that code set uses to encode one character.

The purpose of this step is to obtain the registered unique identifiers for the server's supported code sets for use by the DCE character and code set interoperability features, rather than using the string names for the code sets. The DCE features for character and code set interoperability do not use string names because different operating systems commonly use different string names to refer to the same code set, and clients and

servers passing international characters in a cell of heterogeneous platforms need to ensure that they both refer to the same code set when establishing compatibility.

The code set registry provides the means for clients and servers to uniquely identify a code set while permitting different platforms and the code set converters offered on those platforms to continue to use the string names for the code sets.

See the **rpc_rgy_get_codesets(3rpc)** reference pages for a description of the **rpc_rgy_get_codesets()** routine's signature and arguments.

16.3.4.3 Registering the Server's Supported Code Sets in the Namespace

The next step in writing an internationalized RPC server is to make a call in the server's initialization code to the DCE RPC routine **rpc_ns_mgmt_set_attribute()**, which takes the code sets array returned by **rpc_rgy_get_codesets()** and exports it to the server's entry in the name service database. The routine creates a code sets NSI attribute in the name service database and associates it with the server entry created by the NSI export operation.

The purpose of this step is to register the server's supported code sets into the name service database so that clients can gain access to the information. Note, then, that server entries for internationalized RPC servers will have code sets attributes in addition to the binding attributes and object attributes for the servers. For a general discussion of NSI attributes, see Chapter 14. Refer to the **rpc_ns_mgmt_set_attribute(3rpc)** reference page for a description of the **rpc_ns_mgmt_set_attribute()** routine's signature and arguments.

16.3.4.4 Establishing a Cleanup Function for the Namespace

The last step in writing an internationalized RPC server is to add a call to the DCE RPC routine **rpc_ns_mgmt_remove_attribute()** to the cleanup code within the server's initialization code. This DCE RPC routine will remove the code sets attribute associated with the server entry from the name service database when it is called from the cleanup code as the result of a server crash or exit. See

the **rpc_ns_mgmt_remove_attribute(3rpc)** reference page for a description of the **rpc_ns_mgmt_remove_attribute()** routine's signature and arguments.

16.3.4.5 Sample Server Code

Here is an example of an internationalized RPC server that exports the **cs_test** interface defined in Section 16.3.1.

```
#include <stdio.h>
#include <stdlib.h>
#include <dce/rpc.h>
#include <dce/nsattrid.h>
#include <dce/dce_error.h>
#include <locale.h>
#include <pthread.h>
#include <dce/codesets.h>
#include "cs_test.h"

/*
 * Macro for result checking
 */
#define CHECK_STATUS(t, func, returned_st, expected_st) \
{ \
    if (returned_st == expected_st) { \
    } \
    else { \
 dce_error_inq_text(returned_st, \
  (unsigned char *)unexpected, &dce_status); \
 dce_error_inq_text(expected_st,\
  (unsigned char *)expected, &dce_status); \
 printf("FAILED %s()\nresult:   %s\nexpected:   %s\n\n", \
     func, unexpected, expected); \
    } \
} \

static unsigned char unexpected[dce_c_error_string_len];
static unsigned char expected[dce_c_error_string_len];
```

```
static int  dce_status;

int
main(int argc, char *argv[])
{
    error_status_t  status;
    int    i;
    rpc_ns_handle_t  inq_contxt;
    rpc_binding_vector_t *binding_vector;
    rpc_codeset_mgmt_p_t  arr;
    pthread_t   this_thread = pthread_self();
    sigset_t   sigset;
    char   *nsi_entry_name;
    char   *server_locale_name;
    error_status_t  expected = rpc_s_ok;
    int    server_pid;

    /* The environment variable I18N_SERVER_ENTRY needs
     * to be set before running this program.  This is
     * not a DCE environment variable, so you can set up
     * your own environment variable if you like.
     */

    nsi_entry_name = getenv("I18N_SERVER_ENTRY");

    (void)pthread_mutex_init(&mutex, pthread_mutexattr_default);

    /* Set the locale.  In this way, the current locale
     * information is extracted from XPG/POSIX defined
     * environment variable LANG or LC_ALL.
     */

    setlocale(LC_ALL, "");

    /*
     * Get supported code sets.
     */
    rpc_rgy_get_codesets (
 &arr,
 &status );
```

```
CHECK_STATUS(TRUE, "rpc_rgy_get_codesets", status, expected);

   rpc_server_register_if (
cs_test_v1_0_s_ifspec,
NULL,
NULL,
&status );

   CHECK_STATUS(TRUE, "rpc_server_register_if", status, expected);

   rpc_server_use_all_protseqs (
rpc_c_protseq_max_reqs_default,
&status );

   CHECK_STATUS(TRUE, "rpc_server_use_all_protseqs", status, expected);

   rpc_server_inq_bindings (
&binding_vector,
&status );

   CHECK_STATUS(TRUE, "rpc_server_inq_bindings", status, expected);

   rpc_ns_binding_export (
rpc_c_ns_syntax_default,
(unsigned_char_p_t)nsi_entry_name,
cs_test_v1_0_s_ifspec,
binding_vector,
NULL,
&status );

   CHECK_STATUS(TRUE, "rpc_ns_binding_export", status, expected);

   rpc_ep_register (
cs_test_v1_0_s_ifspec,
binding_vector,
NULL,
NULL,
&status );
```

```
   CHECK_STATUS(TRUE, "rpc_ep_register", status, expected);

   /*
    * Register the server's supported code sets into the name space.
    */
   rpc_ns_mgmt_set_attribute (
rpc_c_ns_syntax_default,
(unsigned_char_p_t)nsi_entry_name,
rpc_c_attr_codesets,
(void *)arr,
&status );

   CHECK_STATUS(TRUE, "rpc_ns_mgmt_set_attribute", status, expected);

   /*
    * Free memory allocated by getting code sets.
    */
   rpc_ns_mgmt_free_codesets (&arr, &status);

   CHECK_STATUS(TRUE, "rpc_ns_mgmt_free_codeset", status, expected);

   sigemptyset(&sigset);
   sigaddset(&sigset, SIGINT);

   if (pthread_signal_to_cancel_np(&sigset, &this_thread) != 0)
   {
printf("pthread_signal_to_cancel_np failed\n");
exit(1);
   }
   TRY
   {
server_pid = getpid();

printf("Listening for remote procedure calls...\n");

rpc_server_listen (
    rpc_c_listen_max_calls_default,
&status );

CHECK_STATUS(TRUE, "rpc_server_listen", status, expected);
```

```
/*
 * Remove code set attributes from namespace on return.
 */
rpc_ns_mgmt_remove_attribute (
    rpc_c_ns_syntax_default,
    (unsigned_char_p_t)nsi_entry_name,
    rpc_c_attr_codesets,
    &status );

CHECK_STATUS(TRUE, "rpc_ns_mgmt_remove_attribute", status, \
  expected);

rpc_ns_binding_unexport (
    rpc_c_ns_syntax_default,
    (unsigned_char_p_t)nsi_entry_name,
    cs_test_v1_0_s_ifspec,
    (uuid_vector_p_t)NULL,
    &status );

CHECK_STATUS(TRUE, "rpc_ns_binding_unexport", status, expected);

rpc_ep_unregister (
    cs_test_v1_0_s_ifspec,
    binding_vector,
    NULL,
    &status );

CHECK_STATUS(TRUE, "rpc_ep_unregister", status, expected);

rpc_binding_vector_free (
    &binding_vector,
    &status );

CHECK_STATUS(TRUE, "rpc_binding_vector_free", status, expected);

rpc_server_unregister_if (
    cs_test_v1_0_s_ifspec,
    NULL,
    &status );
```

```
CHECK_STATUS(TRUE, "rpc_server_unregister_if", status, expected);

(void)pthread_mutex_destroy(&mutex);
   }
   CATCH_ALL
   {
/*
 * Remove code set attribute from namespace on a signal.
 */
rpc_ns_mgmt_remove_attribute (
    rpc_c_ns_syntax_default,
    (unsigned_char_p_t)nsi_entry_name,
    rpc_c_attr_codesets,
    &status );

CHECK_STATUS(TRUE, "rpc_ns_mgmt_remove_attribute", status, \
  expected);

rpc_ns_binding_unexport (
    rpc_c_ns_syntax_default,
    (unsigned_char_p_t)nsi_entry_name,
    cs_test_v1_0_s_ifspec,
    (uuid_vector_p_t)NULL,
    &status );

CHECK_STATUS(TRUE, "rpc_ns_binding_unexport", status, expected);

rpc_ep_unregister (
    cs_test_v1_0_s_ifspec,
    binding_vector,
    NULL,
    &status );

CHECK_STATUS(TRUE, "rpc_ep_unregister", status, expected);

rpc_binding_vector_free (
    &binding_vector,
    &status );
```

```
 CHECK_STATUS(TRUE, "rpc_binding_vector_free", status, expected);

 rpc_server_unregister_if (
     cs_test_v1_0_s_ifspec,
     NULL,
     &status );

 CHECK_STATUS(TRUE, "rpc_server_unregister_if", status, expected);

 (void)pthread_mutex_destroy(&mutex);
    }
    ENDTRY;
}
```

16.3.5 Writing the Client Code

A programmer who is developing an RPC client that supports character and code set interoperability needs to add the following steps to the client code in addition to the basic functions for RPC:

1. Setting the client's locale
2. Establishing a character and code set compatibility evaluation routine that the NSI server binding import routines will call to evaluate potential servers for character and code set compatibility

The next sections explain these steps in detail.

16.3.5.1 Setting the Client's Locale

The first step in developing an internationalized RPC client is to add a call within the client code to a platform-specific function that sets the locale environment for the client. This step establishes

- The name of the client's local code set.

- The names of the code sets for which converters exist on the host and, consequently, into which processes that run on the host can convert if necessary.

The call to the locale-setting function must be the first call made within the client code. An example of a locale-setting function is the POSIX, XPG3, XPG4 **setlocale()** function, which is defined in **locale.h**.

The locale-setting function also establishes the value for two platform-specific macros that indicate

- The maximum number of bytes the local code set uses to encode one character.
- The maximum number of bytes that any of the supported code sets on the host will use to encode one character.

On the POSIX, XPG3, XPG4 platform, these macros are **MB_CUR_MAX** and **MB_LEN_MAX** and are defined in **stdlib.h** and **limits.h**, respectively. The buffer-sizing routines use the **MB_CUR_MAX** macro when calculating the size of a new buffer to hold converted character data.

Note that all hosts that are members of an internationalized DCE cell must provide converters that convert between their supported code sets and the ISO 10646 universal code set. The DCE RPC functions for character and code set interoperability use the universal code set as the default intermediate code set into which a client or server can convert if there are no other compatible code sets between them. Section 16.3.6 discusses intermediate code sets in more detail.

16.3.5.2 Establishing the Compatibility Evaluation Routine

The last step in writing an internationalized RPC client is to call the DCE RPC NSI routine **rpc_ns_import_ctx_add_eval()**. The purpose of this NSI routine is to add evaluation routines to the import context created by the **rpc_ns_binding_import_begin()** routine that the NSI routine **rpc_ns_binding_import_next()** will call to perform additional compatibility evaluation on potential servers.

The internationalized RPC client code calls the **rpc_ns_import_ctx_add_eval()** routine to set up one or more character and code set compatibility evaluation routines to be called from **rpc_ns_binding_import_next()**. The client code must

make the call to **rpc_ns_import_ctx_add_eval()** once for each compatibility routine that it wants to add to the import context for **rpc_ns_binding_import_next()**. See the **rpc_ns_import_ctx_add_eval(3rpc)** reference page for a description of the **rpc_ns_import_ctx_add_eval()** routine's signature and arguments.

The **rpc_ns_import_ctx_add_eval()** must be used in conjunction with the **rpc_ns_binding_import_begin/next/done()** suite of RPC NSI binding functions because these functions provide an import context argument. If you want to use the **rpc_ns_binding_lookup_begin/next/done/select()** suite of RPC NSI routines, your client code will need to perform character and code set evaluation logic on the binding handle returned by **rpc_ns_binding_select()**. Section 16.3.6.4 provides a sample client that performs character and code set evaluation in conjunction with the **lookup** and **select** RPC NSI routines.

16.3.5.3 Sample Client Code

Here is an example of an internationalized RPC client that calls the operation defined in the **cs_test** interface shown in Section 16.3.1. The client establishes the DCE RPC evaluation routine **rpc_cs_eval_without_universal()** as the character and code set evaluation routine to use.

```
#include <stdio.h>
#include <locale.h>
#include <dce/rpc.h>
#include <dce/rpcsts.h>
#include <dce/dce_error.h>

#include "cs_test.h"  /* IDL generated header file */

/*
 * Result check MACRO
 */
#define CHECK_STATUS(t, func, returned_st, expected_st) \
{ \
 if (returned_st == expected_st) { \
/*
 * Do nothing.
```

```
 */
    } else { \
 dce_error_inq_text(returned_st,\
   (unsigned char *)unexpected, &dce_status); \
 dce_error_inq_text(expected_st, \
   (unsigned char *)expected, &dce_status); \
 printf("FAILED %s()\nresult:   %s\nexpected:   %s\n\n", \
     func, unexpected, expected); \
    } \
} \

static unsigned char unexpected[dce_c_error_string_len];
static unsigned char expected[dce_c_error_string_len];
static int  dce_status;

void
main(void)
{
    rpc_binding_handle_t    bind_handle;
    rpc_ns_handle_t         import_context;
    error_status_t     status;
    error_status_t     temp_status;
    cs_byte      net_string[SIZE];
    cs_byte      loc_string[SIZE];
    unsigned char     err_buf[256];
    char      *nsi_entry_name;
    char      *client_locale_name;
    int       i, rpc_num;
    FILE      *fp_in, *fp_out;

    /* The environment variable I18N_SERVER_ENTRY needs
     * to be set before running this program.  This is
     * not a DCE environment variable, so you can set up
     * your own environment variable if you like.
     */

    nsi_entry_name = getenv("I18N_SERVER_ENTRY");

    setlocale(LC_ALL, "");
```

```
   rpc_ns_binding_import_begin (
rpc_c_ns_syntax_default,
(unsigned_char_p_t)nsi_entry_name,
cs_test_v1_0_c_ifspec,
NULL,
&import_context,
&status );

   CHECK_STATUS(TRUE, "rpc_ns_binding_import_begin", status, rpc_s_ok);

   /*
    *  Add code set compatibility checking logic to the context.
    */
   rpc_ns_import_ctx_add_eval (
&import_context,
rpc_c_eval_type_codesets,
(void *)nsi_entry_name,
rpc_cs_eval_without_universal,
NULL,
&status );

   CHECK_STATUS(TRUE, "rpc_ns_import_ctx_add_eval", status, rpc_s_ok);

   while (1) {
rpc_ns_binding_import_next (
    import_context,
    &bind_handle,
    &status );

CHECK_STATUS(TRUE, "rpc_ns_binding_import_next", status, \
  rpc_s_ok);
    if (status == rpc_s_ok)
 break;
    else
    {
 return;
    }
   }

   rpc_ns_binding_import_done (
```

```
&import_context,
&status );

   CHECK_STATUS(TRUE, "rpc_ns_binding_import_done", status, rpc_s_ok);

   rpc_ep_resolve_binding (bind_handle,
cs_test_v1_0_c_ifspec,
&temp_status);

   CHECK_STATUS(TRUE, "rpc_ep_resolve_binding", temp_status, rpc_s_ok);

   if(rpc_mgmt_is_server_listening(bind_handle, &status)
&& temp_status == rpc_s_ok)
   {
; /* Do nothing. */
   }
   else
   {
dce_error_inq_text ((unsigned long)status,
 err_buf, (int *)&temp_status);
printf("is_server_listening error -> %s\n", err_buf);
   }

   /*
    *  This program reads the data from a file.
    */

   fp_in = fopen("./i18n_input_data", "r");

   if (fp_in == NULL)
   {
printf("i18n_input_data open failed\n");
return;
   }

    fp_out = fopen("./i18n_method_fixed_result_file", "w");

    if (fp_out == NULL)
    {
printf("i18n_result_file open failed\n");
```

```
 fclose(fp_in);
 return;
    }

    rpc_num = 1;
    while (!feof(fp_in))
    {
 (void)fgets((char *)net_string, SIZE, fp_in);

 temp_status = cs_fixed_trans(bind_handle, net_string, loc_string);

 if (temp_status != rpc_s_ok)
 {
     dce_error_inq_text(temp_status, err_buf, (int *)&status);

     printf("FAILED %ld  MSG: %s\n", (unsigned long)temp_status, \
       err_buf);
 }
 else
 {
     printf("PASSED rpc #%d\n", rpc_num++);
     (void)fputs((char *)loc_string, fp_out);
     (void)fputs("\n", fp_out);
 }
    }

    fclose(fp_in);
    fclose(fp_out);

    return;
}
```

16.3.6 Writing the Evaluation Routine

Recall from Chapter 1 of the *DCE 1.2.2 Application Development—Introduction and Style Guide* and Chapter 11 of this guide that when a prospective client attempts to import binding information from a namespace entry that it looks up by name, the NSI

import routine checks the binding for compatibility with the client by comparing interface UUIDs and protocol sequences. If the UUIDs match and the protocol sequences are compatible, the NSI operation considers the binding handle contained in the server entry to be compatible and returns it to the client. Internationalized clients need to perform additional compatibility checking on potential server bindings: they need to evaluate the server for character and code set compatibility.

The purpose of the character and code set compatibility evaluation routine is to determine

- Whether the character set the server supports is compatible with the client's character set, since incompatible character sets result in unacceptable data loss during character conversion.
- The level of code set compatibility between client and server, which determines the *conversion method* that the client and server will use when transferring character data between them.

A conversion method is a process for converting one code set into another. There are four conversion methods:

- Receiver Makes It Right (RMIR)—The recipient of the data is responsible for converting the data from the sender's code set to its own code set. This is the method that the RPC communications protocol uses to convert PCS character data between ASCII and EBCDIC code sets.
- Client Makes It Right (CMIR)—The client converts the input character data to be sent to the server into the server's code set before the data is transmitted over the network, and converts output data received from the server from the server's code set into its own local code set.
- Server Makes It Right (SMIR)—The server converts the input character data received from the client into its local code set from the client's code set and converts output data to be sent to the client into the client's code set before the data is transmitted over the network.
- Intermediate—Both client and server convert to a common code set. DCE defines a default intermediate code set to be used when there is no match between the client and server's supported code sets; this code set is the ISO 10646 universal code set. Sites can also specify other code sets to be used as intermediate code sets in preference to ISO 10646; to do this, they run the **csrc** utility. See the **csrc(8dce)** reference pages for a description of **csrc** utility usage.

A character and code set compatibility evaluation routine generally employs a *conversion model* when determining the level of code set compatibility. A conversion model is an ordering of conversion methods; for example, CMIR first, then SMIR, then intermediate. Consequently, the actual conversion method used is determined at runtime.

16.3.6.1 DCE RPC Evaluation Routines

DCE RPC provides two character and code set compatibility evaluation routines: **rpc_cs_eval_with_universal()** and **rpc_cs_eval_without_universal()**. To use either one of these routines, specify their names in the evaluation function argument to the **rpc_ns_import_ctx_add_eval()** routine. (The sample client code shown in Section 16.3.5.3 specifies a DCE RPC character and code set evaluation routine.)

The **rpc_cs_eval_with_universal()** routine first compares the client's local code set with the server's local code set. If they are the same, client-server character and code set compatibility exists. The routine returns to the NSI import routine, which returns the server binding to the client.

If the routine finds that the client and server local code sets differ, it calls the routine **rpc_cs_char_set_compat_check()** to determine client-server character set compatibility. If the client and server are using the same character set, it will be safe for them to exchange character data despite their use of different encodings for the character data. Clients and servers using different character sets are considered to be incompatible since the process of converting the character data from one character set to the other will result in significant data loss.

Using the client and server's local code set identifiers as indexes into the code set registry, the **rpc_cs_char_set_compat_check()** routine obtains the registered values that represent the character set(s) that the specified code sets support. If the client and server support just one character set, the routine compares the values for compatibility. If the values do not match, then the client-server character sets are not compatible; for example, the client is using the German character set and the server is using the Korean character set. In this case, the routine returns the status code **rpc_s_ss_no_compat_charsets** to the evaluation routine so that binding to that server will be rejected.

If the client and server support multiple character sets, the **rpc_cs_char_set_compat_check()** routine determines whether at least two of the sets are compatible. If two or more sets match, the routine considers the character sets compatible and returns a success status code to the evaluation routine.

In the case where the client and server are character set compatible, the **rpc_cs_eval_with_universal()** routine uses the following model to determine a conversion method:

- RMIR (receiver makes it right)
- SMIR (client uses its local code set, server converts to and from it)
- CMIR (server uses its local code set, client converts to and from it)
- Use an intermediate code set
- Use the universal (ISO 10646) code set

This conversion model translates into the following steps:

1. The **rpc_cs_eval_with_universal()** routine takes the client's local code set and searches through the server's code sets array to determine whether it has a converter for the client's local set. Then it takes the server's local code set and searches through the client's code sets array to see if it has a converter for the server's local code set.
2. If both client and server support converters for each other's local code sets (that is, they can convert to and from each other's local code set), the routine sets the conversion method to RMIR.
3. If the server can convert to and from the client's local code set, but the client cannot convert from the server's local code set, the routine sets the conversion method to SMIR.
4. If the client can convert to and from the server's local code set, but the server cannot convert to and from the client's local code set, the routine sets the conversion method to CMIR.

   If the conversion method is SMIR or RMIR, the **rpc_cs_eval_with_universal()** routine sets both the sending tag and the desired receiving tag to the code set value that represents the client's local code set. In the case of CMIR, the routine sets both the sending tag and the desired receiving tag to the code set value that represents the server's local code set.

5. If neither client nor server support each other's local code set, the routine next determines if they both support a code set into which they both can convert to/ from their local code sets. If it finds an intermediate set into which they both can convert, it sets the conversion method to INTERMEDIATE and sets the sending tag and desired receiving tag to the code set value that represents the intermediate code set to use.
6. If the routine does not find any intermediate code set into which client and server can convert, it sets the sending tag and desired receiving tag to the code set value that represents the ISO 10646 universal code set, which is the default intermediate code set that all DCE clients and servers support.

The **rpc_cs_eval_without_universal()** routine uses the following conversion model to determine a conversion method:

- RMIR
- SMIR (client uses its local code set, server converts to and from it)
- CMIR (server uses its local code set, client converts to and from it)
- Intermediate
- Reject for code set incompatibility

Consequently, the **rpc_cs_eval_without_universal()** uses the same evaluation logic as **rpc_cs_eval_with_universal()** except that it rejects the server binding if the client and server do not support a common code set to use as an intermediate code set.

16.3.6.2 Writing Customized Evaluation Routines

Programmers writing internationalized RPC applications can develop their own character and code set compatibility evaluation routines if their applications' needs are not met by the DCE RPC evaluation routines. These programmers may want to use the following DCE RPC routines within their evaluation routine:

- The **rpc_rgy_get_codesets()** routine
- The **rpc_cs_char_set_compat_check()** routine
- The **rpc_cs_binding_set_tags()** routine
- The **dce_cs_loc_to_rgy()** routine

- The **rpc_ns_mgmt_read_codesets()** routine
- The **rpc_ns_mgmt_free_codesets()** routine

Refer to the *DCE 1.2.2 Application Development Reference* for complete details about these routines.

Programmers who write their own evaluation routines can also select when evaluation is performed; that is, they can defer evaluation from occurring in the client code, or they can defer evaluation completely at the client side and let it take place in the server instead. Programmers who desire to defer evaluation to the client stub can write an evaluation routine that sets the client's and server's supported code sets into the binding handle returned by the client, then write the evaluation logic into the stub support routine for tag setting so that it performs evaluation within the client stub.

Applications that do evaluation in the client stub take the chance that the binding handle that is evaluated is the only binding handle available. For example, suppose there are three binding handles. Two are character and code set compatible, and one is incompatible. The incompatible binding is selected for RPC. If you evaluate in the tag-setting routine, you cannot reselect to get the other compatible bindings.

In general, it is recommended that character and code set evaluation take place in the client, rather than the server, for performance reasons. Also, once the server is selected and a connection is established between it and the client, the client cannot typically reselect the server because the code sets are incompatible.

Within the client, it is recommended that evaluation be performed in the client code rather than in the client stub because deferring evaluation to occur in the client stub removes any way for the client to gain access to other potential binding handles.

16.3.6.3 Notes About Tag Setting

The DCE RPC character and code set compatibility evaluation routines set the method and the code set tag values into a data structure in the binding handle returned to the client. These routines always set the sending tag and desired receiving tag to the same code set value.

In addition, if the application uses the DCE RPC routine **rpc_cs_get_tags()** to set the code set tags for the stubs, the value of the server's receiving tag will always be the

value of what the client sent to it in the desired receiving tag. If RMIR is used, the desired receiving tag is the server's current code set.

RPC application programmers who do not want to use the DCE RPC-provided evaluation routines can use the **rpc_cs_binding_set_tags()** routine to set the code set tag values into a binding handle.

16.3.6.4 Example Character and Code Set Evaluation Logic

Here is an example client program of the **cs_test** interface that provides its own character and code set evaluation logic. This example client uses the **rpc_cs_binding_set_tags()** routine to set the code set tags within the client code rather than using a tag-setting routine to set them within the stub code.

```
#include <stdio.h>
#include <locale.h>
#include <dce/rpc.h>
#include <dce/rpcsts.h>
#include <dce/dce_error.h>

#include "cs_test.h"  /* IDL generated header file */

/*
 * Result check MACRO
 */
#define CHECK_STATUS(t, func, returned_st, expected_st) \
{ \
    if (returned_st == expected_st) { \
    ;  /* No operation */

    } else { \
 dce_error_inq_text(returned_st,\
   (unsigned char *)unexpected, &dce_status); \
 dce_error_inq_text(expected_st,\
  (unsigned char *)expected, &dce_status); \
 printf("FAILED %s()\nresult:   %s\nexpected:   %s\n\n", \
     func, unexpected, expected); \
```

```
    } \
} \

static unsigned char    unexpected[dce_c_error_string_len];
static unsigned char    expected[dce_c_error_string_len];
static int              dce_status;


void
main(void)
{
    rpc_binding_handle_t bind_handle;
    rpc_ns_handle_t lookup_context;
    rpc_binding_vector_p_t bind_vec_p;
    unsigned_char_t *entry_name;
    unsigned32  binding_count;
    cs_byte  net_string[SIZE];
    cs_byte  loc_string[SIZE];
    int   i, k, rpc_num;
    int   model_found, smir_true, cmir_true;
    rpc_codeset_mgmt_p_t client, server;
    unsigned32  stag;
    unsigned32  drtag;
    unsigned16  stag_max_bytes;
    error_status_t  status;
    error_status_t  temp_status;
    unsigned char  err_buf[256];
    char   *nsi_entry_name;
    char   *client_locale_name;
    FILE   *fp_in, *fp_out;

    nsi_entry_name = getenv("I18N_SERVER_ENTRY");

    setlocale(LC_ALL, "");

    rpc_ns_binding_lookup_begin (
 rpc_c_ns_syntax_default,
 (unsigned_char_p_t)nsi_entry_name,
 cs_test_v1_0_c_ifspec,
 NULL,
```

```
rpc_c_binding_max_count_default,
&lookup_context,
&status );

   CHECK_STATUS(TRUE, "rpc_ns_binding_lookup_begin", status, rpc_s_ok);

   rpc_ns_binding_lookup_next (
lookup_context,
&bind_vec_p,
&status );

   CHECK_STATUS(TRUE, "rpc_ns_binding_lookup_next", status, rpc_s_ok);

   rpc_ns_binding_lookup_done (
&lookup_context,
&status );

   CHECK_STATUS(TRUE, "rpc_ns_binding_lookup_done", status, rpc_s_ok);

   /*
    *  Get the client's supported code sets
    */
   rpc_rgy_get_codesets (
&client,
&status );

   CHECK_STATUS(TRUE, "rpc_rgy_get_codesets", status, rpc_s_ok);

   binding_count = (bind_vec_p)->count;
   for (i=0; i < binding_count; i++)
   {
if ((bind_vec_p)->binding_h[i] == NULL)
    continue;

rpc_ns_binding_select (
    bind_vec_p,
    &bind_handle,
    &status );

CHECK_STATUS(FALSE, "rpc_ns_binding_select", status, rpc_s_ok);
```

```
if (status != rpc_s_ok)
{
    rpc_ns_mgmt_free_codesets(&client, &status);
    CHECK_STATUS(TRUE, "rpc_ns_mgmt_free_codesets",
     status, rpc_s_ok);
}

rpc_ns_binding_inq_entry_name (
    bind_handle,
    rpc_c_ns_syntax_default,
    &entry_name,
    &status );

CHECK_STATUS(TRUE, "rpc_ns_binding_inq_entry_name", status, \
  rpc_s_ok);
if (status != rpc_s_ok)
{
    rpc_ns_mgmt_free_codesets(&client, &status);
    CHECK_STATUS(TRUE, "rpc_ns_mgmt_free_codesets",
     status, rpc_s_ok);
}

/*
     *  Get the server's supported code sets from NSI
     */
rpc_ns_mgmt_read_codesets (
    rpc_c_ns_syntax_default,
    entry_name,
    &server,
    &status );

CHECK_STATUS(FALSE, "rpc_ns_mgmt_read_codesets", status, \
  rpc_s_ok);

if (status != rpc_s_ok)
{
rpc_ns_mgmt_free_codesets(&client, &status);
    CHECK_STATUS(TRUE, "rpc_ns_mgmt_free_codesets",
     status, rpc_s_ok);
```

```
}

/*
     *  Start evaluation
     */
if (client->codesets[0].c_set == server->codesets[0].c_set)
{
    /*
     *  client and server are using the same code set
     */
    stag = client->codesets[0].c_set;
    drtag = server->codesets[0].c_set;
    break;
}

/*
 *  check character set compatibility first
 */
rpc_cs_char_set_compat_check (
    client->codesets[0].c_set,
    server->codesets[0].c_set,
    &status );

CHECK_STATUS(FALSE, "rpc_cs_char_set_compat_check",
   status, rpc_s_ok);

if (status != rpc_s_ok)
{
    rpc_ns_mgmt_free_codesets(&server, &status);
    CHECK_STATUS(TRUE, "rpc_ns_mgmt_free_codesets",
     status, rpc_s_ok);
}

smir_true = cmir_true = model_found = 0;

for (k = 1; k <= server->count; k++)
{
    if (model_found)
 break;
```

```
    if (client->codesets[0].c_set
 == server->codesets[k].c_set)
    {
 smir_true = 1;
 model_found = 1;
    }

    if (server->codesets[0].c_set
 == client->codesets[k].c_set)
    {
 cmir_true = 1;
 model_found = 1;
    }
}

if (model_found)
{
    if (smir_true && cmir_true)
    {
 /* RMIR model works */
 stag = client->codesets[0].c_set;
 drtag = server->codesets[0].c_set;
 stag_max_bytes
     = client->codesets[0].c_max_bytes;
    }
    else if (smir_true)
    {
 /* SMIR model */
 stag = client->codesets[0].c_set;
 drtag = client->codesets[0].c_set;
 stag_max_bytes
     = client->codesets[0].c_max_bytes;
    }
    else
    {
 /* CMIR model */
 stag = server->codesets[0].c_set;
 drtag = server->codesets[0].c_set;
 stag_max_bytes
     = server->codesets[0].c_max_bytes;
```

```
    }

    /*
     *  set tags value to the binding
     */
    rpc_cs_binding_set_tags (
 &bind_handle,
 stag,
 drtag,
 stag_max_bytes,
 &status );

    CHECK_STATUS(FALSE, "rpc_cs_binding_set_tags",
     status, rpc_s_ok);
    if (status != rpc_s_ok)
    {
 rpc_ns_mgmt_free_codesets(&server, &status);
 CHECK_STATUS(FALSE, "rpc_ns_mgmt_free_codesets",
  status, rpc_s_ok);
 rpc_ns_mgmt_free_codesets(&client, &status);
 CHECK_STATUS(TRUE, "rpc_ns_mgmt_free_codesets",
  status, rpc_s_ok);
    }
}
else
{
    /*
     *  try another binding
     */
    rpc_binding_free (
 &bind_handle,
 &status );

    CHECK_STATUS(FALSE, "rpc_binding_free", status, rpc_s_ok);
    if (status != rpc_s_ok)
    {
 rpc_ns_mgmt_free_codesets(&server, &status);
 CHECK_STATUS(FALSE, "rpc_ns_mgmt_free_codesets", \
   status, rpc_s_ok);
 rpc_ns_mgmt_free_codesets(&client, &status);
```

```
 CHECK_STATUS(TRUE, "rpc_ns_mgmt_free_codesets", \
   status, rpc_s_ok);
    }
}
   }

   rpc_ns_mgmt_free_codesets(&server, &status);
   CHECK_STATUS(FALSE, "rpc_ns_mgmt_free_codesets", status, rpc_s_ok);

   rpc_ns_mgmt_free_codesets(&client, &status);
   CHECK_STATUS(TRUE, "rpc_ns_mgmt_free_codesets", status, rpc_s_ok);

   if (!model_found)
   {
printf("FAILED No compatible server found\n");
tet_result(TET_DCE_FAIL);
   }

   rpc_ep_resolve_binding (bind_handle,
cs_test_v1_0_c_ifspec,
&temp_status);

   CHECK_STATUS(TRUE, "rpc_ep_resolve_binding", temp_status, rpc_s_ok);

   if(rpc_mgmt_is_server_listening(bind_handle, &status)
&& temp_status == rpc_s_ok)
   {
printf("PASSED rpc_mgmt_is_server_listening());
   }
   else
   {
dce_error_inq_text ((unsigned long)status, err_buf,
 (int *)&temp_status);
    printf("is_server_listening error -> %s\n", err_buf);
   }

   fp_in = fopen("./i18n_input_data", "r");

   if (fp_in == NULL)
   {
```

```
printf("i18n_input_data open failed\n");
tet_result(TET_DCE_FAIL);
   }

   fp_out = fopen("./i18n_tags_fixed_result_file", "w");

   if (fp_out == NULL)
   {
printf("i18n_result_file open failed\n");
tet_result(TET_DCE_FAIL);
   }

   rpc_num = 1;
   while (!feof(fp_in))
   {
(void)fgets((char *)net_string, SIZE, fp_in);

temp_status = cs_fixed_trans(bind_handle, net_string, loc_string);

if (temp_status != rpc_s_ok)
{
    dce_error_inq_text(temp_status, err_buf, (int *)&status);

    printf("FAILED %ld  MSG: %s\n", (unsigned long)temp_status, \
      err_buf);
}
else
{
    printf("PASSED rpc #%d\n", rpc_num++);
    (void)fputs((char *)loc_string, fp_out);
    (void)fputs(", fp_out);
}
   }

   fclose(fp_in);
   fclose(fp_out);

   return;
}
```

Chapter 17

Topics in RPC Application Development

This chapter describes special features of DCE RPC for application development. The topics include

- Memory management
- Error handling
- Context handles
- Pipes
- Nested calls and callbacks
- Routing RPCs
- Portable data and the IDL encoding services

17.1 Memory Management

When called to handle a remote operation, RPC client stubs allocate and free memory by using whatever memory management scheme is currently in effect. The *client code*—the generic code that can be called from either RPC clients or RPC servers—can use DCE RPC stub support routines to control which memory management scheme the stubs will use.

If client code has not explicitly set the memory management routines, the RPC client stubs use the following defaults:

- When called from manager code, and the operation contains one or more parameters that are full or unique pointers, or the ACF **enable_allocate** attribute has been applied, the client stubs use the **rpc_ss_allocate()** and **rpc_ss_free()** routines.
- When called from any other context, the RPC client stubs use the operating system allocation and free routines (for example, **malloc()** and **free()**) on POSIX platforms.

Note that the memory management scheme established, whether explicitly or by default, is on a per-thread basis.

RPC server stubs do not allocate memory. Instead, they rely on the *manager code*—the code that the server stubs call—to allocate it for them.

The following sections gives guidelines for how client code and manager code should use the the various allocation and free routines provided with DCE.

Note: DCE provides two versions of DCE RPC stub support routines. The **rpc_ss_*** () routines raise an exception, while the **rpc_sm_*** () routines return an error status value. In all other ways, the routines are identical. It is generally recommended that you use the **rpc_sm_*** () routines instead of the **rpc_ss_*** () routines for compliance with the *Application Environment Specification/ Distributed Computing*.

17.1.1 Using the Memory Management Defaults

If it does not matter to the client code which memory allocation routine the RPC client stubs use, the client code should call the **rpc_ss_client_free()** routine to free any memory that the client stub allocates and returns. The **rpc_ss_client_free()** routine uses the current free routine that is in effect. Client code that uses **rpc_ss_client_free()** must use caution if it calls other routines before it frees all of the pieces of allocated storage with **rpc_ss_client_free()**, because it is possible that the called code has been written so that it swaps in a different allocation/free pair without reestablishing the previous allocation/free pair on exit.

17.1.2 Using rpc_ss_allocate and rpc_ss_free

Both client code and manager code can use **rpc_ss_allocate()** and **rpc_ss_free()**. The next sections describe how.

17.1.2.1 Using **rpc_ss_allocate** and **rpc_ss_free** in Manager Code

Manager code uses either the **rpc_ss_allocate()** and **rpc_ss_free()** routines or the operating system allocation and free routines to allocate and free memory.

Manager code uses **rpc_ss_allocate()** to allocate storage for data that the server stub is to send back to the client. Manager code can either use **rpc_ss_free()** to free the storage explicitly, or it can rely on the server stub to free it. After the server stub marshalls the output parameters, it releases any storage that the manager code has allocated with **rpc_ss_allocate()**.

Manager code can also use the **rpc_ss_free()** routine to release storage pointed to by a full pointer in an input parameter and have the freeing of the memory reflected on return to the calling application if the **reflect_deletions** attribute has been specified as an operation attribute in the interface definition. See Chapter 18 for instructions on how to declare the **reflect_deletions** operation attribute.

Manager code uses the operating system allocation routine to create storage for its internal data. The server stub does not automatically free memory that operating system

allocation routines have allocated. Instead, manager code must use the operating system free routine to deallocate the memory explicitly before it exits.

When manager code makes a remote call, the default memory management routines are **rpc_ss_allocate()** and **rpc_ss_free()**.

17.1.2.2 Using **rpc_ss_allocate** and **rpc_ss_free** in Client Code

Client code may also want to use the **rpc_ss_allocate()** and **rpc_ss_free()** routines as the stub memory management scheme. However, before client code can use **rpc_ss_allocate()** and **rpc_ss_free()**, it must first call the **rpc_ss_enable_allocate()** routine, which enables the use of **rpc_ss_allocate()**. If client code calls **rpc_ss_enable_allocate()**, it must also call the **rpc_ss_disable_allocate()** routine before it exits its thread to disable use of **rpc_ss_allocate()**. This routine releases all of the memory allocated by calls to **rpc_ss_allocate()** in that thread since the call to **rpc_ss_enable_allocate()** was made. As a result, client code can either free each piece of allocated storage with **rpc_ss_free()**, or it can have **rpc_ss_disable_allocate()** free it all at once when it disables the **rpc_ss_allocate/free** memory management scheme.

Before calling **rpc_ss_enable_allocate()**, client code must ensure that it has not been called by code that has already set up the **rpc_ss_allocate/free** memory management scheme. As a result, if the client code can ensure that it has not been called from a manager routine, *and* it can ensure that any previous calls to **rpc_ss_enable_allocate()** have been paired with calls to **rpc_ss_disable_allocate()**, it can safely call **rpc_ss_enable_allocate()**.

If client code cannot ensure that these conditions are true, it should check to make sure the **rpc_ss_allocate/free** scheme has not already been set up. For example:

```
/* Get RPC memory allocation thread handle */

    rpc_ss_thread_handle_t thread_handle;
    idl_void_p_t (*p_saved_alloc)(unsigned long);
    void (*p_saved_free)(idl_void_p_t);

    TRY
        thread_handle = rpc_ss_get_thread_handle();
```

```
    CATCH(pthread_badparam_e)
        thread_handle = NULL;
    ENDTRY

    if (thread_handle == NULL)    {

     /* Set up rpc_ss_allocate environment */

        rpc_ss_enable_allocate();
    }

    rpc_ss_swap_client_alloc_free(
        appl_client_alloc,appl_client_free,
        &p_saved_alloc,&p_saved_free);
```

After control returns from the client stub, the client code should again check to see whether **rpc_ss_allocate/free** has already been enabled before it calls **rpc_ss_disable_allocate()**:

```
    rpc_ss_set_client_alloc_free(p_saved_alloc,p_saved_free);

/* If we set up rpc_ss_allocate environment, disable it now */

    if (thread_handle == NULL)
        rpc_ss_disable_allocate();
```

17.1.3 Using Your Own Allocation and Free Routines

At times it might be necessary for client code to change the routines that the client stubs use to allocate and free memory. For example, client code that is making an RPC call might want to direct the RPC client stubs to use special debug versions of **malloc()** and **free()** that check for memory leaks. Another example might be an application that uses DCE RPC but needs to preserve its users' ability to free memory returned from the application by using the platform's memory management scheme (rather than exposing the user to DCE).

Client code that wants to use its own memory allocation and free routines can use the **rpc_ss_swap_client_alloc_free()** routine to exchange the current client allocation and freeing mechanism for one supplied in the call. The routine returns pointers to the memory allocation and free routines formerly in use. Before calling **rpc_ss_swap_client_alloc_free()**, client code must ensure that it has not been called from a manager routine.

Deallocation of allocated storage returned from the client stubs is not automatic. Therefore, client code must ensure that it uses the free routine that it specified in the call to **rpc_ss_swap_client_alloc_free()** to deallocate each piece of allocated storage.

Client code that swaps in memory management routines with **rpc_ss_swap_client_alloc_free()** should use the **rpc_ss_set_client_alloc_free()** routine before it exits to restore the old allocation and free routines.

17.1.4 Using Thread Handles in Memory Management

There are two situations where control of memory management requires the use of thread handles. The more common situation is when the manager thread spawns additional threads. The less common situation is when a program transitions from being a client to being a server, then reverts to being a client.

17.1.4.1 Spawning Threads

When a remote procedure call invokes the manager code, the manager code may wish to spawn additional threads to complete the task for which it was called. To spawn additional threads that are able to perform memory management, the manager code must first call the **rpc_ss_get_thread_handle()** routine to get its thread handle and then pass that thread handle to each spawned thread. Each spawned thread must call the **rpc_ss_set_thread_handle()** routine with the handle received from the manager code.

These routine calls allow the manager and its spawned threads to share a common memory management environment. This common environment enables memory allocated by the spawned threads to be used in returned parameters and causes all

allocations in the common memory management environment to be released when the manager thread returns to the server stub.

The main manager thread must not return control to the server stub before all the threads it spawned complete execution; otherwise, unpredictable results may occur.

The listener thread can cancel the main manager thread if the remote procedure call is orphaned or if a cancellation occurs on the client side of the application. You should code the main manager thread to terminate any spawned threads before it exits. The code should anticipate exits caused by an unexpected exception or by being canceled.

Your code can handle all of these cases by including a **TRY/FINALLY** block to clean up any spawned threads if a cancellation or other exception occurs. If unexpected exceptions do not concern you, then your code can perform two steps. They are disabling cancelability before threads are spawned followed by enabling cancelability after the join operation finishes and after testing for any pending cancel operations. Following this disable/enable sequence prevents routine **pthread_join()** from producing a cancel point in a manager thread that has spawned threads which, in turn, share thread handles with the manager thread.

17.1.4.2 Transitioning from Client to Server to Client

Immediately before the program changes from a client to a server, it must obtain a handle on its environment as a client by calling **rpc_ss_get_thread_handle()**. When it reverts from a server to a client, it must reestablish the client environment by calling the **rpc_ss_set_thread_handle()** routine, supplying the previously obtained handle as a parameter.

17.2 Guidelines for Error Handling

During a remote procedure call, server and communications errors may occur. These errors can be handled using any or all of the following methods:

- Writing exception handler code to recover from the error or to exit the application
- Using the **fault_status** attribute in the ACF to report an RPC server failure

- Using the **comm_status** attribute in the ACF to report a communications failure

Use of exceptions, where the procedure exits the program due to an error, tends to improve code quality. It does this by making errors obvious because the program exits at that point, and by lessening the amount of code needed to detect error conditions and handle them. When you use the **fault_status** attribute, an exception that occurs on the server is not reported to the client as an exception. The variable to which the **comm_status** attribute is attached contains error codes that report errors that would not have occurred if the application were not distributed over a communications network. The **comm_status** attribute provides a method of handling RPC errors without using an exception handler.

17.2.1 Exceptions

Exceptions report either RPC errors or errors in application code. Exceptions have the following characteristics:

- You do not have to adjust procedure declarations between local and distributed code.
- You can distribute existing interfaces without changing code.
- You do not have to check for failures. This results in more robust code because errors are reported even if they are not checked.
- Your code is more efficient when there is no recovery coded for failures.
- You can use a simpler coding style.
- Exceptions work well for coarse-grained exception handling.
- If your application does not contain any exception handlers and the application thread gets an error, the application thread is terminated and a system-dependent error message from the threads package is printed.

Note: RPC exceptions are equivalent to RPC status codes. To identify the status code that corresponds to a given exception, replace the **_x_** string of the exception with the string **_s_** . For example, the exception **rpc_x_comm_failure** is equivalent to the status code **rpc_s_comm_failure**. The RPC exceptions are defined in the **dce/rpcexc.h** header file, and the equivalent status codes are described in the *DCE 1.2.2 Problem Determination Guide*.

The set of exceptions that can always be returned from the server to the client (such as the **rpc_x_invalid_tag** exception) are referred to as *system exceptions*. These exceptions are defined in **dce/rpcexec.h** and **dce/exec_handling.h**.

An interface definition can also specify a set of user-defined exceptions that the interface's operations can return to the client. You can declare user-defined exceptions in an interface definition by using the **exceptions** interface attribute, which is described in Chapter 18.

If a user-defined exception in the implementation of a server operation occurs during server execution, the server terminates the operation and propagates the exception to the client in a manner similar to the way system exceptions are propagated. If a server implementation of an operation raises an exception that is neither a system exception nor a user-defined exception, the exception returned to the client is **rpc_x_unknown_remote_fault** .

By default, the IDL compiler defines and initializes all exceptions under a once block in the generated stubs. If you want to share exception names in multiple interfaces or you desire greater control over how these exceptions are defined and initialized, you can use the ACF **extern_exceptions** attribute to disable the automated mechanism that the IDL compiler uses to define and initialize exceptions. See Chapter 19 for more information on the **extern_exceptions** attribute.

Because exceptions are associated with operation implementation, they are not imported into other interfaces by way of the **import** declaration. For more information about using exceptions to handle errors, see Part 2 of this guide.

17.2.2 The fault_status Attribute

The **fault_status** attribute requests that errors occurring on the server due to incorrectly specified parameter values, resource constraints, or coding errors be reported by a designated status parameter instead of by an exception.

If a user-defined exception is returned from a server to a client that has specified **fault_status** on the operation in which the exception occurred, the value given to the **fault_status** parameter is **rpc_s_fault_user_defined**.

The **fault_status** attribute has the following characteristics:

- Occurs where you do not want transparent local/remote behavior
- Occurs where you expect that you may be passing incorrect data to the server or the server is not coded robustly, or both
- Works well for fine-grained error handling
- Requires that you adjust procedure declarations between local and distributed code
- Controls the reporting only of errors that come from the server and that are reported via a fault packet

For more information on the **fault_status** attribute, see Chapter 19.

17.2.3 The comm_status Attribute

The **comm_status** attribute requests that RPC communications failures be reported through a designated status parameter instead of by an exception. The **comm_status** attribute has the following characteristics:

- Occurs where you expect communications to fail routinely; for instance, no server is available, the server has no resources, and so on
- Works well for fine-grained error handling; for example, trying a procedure many times until it succeeds
- Requires that you adjust procedure declarations between local and distributed code to add the new status parameter
- Controls the reporting of errors only from RPC runtime error status codes

For more information on the **comm_status** attribute, see Chapter 19.

17.2.4 Determining Which Method to Use for Handling Exceptions

Some conditions are better for using the **comm_status** or **fault_status** attribute on an operation, rather than the default approach of handling exceptions.

The **comm_status** attribute is useful only if the call to the operation has a specific recovery action to perform for one or more communications failures; for example,

rpc_s_comm_failure or **rpc_s_no_more_bindings**. The **comm_status** attribute is recommended only when the application knows that it is calling a remote operation. If you expect communications to fail often because the server does not have enough resources to execute the call, you can use this attribute to allow the call to be retried several times. If you are using an implicit or explicit binding, you can use the **comm_status** attribute if you want to try another server because the operation cannot be performed on the one you are currently using. You can also use an exception handler for each of the two previous instances.

In general, the advantange of using **comm_status** if the recovery is local to the routine is that the overhead is less. The disadvantage of using **comm_status** is that it results in two different operation signatures. Distributed calls contain the **comm_status** attribute, however; local calls do not. Also, if all of the recovery cannot be done locally (where the call is made), there must be a way to pass the status to outer layers of code to process it.

The **fault_status** attribute is useful only if the call to the operation has a specific recovery action to perform for one or more server faults; for example, **rpc_s_invalid_tag**, **rpc_s_fault_pipe_comm_error** , **rpc_s_fault_int_overflow**, or **rpc_s_fault_remote_no_memory** . Use **fault_status** only when the application calls a remote operation and wants different behavior than if it calls the same operation locally. If you are requesting an operation on a large data set, you can use this attribute to trap **rpc_s_fault_remote_no_memory** and retry the operation to a different server, or you may break your data set into two smaller sections. You can also handle the previous case with exception handlers. The advantange of using **fault_status** if the recovery is local is that the overhead is less. The disadvantage of **fault_status** is that the operation is different between the local and distributed case. Also, if all of the recovery cannot be done locally, there must be a way to pass the status to outer layers of code to process it.

17.2.5 Examples of Error Handling

The following subsections present two examples of error handling. The first example assumes that the **comm_status** attribute is in use in the ACF. The second example assumes that the **comm_status** attribute is not in use.

17.2.5.1 The Matrix Math Server Example

Assume that you have an existing local interface that provides matrix math operations. Since it is local, errors such as floating-point overflow or divide by zero are returned to the caller of a matrix operation as exceptions. It is likely that these exceptions are caused by providing data to the operation in an improper form.

In this case, the exceptions are part of the interface, so **fault_status** changes the way the application calls the matrix interface and probably is undesirable. Depending on the environment, finding a server may not be difficult (if the network is relatively stable and has enough resources), and adding **comm_status** serves only to introduce differences between the local and distributed applications.

If a decision as to what action to take is based upon a communications failure, then you may try to add the conditional code **comm_status** requires. Otherwise, using **auto_handle** allows an attempt on each available server. If no server is available, the application terminates because it cannot proceed. You can add an exception handler to the main program to report the error in a user-friendly manner.

17.2.5.2 The Stock Quote Application Example

Assume that you have an application that reads from stock quote servers and displays graphs of the data. Since you do not expect to get server failures because it is a commercial-quality server, you are not interested in writing code to handle values returned from **fault_status**. If high availability and robustness is important, you may have a list of recovery plans to make sure a stock analyst can get the necessary information as quickly as possible. For example:

```
retry_count = 10;
do  {
    query_stock_quote(h, ...,&st);
    switch (st)         /* st parameter can be used because */
    {                   /* [comm_status] is in the ACF */
        case rpc_s_ok:
            break;
        case rpc_s_comm_failure:
```

```
            retry_count -= 1;
            break;
        case rpc_s_network_unreachable:
            h = some_other_handle;
            break;
        case
            .
            .
            .
        default:
            retry_count -= 1;
    }
}
while ((st == rpc_s_ok) || (retry_count <= 0))
```

If this is not a critical application, you may only report that the server is currently unavailable. Depending upon the design of the application, there may be several places to put the exception handler to report the failure but continue processing. For example:

```
TRY
    update_a_quote(...);
CATCH_ALL
    display_message("Stock quote not currently available");
ENDTRY
```

This example assumes that **update_a_quote()** eventually calls the remote operation **query_stock_quote()** and that this call may raise an exception that is detected and reported here.

The advantage of using exceptions in this case is that all of the work done in **update_a_quote()** has the same error recovery and it does not need to be repeated at every call to a remote operation. Another advantage is that, if one of the remote operations does have a recovery for one exception, it can handle that one exception and allow the rest to propagate to the more general handler in an outer layer of the code.

17.3 Context Handles

During a series of remote procedure calls, the client may need to refer to a context maintained by a specific server instance. Server application code can maintain information it needs for a particular client (such as the state of RPC the client is using) as a context. To provide a client with a means of referring to its context, the client and server pass back and forth an RPC-specific parameter called a *context handle*. A context handle is a reference (a pointer) to the server instance and the context of a particular client. A context handle ensures that subsequent remote procedure calls from the client can reach the server instance that is maintaining context for the client.

On completing the first procedure in a series, the server passes a context handle to the client. The context handle identifies the context that the server uses for subsequent operations. The client is not supposed to do anything with the context handle; it merely passes it to subsequent calls as needed, and it is used internally by the remote calls. This allows applications to have such things as remote calls that handle file operations much as local calls would; that is, a client application can remotely open a file, get back a handle to it, and then perform various other remote operations on it, passing the context handle as an argument to the calls. A context handle can be used across interfaces (where a single server offers the multiple interfaces), but *a context handle belongs only to the client that caused it to be activated.*

The server maintains the context for a client until the client calls a remote procedure that terminates use of the context or communications are lost. In the latter case, the server's runtime can invoke a context rundown procedure. This application-specific routine is called by the server stub automatically to reclaim (rundown) the pointed-to resource in the event of a communications break between the server and client. For example, in the case of the remote file pointer just mentioned, the context rundown routine would simply close the file.

As usual with RPC, you need to apply indirection operators in a variety of ways to maintain the correct **[in]** and **[out]** semantics. Typical declarations for a context handle are as follows. In the **.idl** file, declare a named type such as

```
typedef [context_handle] void* my_handle_t;
```

A manager routine that returns a context handle as an **out** parameter declares it as

```
my_handle_t *h;
```

The routine then sets the value of the handle as follows:

```
*h = &context_data;
```

A routine that refers to a context handle as an **in** parameter declares it as

```
my_handle_t h;
```

and dereferences the handle as follows:

```
context_data = (my_handle_t*)h;
```

For the **in,out** case, the routine uses the same declaration as in the **out** case, and dereferences the handle as follows:

```
context_data = (my_handle_t*)*h;
```

The following extensive example shows a simple use of context handles. In the sample code, the client requests a unit of storage from the server, using the **store_open()** call, and receives a handle to the allocated storage. The **store_read()**, **store_write()** , and **store_set_ptr()** routines allow the client to read from and write to specific locations in the allocated storage. The **store_close()** routine releases the server resources.

17.3.1 Context Handles in the Interface

The **.idl** file declarations for the **store** interface are as follows:

```
/*
 * store.idl
```

```
 * A sample interface that demonstrates server maintained context.
 * The client requests temporary storage of a specified size,
 * and the server returns a handle that can be used to read and
 * write to storage.  The interface doesn't care how the
 * server implements the storage.
 */
[
uuid(0019b8c5-e8b5-1c84-9a41-0000c0d4de56),
pointer_default(ref),
version(1.0)
]
interface store
{

    /* A context handle used to access remote storage:   */
    typedef [context_handle] void* store_handle_t;

    /* A storage object name string:                     */
    /*  typedef [string] char* store_name_t; */

    /* A buffer type for data:                           */
    typedef byte store_buf_t[*];

/* Note that the context handle is an [out] parameter of the open  */
/*  routine, an [in, out] parameter of the close routine, and an   */
/*  [in] parameter of the other routines.  If the context handle   */
/*  were treated as an [in] parameter of the close routine, the    */
/*  stubs would never learn that the context had been set to NULL, */
/*  and would consider the context to still be live.  This would   */
/*  result in the rundown routine's being called when the client   */
/*  terminated, even though there would be no context to run down. */

    void store_open(
 [in] handle_t binding,
 [in] unsigned32 store_size,
 [out] store_handle_t *store_h,
 [out] error_status_t *status
    );

    void store_close(
```

```
 [in,out] store_handle_t *store_h,
 [out] error_status_t *status
    );

    void store_set_ptr(
 [in] store_handle_t store_h,
 [in] unsigned32 offset,
 [out] error_status_t *status
    );

    void store_read(
 [in] store_handle_t store_h,
 [in] unsigned32 buf_size,
 [out, size_is(buf_size), length_is(*data_size)] \
   store_buf_t buffer,
 [out] unsigned32 *data_size,
 [out] error_status_t *status
    );

    void store_write(
 [in] store_handle_t store_h,
 [in] unsigned32 buf_size,
 [in, size_is(buf_size)] store_buf_t buffer,
 [out] unsigned32 *data_size,
 [out] error_status_t *status
    );

}
```

17.3.2 Context Handles in a Server Manager

Server manager code to provide a rudimentary implementation of the **store** interface is as follows:

```
/* context_manager.c -- implementation of "store" interface.       */
/*                                                                  */
```

```
/* The server maintains a certain number of storage areas, only one   */
/*  of which can be (or should be) opened by a single client at a     */
/*  time. More than one client can, however, apparently be invoked    */
/*  (up to thenumber of separate storelets == store handles           */
/*  available, defined by the value of NUM_STORELETS).  Each client   */
/*  keeps track of its store(and likewise enables the server to do    */
/*  the same) by means of the context handle it receives when it      */
/*  opens its store.                                                  */
/*                                                                    */
/*********************************************************************/

#include <stdio.h>
#include <string.h>
#include <malloc.h>
#include <pthread.h>
#include <dce/dce_error.h>
#include <dce/daclif.h>

#include "context.h"

#define NUM_STORELETS 10

/*********************************************************************/
/* The actual "storelet" structure...                               */

typedef struct store_hdr{
    pthread_mutex_t ref_lock;
    unsigned32 size;
    unsigned32 refcount;
    idl_byte *storage;
} store_hdr_t;

store_hdr_t headers[NUM_STORELETS]; /* There's an array of these.    */

/*********************************************************************/
/* The store specification structure; note that it is equivalent to  */
/*  the  handle; the pointer to it is returned as the handle by the  */
/*  store_open() routine below...                                    */
/*  The assumption is that all access to a given handle is serialized*/
/*  in a single thread, so no locking is needed for these.          */
```

```
typedef struct store_spec{
    unsigned32 number;     /* The storelet number we've opened.      */
    unsigned32 offset;     /* The current read/write position.       */
} store_spec_t;  /* There's only one of these; it's the handle that  */
                 /*  gives access to one of the NUM_STORELETS set of */
                 /*  "storelets".                                    */


/* The server entry name:                                            */
extern unsigned_char_p_t entry;


/* Initialization control block:                                     */
pthread_once_t init_once_blk = pthread_once_init;

/******
*
* store_mgmt_init -- Zeroes out all the storelet structures; executed
*                    only once per server instance, as soon as a client
*                    has called the store_open() routine.
*
******/
/*********************************************************************/
void
store_mgmt_init(
)
{
    int i;
    store_hdr_t *hdr;

    fprintf(stdout, "Store Manager: Initializing Store);
    memset(headers, 0, sizeof(store_hdr_t) * NUM_STORELETS);
    for (i = 0; i < NUM_STORELETS; i++)
    {
 hdr = headers + i;
 pthread_mutex_init(
     (pthread_mutex_t *)hdr,
     pthread_mutexattr_default);
    }
```

```
}

/******
*
* store_open -- Opens a store and returns a handle to it.  Store
*               consists  of one "storelet" selected from array of
*               NUM_STORELETS.
******/
/******************************************************************/
void
store_open(
    handle_t binding,
    unsigned32 store_size,    /* Size specified for actual storage.  */
    store_handle_t *store_h,  /* To return the store handle in.      */
    error_status_t *status
)
{
    int i;                 /* Index variable.                        */
    store_spec_t *spec;    /* Store specification == handle.         */
    store_hdr_t *hdr;      /* Storelet structure.                    */

    /* Do the store initialization if this is the first open call... */
    /* Zero out the store headers...                                 */
    pthread_once(&init_once_blk, store_mgmt_init);

 /* The following loop goes through all the storelets, looking for   */
 /*  one whose reference count is zero.  As soon as one such is      */
 /*  found, a handle is allocated for it, storage is allocated for   */
 /*  its store structure, and the loop (and the call) terminates. If */
 /*  no unreferenced storelet is found, a status of -1 is returned   */
 /*  and no handle is allocated...                                   */
    for(i = 0; i < NUM_STORELETS; i++)
    {
 /* Go to the next storelet...                               */
 hdr = headers + i;

 /* Is it unreferenced?...                                   */
 if (hdr->refcount == 0)
 {
```

```
   /* If so, lock the header...                        */
   *status = pthread_mutex_lock((pthread_mutex_t *)hdr);
   if (*status != 0)
   {
return;
   }

   /* ...and check the reference count again...        */
   if (hdr->refcount == 0)
   {
/* Now we know we "really" have this one.   */
/* Only one open is allowed, so lock only   */
/*  the reference count...                  */
hdr->refcount++;

/* Now unlock the header so other threads   */
/*  can continue to check it...             */
*status = pthread_mutex_unlock((pthread_mutex_t *)hdr);
if (*status != 0)
    return;

/* Now allocate space for the specifica-    */
/*  tion structure...                       */
spec = (store_spec_t *)malloc(sizeof(store_spec_t));
spec->number = i;
spec->offset = 0;
*store_h = spec;

/* Allocate space for the storage part of   */
/*  the header...                           */
hdr->storage = (idl_byte *)malloc(store_size);
hdr->size = store_size;

    /* Finally, set the return status to OK,    */
    /*  and return...                           */
*status = error_status_ok;
return;
   }

   /* If the reference count turned out to have        */
```

```
     /*  been accessed between our first check and our   */
     /*  locking the mutex, we must now unlock the mutex */
     /*  preparatory to looping around to check the next */
     /*  storelet...                                     */
     *status = pthread_mutex_unlock((pthread_mutex_t *)hdr);
     if (*status != 0)
     {
  return;
     }
 }
    }

    /* The following is reached only if we never found a free        */
    /*  storelet...                                                   */
    *store_h = NULL;
    *status = -1;

}

/******
*
* store_set_ptr -- Insert a new value into the store buffer pointer.
*
*******/
/*****************************************************************/
void store_set_ptr(
    store_handle_t store_h,     /* The store handle.                */
    unsigned32 offset,   /*Value to insert into store buffer pointer.*/
    error_status_t *status
)
{
    store_spec_t *spec;              /* Our pointer to store handle. */

    spec = (store_spec_t *)store_h;  /* Get the store spec.          */
    spec->offset = offset;    /*Copy in the new buffer pointer value.*/
    *status = error_status_ok;
}

/******
*
```

```
* store_close -- Close the opened storelet.
*
******/
/*******************************************************************/
void
store_close(
    store_handle_t *store_h,                /* Store handle.         */
    error_status_t *status
)
{
    store_spec_t *spec;             /* Our pointer to store handle.  */
    store_hdr_t *hdr;               /* Pointer to a storelet.        */

    printf("Store Manager: Closing Store);

    spec = (store_spec_t *)*store_h; /* Get the store spec.          */
    hdr = headers + spec->number;    /*Point to the correct storelet.*/

    /* If the thing is actually opened, close it...                 */
    if (hdr->refcount > 0)
    {
 /* Lock the header first...                                */
 *status = pthread_mutex_lock((pthread_mutex_t *)hdr);
 if (*status != 0)
 {
     printf("Close: lock failed);
     return;
 }

 /* Check the reference count to make sure no one slipped in */
 /*  before we could lock the header, and already closed the */
 /*  critter...                                              */
 if (hdr->refcount > 0)
 {
     /* The store is open, and it's locked by us, so we  */
     /*  can safely close it. So do it. First, decrement */
     /*  the reference count...                          */
     hdr->refcount--;

     /* Is it completely closed now?                     */
```

```
     if (hdr->refcount == 0)
     {
  /* If so, get rid of its storage space...   */
  hdr->size = 0;
  free(hdr->storage);
     }
 }

 /* If the store turned out to be closed before we could     */
 /*  close it, we have nothing to do but release the lock... */
 *status = pthread_mutex_unlock((pthread_mutex_t *)hdr);
 if (*status != 0)
 {
     printf("Close: unlock failed);
     return;
 }
    }

    /* And free our handle space...                               */
    free(spec);

    /* Be sure to NULL the context handle.  Otherwise, the context   */
    /*  will be considered to be live as long as the client is run-  */
    /*  ning...                                                       */
    *store_h = NULL;
    *status = error_status_ok;
}

/******
*
* store_read -- Read a certain number of bytes from the opened store.
*
******/
/*********************************************************************/
void
store_read(
    store_handle_t store_h,   /* Store handle.                       */
    unsigned32 buf_size,      /* Number of bytes to read.            */
    store_buf_t buffer,       /* Space to return data read in.       */
    unsigned32 *data_size,    /* To return number of bytes read in.  */
```

```
    error_status_t *status
)
{
    store_spec_t *spec;       /* Our handle pointer.                 */
    store_hdr_t *hdr;         /* Pointer to a storelet.              */

    spec = (store_spec_t *)store_h;  /* Get the storelet spec.       */
    hdr = headers + spec->number;    /*Point to the correct storelet.*/

    /* If the amount we're to read is less than the amount left to be*/
    /*  read, then read it...                                        */
    if (buf_size <= hdr->size)
    {

 /* Copy bytes from the storelet storage, beginning at off-  */
 /*  set, into the return buffer, up to the size of the      */
 /*  buffer...                                               */
 memcpy(buffer, hdr->storage + spec->offset, buf_size);

 /* Update the storelet buffer pointer past what we've just  */
 /*  read...                                                 */
 spec->offset += buf_size;

 /* Show return size of data read...                         */
 *data_size = buf_size;
 *status = error_status_ok;
 return;
    }

    /* If there's less data left than has been specified to read,  */
    /* don't read it...                                            */
    *data_size = 0;
    *status = -1;
}

/******
*
* store_write -- Write some data into the opened store.
*
******/
```

```
void
store_write(
    /* handle_t IDL_handle,*/  /* If the server ACF declares         */
                               /*  [explicit_handle]                 */
    store_handle_t store_h,    /* Store handle.                      */
    unsigned32 buf_size,       /* Number of bytes to write.          */
    store_buf_t buffer,        /* Data to be written.                */
    unsigned32 *data_size,     /* To return number of bytes written. */
    error_status_t *status
)
{
    store_spec_t *spec;            /* Our pointer to store handle.   */
    store_hdr_t *hdr;              /* Pointer to a storelet.         */

    /* Do an access check on IDL_handle here...                      */
    /* [--ORIGINAL NOTE] -- I don't know what the above means.       */

    spec = (store_spec_t *)store_h;  /* Get the storelet spec.       */
    hdr = headers + spec->number;    /*Point to the correct storelet.*/

    /* If the amount of unused room left in the storelet is greater  */
    /*  than what we're supposed to write in it, write it...         */
    if ((hdr->size - spec->offset) > buf_size)
    {

 /* Copy bytes from the buffer into the storelet storage,    */
 /*  beginning at the current read/write position...         */
 memcpy(hdr->storage + spec->offset, buffer, buf_size);

 /* Update the storelet buffer pointer to point past what    */
 /*  we've just written...                                   */
 spec->offset += buf_size;

 /* Add a null in case we want to read the store as a        */
 /*  string...                                               */
 *(hdr->storage + spec->offset) = 0;

 /* Show return size of data written...                      */
 *data_size = buf_size;
```

```
 *status = error_status_ok;
 return;
    }

    /* If we don't have room to write the whole buffer, don't write  */
    /*  anything...                                                  */
    *data_size = 0;
    *status = error_status_ok;
}

/******
 *
 * print_manager_error-- Manager version.  Prints text associated with
 * bad status code.
 *
 *
 ******/
void
print_manager_error(
char *caller,  /* String identifying routine that received the error.*/
error_status_t status) /* status we want to print the message for.   */
{
    dce_error_string_t error_string;
    int print_status;

    dce_error_inq_text(status, error_string, &print_status);
    fprintf(stderr," Manager: %s: %s, caller, error_string);

}
```

The sample implementation of the store interface is obviously too limited for any practical use, but it does demonstrate the application of context handles in a straightforward way. A context handle returned by the **store_open()** routine is opaque to the client. To the server, it is a pointer to the server's representation of a storage unit. In this case, it points to a structure that keeps track of the client's current location within a specific piece of server-maintained storage.

Aside from deallocating the actual storage, the **store_close()** routine sets the context handle to NULL. The NULL value indicates to the server stub that the context is no

longer active, and the stub, in turn, tells the RPC runtime not to maintain the context. For example, after the **store_close()** routine has been invoked, the rundown routine will not be invoked if communication ends between client and server. The context rundown routine takes care of closing the client's storage in case of a communication failure while the context is active.

The global array of *store_hdr* structures that keeps track of allocated storage, obviously servers no practical purpose in the example. (Presumably the operating system is already doing this!) However, it does provide a demonstration of the fact that global server manager data is shared data in the implicitly multithreaded server environment. The routines that manipulate this shared data may be called simultaneously by multiple server threads (in response to multiple simultaneous client calls); therefore, locking must be provided, in this case on the *refcount* field. The sample also demonstrates how the **pthread_once**() facility can be used to provide one-time initialization of the shared data on the first **store_open()** call.

As an exercise, the storage interface can easily be made more interesting by providing multiple clients simultaneous access to a given storage area. To implement this, the application could add a *store_name* parameter to the **store_open()** routine and replace the *refcount* field with counts of readers and writers. The division of the storage management between the *store_hdr* and the *store_spec* data structures is intended to facilitate this; the *store_hdr* holds shared state relating to each store, while the *store_spec* holds each thread's private state.

17.3.3 Context Rundown

Context handles typically point to some state maintained by a server instance for a client over a series of RPC operations. If the series of operations fails to complete because communication is lost between client and server, the server will probably have to take some kind of recovery action such as restoring data to a consistent state and freeing resources.

The stub detects outstanding context when it marshals context handle parameters. Outstanding context is considered to exist from the point at which a non-NULL pointer value is returned, until a NULL pointer value is returned. When outstanding context exists, the server stub code will call a context rundown routine in response to certain exceptions that indicate a loss of contact with the client. You should note that the exact timing of the call depends on the transport. In particular, with the connectionless

protocol, servers that maintain context for clients expect clients to indicate periodically that they are still running. If the server fails to hear from the client during a specified timeout period, the server will assume that the client has stopped and call the context rundown routine. This can mean a substantial delay between the time the client actually fails and the time at which context maintained for the client is actually cleaned up. If the context being held represents a scarce resource on the server, one consequence of the delayed rundown may be that failed calls continue to hold the scarce resource for some time before it is made available again.

Since a context handle may be freely shared among threads of the calling client context, it is possible for outstanding context to exist for more than one call simultaneously. Such shared context is considered to be outstanding as long as it is outstanding for any of the participating threads. Also, any communications failures are likely to be detected at different times for each such call thread, and the difference in timing may be especially noticeable in the case of the connectionless protocol. Context rundown occurs only after all server call threads have been terminated. This means that call operations in progress on the server need not be concerned that the context they are operating on will be changed unexpectedly. Imagine a situation in which context handles represent open file descriptors, and the rundown routine closes the files. A manager thread that shares these descriptors via a context handle is guaranteed that the files will remain open even if a communications failure is detected in another thread that also is using the same context handle.

```
/******
*
* store_handle_t_rundown -- Closes the opened storelet.
*
******/
/**************************************************************/
void
store_handle_t_rundown(
    store_handle_t store_h
)
{
    error_status_t st;

    printf("Store Manager: Running down context.);
    store_close(&store_h, &st);
}
```

17.3.4 Binding and Security Information

One element that is clearly missing from the context handle sample code is any access checking. To do this, it is necessary to get the client binding, although it may not be immediately obvious how to do this with a context handle. The answer is actually quite simple but, to understand it, it helps to have a clear idea of how binding parameters operate in RPC.

Every call requires binding information, whether this is supplied explicitly as a binding parameter or not. When a call is made with a binding handle, the client uses cached binding information associated with the binding handle. When no binding handle parameter is passed, the client derives the binding information it needs by some other means. For example, with a context handle, the client uses cached binding information associated with the context handle.

Even when an explicit binding handle parameter is present, the handle is not marshalled as call data in the same way other call parameters are. Similarly, on the server side, when a binding handle parameter is present in a manager operation, it is *unmarshalled* simply as a reference to the binding information cached by the server runtime for the call. It is irrelevant whether the call was made with an explicit binding handle parameter on the client side.

Therefore, it is perfectly possible for a server manager operation to have a binding handle as a parameter even when the client RPC call is made without an explicit binding parameter.

The mechanics of this are to use different **.acf** declarations on the client and server sides. The **.idl** file declaration for the operation does not declare an explicit binding handle parameter, but the server **.acf** file applies the **[explicit_handle]** attribute to the operation. This results in a server stub that expects to unmarshal a binding handle as the first parameter of the operation, while the client stub does not expect an explicit binding handle parameter for the call.

An example of a server-side **.acf** file for the store interface is as follows:

```
/* store.acf - server side
 * Unmarshal a client binding handle on each call
 */
```

```
interface store
{
    store_open();
    [explicit_handle]store_close();
    [explicit_handle]store_set_ptr();
    [explicit_handle]store_read();
    [explicit_handle]store_write();
}
```

You could achieve the same effect by using different **.idl** files for the client and server, but this is not recommended. The **.idl** file serves as the canonical representation of an interface and hence should be the same for all clients and servers.

This technique can be used in a number of ways; for example, to permit the client to use implicit binding while the server manager operations extract authorization information from a client binding handle. In the case of a context handle, the principle is the same. You use the server **.acf** declarations to add a binding parameter to the call on the server side. The client continues to call using the context handle, while the server manager receives the client binding as a first extra parameter.

In the case of the sample code, the client calls to the store interface remain the same, but the server manager implementations now contain an extra parameter. For example:

```
void
store_write(
    handle_t IDL_handle,
    store_handle_t store_h,
    unsigned32 buf_size,
    store_buf_t buffer,
    unsigned32 *data_size,
    error_status_t *status
)
{
    store_spec_t *spec;
    store_hdr_t *hdr;

    if (check_access(IDL_handle, sec_acl_perm_write) == 0)
    {
```

```
            *status = str_s_no_perms;
            return;
        }
        .
        .
        .
}
```

17.4 Pipes

Pipes are a mechanism for efficiently handling large quantities of data by overlapping the transfer and processing of data. Input data is transferred in chunks to the server for processing, and output data is processed by the server in chunks and transferred to the client. A pipe is declared in a type definition of an interface definition, and the data type is used as parameters in the operations of the interface. The server manager calls stub pipe support routines in a loop, and the client stub calls pipe support routines that the client application must provide.

One of the pipe support routines that the client must provide is an **alloc** routine, which allocates a buffer for each chunk of pipe data. Given that pipes are intended to process data asynchronously, consuming it as it arrives, the **alloc** routine should not just blindly allocate a new buffer each time it is called, since the net effect would be to allocate space for the whole stream. A reasonable approach is either to declare a buffer statically or allocate it on the first call (per thread), and thereafter simply return the same buffer. The following code example shows the form an **alloc** routine takes in client application code.

```
#define CLIENT_BUFFER_SIZE 2048
idl_byte client_buffer[CLIENT_BUFFER_SIZE];

void client_alloc (state, bsize, buf, bcount)
    rpc_ss_pipe_state_t state;
    unsigned int bsize;
    byte **buf;
    unsigned int *bcount;
{
```

```
    *buf = client_buffer;
    *bcount = CLIENT_BUFFER_SIZE;
}
```

17.4.1 Input Pipes

In the following example, a client sends the contents of a file to a server as a set of chunks allocated from the same static buffer. The chunks are processed (in this case simply printed) as they arrive.

The declaration in the interface definition is as follows:

```
typedef pipe char test_pipe_t;

void pipe_test1(
    [in] handle_t handle,
    [in] test_pipe_t test_pipe,
    [out] error_status_t *status
);
```

Note that the pipe is declared as a **typedef**, resulting in an IDL-generated C typedef for **test_pipe_t**, which is a structure containing pointers to the pipe support routines and a pipe state field. The server manager and client code then implement the pipe in a complementary fashion.

For an **[in]** pipe, the server manager code consists of a cycle of calls to the **test_pipe.pull** routine (a server stub routine) which terminates when a zero-length chunk is received:

```
void
pipe_test1(
    handle_t binding_h,
    test_pipe_t test_pipe,
    error_status_t *status
)
```

```
{
    char buffer[SBUFFSIZE];
    int count;
    char *cptr;
    do
    {
        (*(test_pipe.pull))(test_pipe.state, buffer, \
   SBUFFSIZE, &count);
        for (cptr = buffer; cptr < buffer + count; cptr++)
            putchar(*cptr);
    } while (count > 0);
}
```

Using the buffer supplied by the manager, the **test_pipe.pull** routine unmarshals an amount of data that is nonzero, but not more than the buffer can hold. There is no guarantee that the buffer will be filled. The actual amount of data in the buffer is indicated by the **count** parameter returned in the **test_pipe.pull** routine. This count equals the number of **test_pipe_t** data elements in the buffer.

The **test_pipe.pull** routine signals the end of data in the pipe by returning a chunk whose count is 0 (zero). Any attempt to pull data from the pipe after the zero-length chunk has been encountered will cause an exception to be raised. The **in** pipes must be processed in the order in which they occur in the operation signature. Attempting to pull data from an **in** pipe before end-of-data on any preceding **in** pipe has been encountered will result in an exception being raised. If the manager code attempts to write to an **out** pipe or return control to the server stub before end-of-data has been encountered on the last **in** pipe, an exception will be raised. (Note that there is no guarantee that chunks seen by the manager will match the chunks supplied by the client's **pull** routine.)

The client application code must supply **pull** and **alloc** routines and a pipe state. These routines must work together to produce a sequence of pointers to chunks, of which only the last is empty. In the following example, the client code provides a **test_pipe.pull** routine that reads chunks of the input file into a buffer and returns a count of the chunk size, returning a zero count when the end of the file is reached. The pipe state block is used here simply as a convenient way to make the file state available to the **pull** routine. Applications need not make any use of the pipe state.

```
/* Client declares types and routines */

typedef struct client_pipe_state_t {
    idl_char *filename;
    idl_boolean file_open;
    int file_handle;
} client_pipe_state_t;

client_pipe_state_t client_in_pipe_state = {false, 0};

void client_pull(state,buf,esize,ecount)
    client_pipe_state_t * state;
    byte *buf;
    unsigned int esize;
    unsigned int *ecount;
{
    if ( ! state->file_open )
    {
        state->file_handle = open(state->filename,O_RDONLY);
        if (state->file_handle == -1)
        {
            printf("Client couldn't open %s, state->filename);
            exit(0);
        }
        state->file_open = true;
    }
    *ecount = read( state->file_handle, buf, esize );
    if (*ecount == 0)
    {
        close(state->file_handle);
        state->file_open = false;
    }
}
```

Finally, the client must do the following:

1. Allocate the **test_pipe_t** structure.
2. Initialize the **test_pipe_t.pull**, **test_pipe_t.alloc**, and **test_pipe_t.state** fields.
3. Include code where appropriate for checking the **pipe_t.state** field.

4. Pass the structure as the pipe parameter. The structure can be passed either by value or by reference, as indicated by the signature of the operation that contains the pipe parameter:

```
/* Client initializes pipe */
test_pipe_t test_pipe;

test_pipe.pull = client_pull;
test_pipe.alloc = client_alloc;
test_pipe.state = (rpc_ss_pipe_state_t)&client_in_pipe_state;

/* Client makes call */

pipe_test1(binding_h, test_pipe, &status);
```

To transmit a large amount of data that is already in the proper form in memory (that is, the data is already an array of **test_pipe_t**), the client application code can have the **alloc** routine allocate a buffer that already has the information in it. In this case, the **pull** routine becomes a null routine.

17.4.2 Output Pipes

An **[out]** pipe is implemented in a similar way to an input pipe, except that the client and server make use of the **push** routine instead of the **pull** routine. The following samples show an **[out]** pipe used to read the output from a shell command executed by the server.

The declarations in the interface definition are as follows:

```
typedef pipe char test_pipe_t;

void pipe_test2(
    [in] handle_t handle,
    [in, string]  char cmd[],
    [out] test_pipe_t *test_pipe,
```

```
    [out] error_status_t *status
);
```

The server manager routines demonstrate a couple of possible implementations. In each case, the manager makes a cycle of calls to the server stub's **push** routine, ending by pushing a zero-length chunk:

```
#include <dirent.h>
#define SBUFFSIZE 256

void
pipe_test2(
    handle_t binding_h,
    idl_char *cmd,
    test_pipe_t *test_pipe,
    error_status_t *status
)
{

    DIR *dir_ptr;
    struct dirent *directory;

    char buffer[SBUFFSIZE];
    FILE *str_ptr;
    int n;

    /* An elementary mechanism to execute a command and get
     * the output back.  Note that popen() and fread() are
     * thread-safe, so the whole process won't block while
     * the call thread waits for them to return.
     *
     * This is potentially a dangerous operation!
     * Here we'll only allow a couple of "safe" commands.
     */

    if (!strcmp(cmd, "ps") || !strcmp(cmd, "ls"))
    {
        if ((str_ptr = popen(cmd, "r")) == NULL)
            return;
```

```
        while ((n = fread(buffer, sizeof(char), \
   SBUFFSIZE, str_ptr)) > 0)
        {
            (*(test_pipe->push))(test_pipe->state, buffer, n);
        }
        (*(test_pipe->push))(test_pipe->state, buffer, 0);
        fclose(str_ptr);
    }

    /* Here's another method: list an arbitrary directory
     * This time, we buffer the directory names as null-
     * terminated strings of various lengths.  The client
     * will need to provide formatting of the output stream,
     * for example, by substituting a CR for each NULL byte.
     */

    /*
    if ((dir_ptr = opendir(cmd)) == NULL)
    {
        printf("Can't open directory %s, cmd);
        return;
    }
    while ((directory = readdir(dir_ptr)) != NULL)
    {
        if (directory->d_ino == 0)
            continue;
        (*(test_pipe->push))(test_pipe->state, \
   directory->d_name,
                                strlen(directory->d_name)+1);
    }
    (*(test_pipe->push))(test_pipe->state, \
      directory->d_name, 0);
    closedir(dir_ptr);
    */

    *status = error_status_ok;
}
```

The stub enforces well-behaved pipe filling by the manager by raising exceptions as necessary. After all **in** pipes have been drained completely, the **out** pipes must be completely filled, in order.

The client code uses the same declarations as in the input pipe example, except that instead of using a **client_pull** routine it uses a **test_push** routine that prints out the contents of each received buffer:

```
/*
 * Our push routine prints each received buffer-full.
 */
void test_push(
    rpc_ss_pipe_state_t *state,
    idl_char *buf,
    unsigned32 count
)
{
    unsigned_char_t *cptr;
    for (cptr = buf; cptr < buf + count; cptr++)
    {
        /* For the second, directory reading example,
           uncomment the following:
        if (*cptr == 0)
            *cptr = ';
         */
        putchar(*cptr);
    }
}
```

For an **out** pipe, the client code must do the following:

1. Allocate the **test_pipe_t** structure.
2. Initialize the **test_pipe_t.push** and **test_pipe_t.state** fields.
3. Pass the structure as the pipe parameter, either by value or by reference.

```
test_pipe_t test_pipe;
```

```
test_pipe.alloc = (void (*)())client_alloc;
test_pipe.push = (void (*)())test_push;
test_pipe.state = (rpc_ss_pipe_state_t)&out_test_pipe_state;

pipe_test2(binding_h, cmd, &test_pipe, &status);
```

The client stub unmarshals chunks of the pipe into a buffer and calls back to the application, passing a reference to the buffer. To allow the application code to manage its memory usage, and possibly avoid unnecessary copying, the client stub first calls back to the application's **test_pipe.alloc** routine to get a buffer. In some cases, this may result in the **test_pipe.push** routine's not having any work to do.

The client stub may go through more than one (**test_pipe.alloc** , **test_pipe.push**) cycle in order to unmarshal data that the server marshalled as a single chunk. Note that there is no guarantee that chunks seen by the client stub will match the chunks supplied by the server's **push** routine.

17.4.3 Pipe Summary

The pipe examples show how the client and server tasks are complementary. The client implements the appropriate callback routines (**test_pipe.alloc** and either **test_pipe.push** or **test_pipe.pull**), and the server manager makes a cycle of calls to either **test_pipe.push** or **test_pipe.pull** of the stub. The application code gives the illusion that the server manager is calling the client-supplied callbacks. In fact, the manager is actually calling stub-supplied callbacks, and the client callbacks are asynchronous: a server manager call to one of the callback routines does not necessarily result in a call to the corresponding client callback.

One result of this is that the client and server should not count on the chunk sizes being the same at each end. For example, in the last directory reading example, the manager calls the **test_pipe.push** routine once with each NULL-terminated filename. However, the client **test_push** routine does not necessarily receive the data stream one filename at at time. For example, if the **test_push** routine attempted to print the filenames using **printf("%s\n",buf);** , it might fail. An interesting exercise would be to add **printf()** routines to the client callbacks and the server manager to show when each callback is made.

Note also that the use of the pipe *state* field by the client is purely local and entirely at the discretion of the client. The state is not marshalled between client and server, and the server stubs use the local *state* field in a private manner. The server manager should not alter the state field.

Pipes may also be **[in,out]**, although the utility of this construct is somewhat limited. Ideally, a client would like to be able to pass a stream of data to the server and have it processed and returned asynchronously. In practice, the input and output streams must be processed synchronously; that is, all input processing must be finished before any output processing can be done. This means that **[in, out]** pipes, while they can reduce latency within both the server and the client, cannot reduce latency between server and client; the client must still wait for all server processing to finish before it can begin to process the returned data stream.

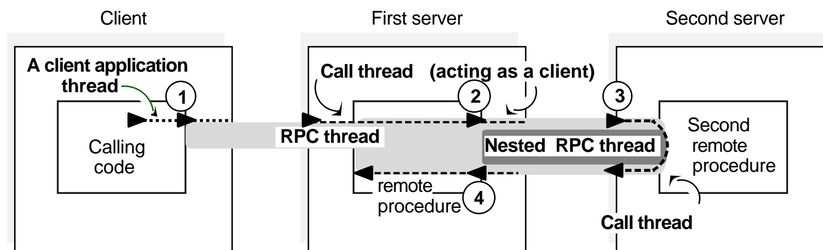
For an **in,out** pipe, both the **pull** routine (for the **in** direction) and a **push** routine (for the **out** direction) must be initialized, as well as the **alloc** routine and the state. During the last **pull** call (when it will return a zero count to indicate that the pipe is drained), the application's **pull** routine must reinitialize the pipe state so that the pipe can be used by the **push** routine correctly.

17.5 Nested Calls and Callbacks

A called remote procedure can call another remote procedure. The call to the second remote procedure is nested within the first call; that is, the second call is a nested remote procedure call. A nested call involves the following general phases, as illustrated in Figure 17-1:

1. A client makes an initial remote procedure call to the first remote procedure.
2. The first remote procedure makes a nested call to the second remote procedure.
3. The second remote procedure executes the nested call and returns it to the first remote procedure.
4. The first remote procedure then resumes executing the initial call.

Figure 17–1. Phases of a Nested RPC Call

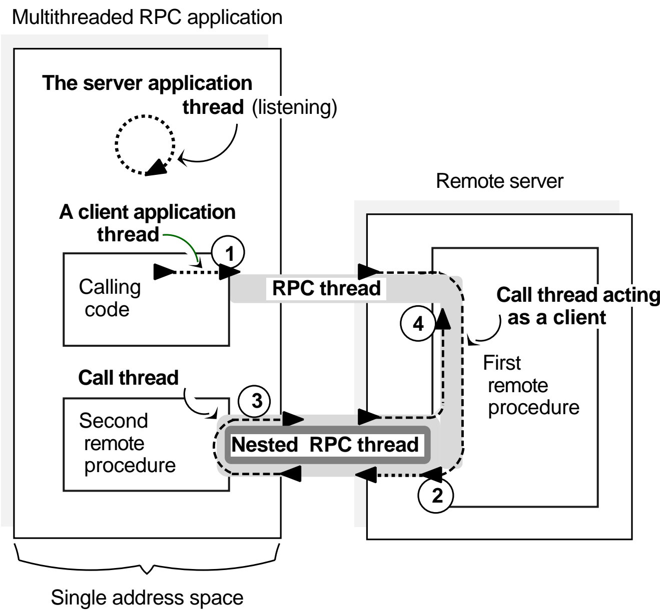


A specialized form of a nested remote procedure call involves a called remote procedure that is making a remote procedure call (callback) to the address space of the calling client application thread. Calling the client's address space requires that a server application thread be listening in that address space. Also, the second remote procedure needs a server binding handle for the address space of the calling client.

The remote procedure can ask the local RPC runtime to convert the client binding handle, provided by the server runtime, into a server binding handle. This is done by calling the **rpc_binding_server_from_client()** routine. This routine returns a partially bound binding handle (the server binding information lacks an endpoint). For a nested remote procedure call to find the address space of the calling client, the application must ensure that the partially bound binding handle is filled in with the endpoint of that address space. The the **rpc_binding_server_from_client(3rpc)** reference page discusses alternatives for ensuring that the endpoint is obtainable for a nested remote procedure call.

Using the server binding handle, a remote procedure can attempt a nested remote procedure call. The nested call involves the general phases illustrated by Figure 17-2.

Figure 17–2. Phases of a Nested RPC Call to Client Address Space



The application threads in the preceding figure are performing the following activities:

1. A client application thread from a multithreaded RPC application makes an initial remote procedure call to the first remote procedure.

2. After converting the client binding handle into a server binding handle and obtaining the endpoint for the address space of the calling client application thread, the first remote procedure makes a nested call to the second remote procedure at that address space.

3. The second remote procedure executes the nested call and returns it to the first remote procedure.

4. The first remote procedure then resumes executing the initial call (the client).

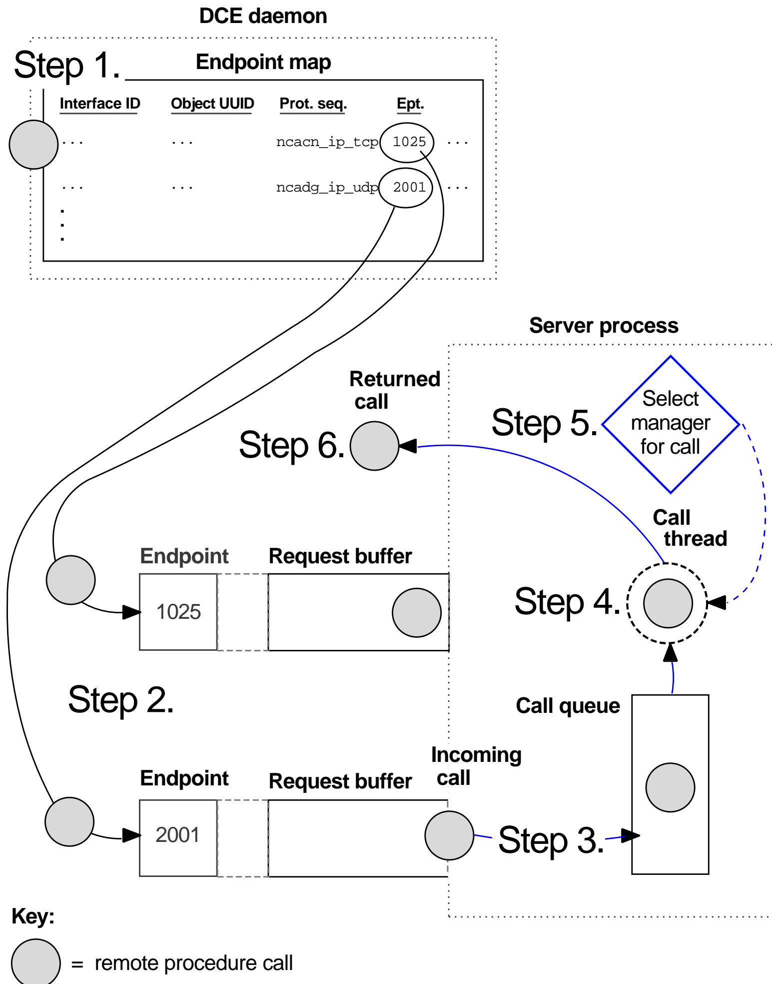
17.6 Routing Remote Procedure Calls

The following section discusses routing incoming remote procedure calls between their arrival at a server's system and the server's invocation of the requested remote procedure. The following routing steps are discussed:

1. If a client has a partially bound server binding handle, before sending a call request to a server, the client runtime must get the endpoint of a compatible server from the endpoint mapper service of the server's system. This endpoint becomes the server address for a call request.
2. When the request arrives at the endpoint, the server's system places it in a request buffer belonging to the corresponding server.
3. As one of its scheduled tasks, the server gets the incoming calls from the request buffer. The server either accepts or rejects an incoming call, depending on available resources. If no call thread is available, an accepted call is queued to wait its turn for an available call thread.
4. The server then allocates an available call thread to the call.
5. The server identifies the appropriate manager for the called remote procedure and invokes the procedure in that manager to execute the call.
6. When the call thread finishes executing a call, the server returns the call's output arguments and control to the client.

Figure 17-3 illustrates these steps.

Figure 17–3. Steps in Routing Remote Procedure Calls



The concepts in the following subsections are for the advanced RPC developer. The first subsection discusses how clients obtain endpoints when using partially bound binding handles. Then we discuss how a system buffers call requests and how a server queues incoming calls; this information is relevant mainly to advanced RPC developers. The final subsection discusses how a server selects the manager to execute

a call; it is relevant for developing an application that implements an interface for different types of RPC objects.

17.6.1 Obtaining an Endpoint

The endpoint mapper service of **dced** maintains the local endpoint map. The endpoint map is composed of elements which contain fully bound server binding information for a potential binding and an associated interface identifier and object UUID (which may be nil). Optionally, a map element can also contain an annotation such as the interface name.

Servers use the local endpoint mapper service to register their binding information. Each interface for which a server must register binding information requires a separate call to an **rpc_ep_register...()** routine, which calls the endpoint map service. The endpoint map service uses a new map element for every combination of binding information specified by the server. Figure 17-4 shows the correspondence between server binding information specified by a server and a graphic representation of the resulting endpoint map elements.

Figure 17–4. Mapping Information and Corresponding Endpoint Map Elements

Server's Inputs to Endpoint–Register Operation

interface–handle → **Interface ID:**
```
2FAC8900-31F8-11CA-B331-08002B13D56D,1.0
```
binding–handle–list * → **Server addresses:**
```
ncacn_ip_tcp:16.20.15.25[1025]
ncadg_ip_udp:16.20.15.25[2001]
```
object–UUID–list → **Object UUIDs:**
```
47F40D10-E2E0-11C9-BB29-08002B0F4528
30DBEEA0-FB6C-11C9-8EEA-08002B0F4528
16977538-E257-11C9-8DC0-08002B0F4528
```

* Binding handles also enable the endpoint map service to learn the server's RPC protocol version and transfer syntaxes; this information is identical for every map element, however, and is ignored here to simplify the following representation of endpoint map elements. For the same reason, the network address of the server's host system is omitted from this representation of map elements.

Corresponding Representation of Endpoint Map Elements

Interface ID	Object UUID	Prot. seq.	Ept.
2FAC8900-31F8-11CA-B331-08002B13D56D,1.0	47F40D10-E2E0-11C9-BB29-08002B0F4528	ncacn_ip_tcp	1025
2FAC8900-31F8-11CA-B331-08002B13D56D,1.0	47F40D10-E2E0-11C9-BB29-08002B0F4528	ncadg_ip_udp	2001
2FAC8900-31F8-11CA-B331-08002B13D56D,1.0	16977538-E257-11C9-8DC0-08002B0F4528	ncacn_ip_tcp	1025
2FAC8900-31F8-11CA-B331-08002B13D56D,1.0	16977538-E257-11C9-8DC0-08002B0F4528	ncadg_ip_udp	2001
2FAC8900-31F8-11CA-B331-08002B13D56D,1.0	30DBEEA0-FB6C-11C9-8EEA-08002B0F4528	ncacn_ip_tcp	1025
2FAC8900-31F8-11CA-B331-08002B13D56D,1.0	30DBEEA0-FB6C-11C9-8EEA-08002B0F4528	ncadg_ip_udp	2001

A remote procedure call made with server binding information that lacks an endpoint uses an endpoint from the endpoint map service. This endpoint must come from binding information of a compatible server. The map element of a compatible server contains the following:

- A compatible interface identifier

The requested interface UUID and compatible version numbers are necessary. For the version to be compatible, the major version number requested by the client and registered by the server must be identical, and the requested minor version number must be less than or equal to the registered minor version number.

- The requested object UUID, if registered for the interface
- A server binding handle that refers to compatible binding information that contains the following:
  - A protocol sequence from the client's server binding information
  - The same RPC protocol major version number that the client runtime supports
  - At least one transfer syntax that matches one used by the client's system

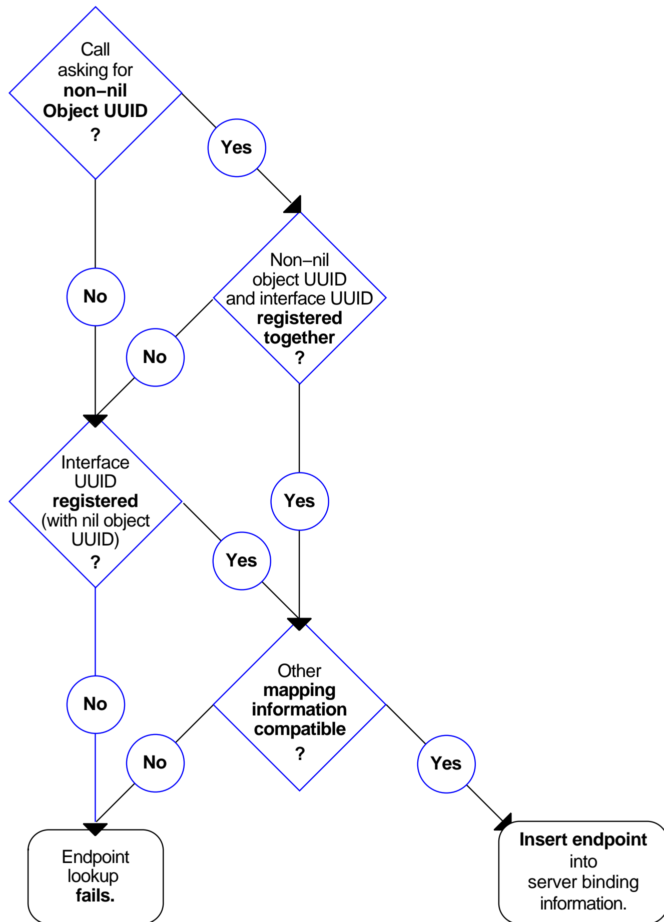
To identify the endpoint of a compatible server, the endpoint service uses the following rules:

1. If the client requests a nonnil object UUID, the endpoint map service begins by looking for a map element that contains both the requested interface UUID and object UUID.
   a. On finding an element containing both of the UUIDs, the endpoint map service selects the endpoint from that element for the server binding information used by the client.
   b. If no element contains both UUIDs, the endpoint map service discards the object UUID and starts over (see rule 2).
2. If the client requests the nil object UUID (or if the requested nonnil object UUID is not registered), the endpoint map service looks for an element containing the requested interface UUID and the nil object UUID.
   a. On finding that element, the endpoint map service selects the endpoint from the element for the client's server binding information.
   b. If no such element exists, the lookup fails.

The RPC protocol service inserts the endpoint of the compatible server into the client's server binding information.

Figure 17-5 illustrates the decisions the endpoint map service makes when looking up an endpoint for a client.

Figure 17–5. Decisions for Looking Up an Endpoint



You can design a server to allow the coexistence on a host system of multiple interchangeable instances of a server. Interchangeable server instances are identical, except for their endpoints; that is, they offer the same RPC interfaces and objects over the same network (host) address and protocol sequence pairs. For clients, identical server instances are fully interchangeable.

Usually, for each such combination of mapping information, the endpoint map service stores only one endpoint at a time. When a server registers a new endpoint for mapping

information that is already registered, the endpoint map service replaces the old map element with the new one.

For interchangeable server instances to register their endpoints in the local endpoint map, they must instruct the endpoint map service not to replace any existing elements for the same interface identifier and object UUID. Each server instance can create new map elements for itself by calling the **rpc_ep_register_no_replace()** routine.

When a client uses a partially bound binding handle, load sharing among interchangeable server instances depends on the RPC protocol the client is using.

- Connectionless (datagram) protocol

  The map service selects the first map element with compatible server binding information. If necessary, a client can achieve a random selection among all the map elements with compatible binding information. However, this requires that, before making a remote procedure call, the client needs to resolve the binding by calling the **rpc_ep_resolve_binding()** routine.

- Connection-oriented protocol

  The client RPC runtime uses the **rpc_ep_resolve_binding()** routine, and the endpoint map service selects randomly among all the map elements of compatible servers.

For an alternative selection criteria, a client can call the **rpc_mgmt_ep_elt_inq_**{**begin**, **next**,**done**}**()** routines and use an application-specific routine to select from among the binding handles returned to the client.

When a server stops running, its map elements become outdated. Although the endpoint map service routinely removes any map element containing an outdated endpoint, a lag time exists when stale entries remain. If a remote procedure call uses an endpoint from an outdated map element, the call fails to find a server. To avoid clients getting stale data from the endpoint map, before a server stops, it should remove its own map elements.

A server also has the option of removing any of its own elements from the local endpoint map and continuing to run. In this case, an unregistered endpoint remains accessible to clients that know it.

17.6.2 Buffering Call Requests

Call requests for RPC servers come into the RPC runtime over the network. For each endpoint that a server registers (for a given protocol sequence), the runtime sets up a separate request buffer. A request buffer is a first-in, first-out queue where an RPC system temporarily stores call requests that arrive at an endpoint of an RPC server. The request buffers allow the runtime to continue to accept requests during heavy activity. However, a request buffer may fill up temporarily, causing the system to reject incoming requests until the server fetches the next request from the buffer. In this case, the calling client can try again, with the same server or a different server. The client does not know why the call is rejected, nor does the client know when a server is available again.

Each server process regularly dequeues requests, one by one, from all of its request buffers. At this point, the server process recognizes them as incoming calls. The interval for removing requests from the buffers depends on the activities of the system and of the server process.

How the runtime handles a given request depends partly on the communications protocol over which it arrives, as follows:

- A call over a connectionless transport is routed by the server's system to the call request buffer for the endpoint specified in the call.
- A call over a connection-oriented transport may be routed by the server's system to a request buffer or the call may go directly to the server process.

  Whether a remote procedure call goes to the request buffer depends on whether the client sends the call over an established connection. If a client makes a remote procedure call without an established connection, the server's system treats the call request as a connection request and places the call request into a request buffer. If an established connection is available, the client uses it for the remote procedure call; the system handles the call as an incoming call and sends it directly to the server process that owns the connection.

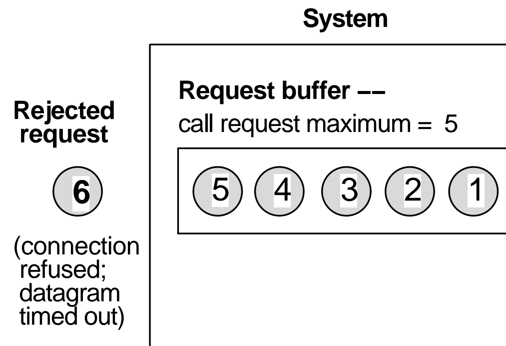
Whether a server gets an incoming call from a request buffer or over an existing connection, the server process manages the call identically. A server process applies a clear set of call-routing criteria to decide whether to dispatch a call immediately, queue it, or reject it (if the server is extremely busy). These call-routing criteria are discussed in Section 17.6.3.

When telling the RPC runtime to use a protocol sequence, a server specifies the number of calls it can buffer for the specified communications protocol (at a given endpoint). Usually, it is best for a server to specify a default buffer size, represented by a literal whose underlying value depends on the communications protocol. The default equals the capacity of a single socket used for the protocol by the server's system.

The default usually is adequate to allow the RPC runtime to accept all the incoming call requests. For a well-known endpoint, the size of a request buffer cannot exceed the capacity of a single socket descriptor (the default size); specifying a higher number causes a runtime error. For well-known endpoints, specify the default for the maximum number of call requests.

For example, consider the request buffer at full capacity as represented in Figure 17-6. This buffer has the capacity to store five requests. In this example, the buffer is full, and the runtime rejects incoming requests, as is happening to the sixth request.

Figure 17–6. A Request Buffer at Full Capacity



17.6.3 Queuing Incoming Calls

Each server process uses a first-in, first-out call queue. When the server is already executing its maximum number of concurrent calls, it uses the queue to hold incoming calls. The capacity of queues for incoming calls is implementation dependent; most implementations offer a small queue capacity, which may be a multiple of the maximum number of concurrently executing calls.

A call is rejected if the call queue is full. The appearance of the rejected call depends on the RPC protocol the call is using, as follows:

- Connectionless (datagram) protocol

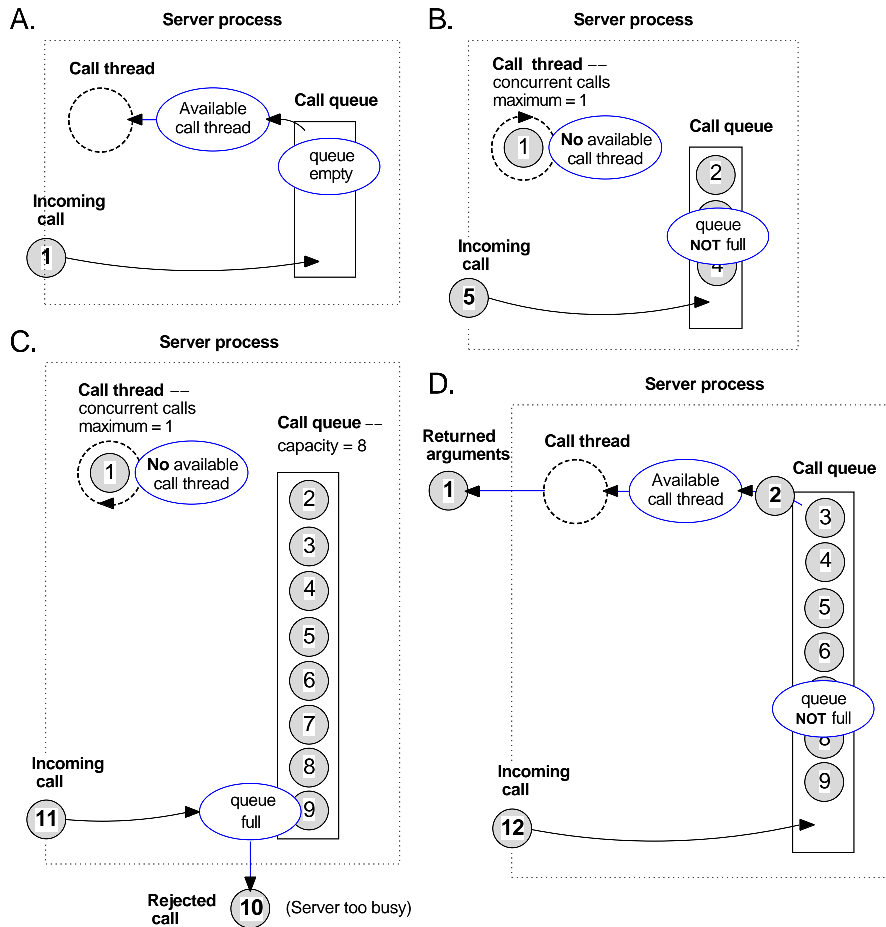
  The server does not notify the client about this failure. The call fails as if the server does not exist, returning an **rpc_s_comm_failure** communications status code (**rpc_x_comm_failure** exception).

- Connection-oriented protocol

  The server rejects the call with an **rpc_s_server_too_busy** communications status code (**rpc_x_server_too_busy** exception).

The server process routes each incoming call as it arrives. Call routing is illustrated by the server in Figure 17-7. This server has the capacity to execute only one call concurrently. Its call queue has a capacity of eight calls. This figure consists of four stages (A through D) of call routing by a server process. On receiving any incoming call, the server begins by looking at the call queue.

Figure 17–7. Stages of Call Routing by a Server Process



The activities of the four stages in the preceding figure are described as follows:

1. In stage **A**, call **1** arrives at a server that lacks any other calls. When the call arrives, the queue is empty and a call thread is available. The server accepts the call and immediately passes it to a call thread. The requested remote procedure executes the call in that thread, which becomes temporarily unavailable.

2. In stage **B**, call **5** arrives. The call queue is partially full, so the server accepts the call and adds it to the end of the queue.

3. In stage **C**, call **11** arrives. The queue is full, so the server rejects this call, as it rejected the previous call, **10**. (The caller can try again with the same or a different server.)

4. In stage **D**, the called procedure has completed call **1**, making the call thread available. The server has removed call **2** from the queue and is passing it to the call thread for execution. Thus, the queue is partially empty as call **12** arrives, so the server accepts the call and adds it to the queue.

17.6.4 Selecting a Manager

[2]Unless an RPC interface is implemented for more than one specific type of object, selecting a manager for an incoming call is a simple process. When registering an interface with a single manager, the server specifies the nil type UUID for the manager type.
In the absence of any other manager, all calls, regardless of whether they request an object, go to the nil type manager.

The situation is more complex when a server registers multiple managers for an interface. The server runtime must select from among the managers for each incoming call to the interface. The DCE RPC dispatching mechanism requires a server to set a nonnil type UUID for a set of objects and for any interface that will access the objects in order to register a manager with the same type UUID.

To dispatch an incoming call to a manager, a server does the following:

1. If the call contains the nil object UUID, the server looks for a manager registered with the nil type UUID (the nil type manager).

   a. If the nil type manager exists for the requested interface, the server dispatches the call to that manager.

   b. Otherwise, the server rejects the call.

2. If the call contains a nonnil object UUID, the server looks to see whether it has set a type for the object (by assigning a nonnil type UUID).

   If the object lacks a type, the server looks for the nil type manager.

2. The API uses NULL to specify a synonym to the address of the nil UUID, which contains only zeros.

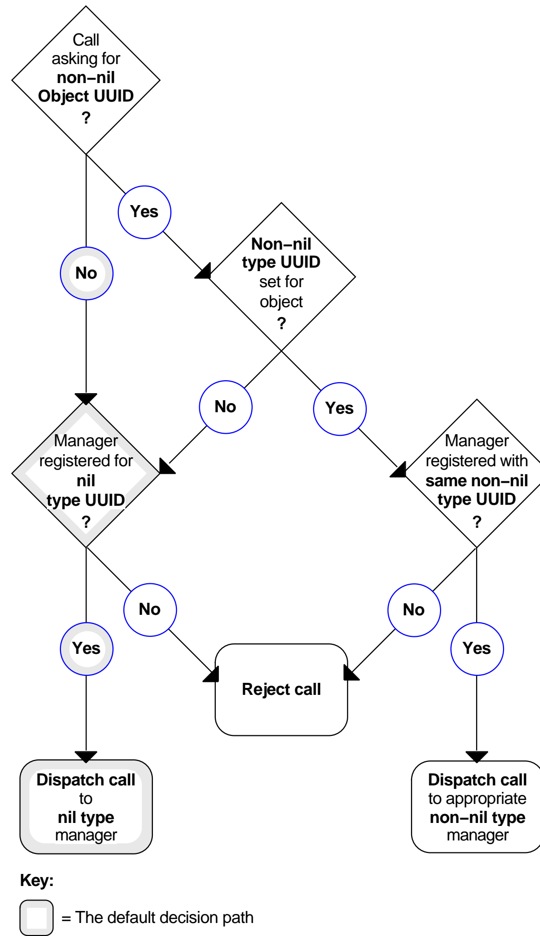
   a. If the nil type manager exists for the requested interface, the server dispatches the call to that manager.

   b. Otherwise, the server rejects the call.

3. If the object has a type, the call requires a remote procedure of a manager whose type matches the object's type. In its absence, the RPC runtime rejects the call.

Figure 17-8 illustrates the decisions a server makes to select a manager to which to dispatch an incoming call.

Figure 17–8. Decisions for Selecting a Manager



17.7 Creating Portable Data via the IDL Encoding Services

The IDL encoding services provide client and server RPC applications with a method for encoding data types in input parameters into byte stream format and decoding data

types in output parameters from a byte stream without invoking the RPC runtime. Encoding and decoding functions are just like marshalling and unmarshalling, except that the data is stored locally and is not transmitted over the network; the IDL encoding services separate the data marshalling and unmarshalling functions from interaction with the RPC runtime.

Client and server applications can use the IDL encoding services to flatten (or serialize) a data structure, even binary data, and then store it; for example, by writing it to a file on disk. An RPC application on any DCE machine, regardless of its data type size and byte endianess, is then able to use the IDL encoding services to decode previously encoded data. Without the IDL encoding services, you cannot create a file of data on one machine and then successfully read that data on another machine that has different size data types and byte endianess.

The IDL encoding services can generate code that takes the input parameters to a procedure and places them in a standard form in one or more buffers that are delivered to user code. This process is called *encoding*. Encoded data can be written to a file or forwarded by a messaging system. The IDL encoding services can also generate code that delivers, as the output parameters of a procedure, data that has been converted into the standard form by encoding. Delivery of data in this way is called *decoding*. Data to be decoded can be read from a file or received by a messaging system.

Applications use the ACF attributes **encode** and **decode** as operation attributes or as interface attributes to direct the IDL compiler to generate IDL encoding services stubs for operations rather than generating RPC stubs. See Chapter 19 for usage information on **encode** and **decode**.

17.7.1 Memory Management

IDL encoding services stubs handle memory management in the same way as RPC client stubs: when you call an operation to which the **encode** and/or **decode** attributes have been applied, the encoding services stub uses whatever client stub memory management scheme is currently in effect. See Section 17.1 for further details on client stub memory management defaults and setting up memory management schemes.

You can control which memory management scheme the stubs will use by calling the **rpc_ss_swap_client_alloc_free()** and **rpc_ss_set_client_alloc_free()** routines. The first routine sets the memory management routines used by both the encoding and

decoding stubs, and the second routine restores the previous memory management scheme after encoding and decoding are complete.

Note that the memory management scheme established, whether explicitly or by default, is on a per-thread basis.

17.7.2 Buffering Styles

There are a number of different ways in which buffers containing encoded data can be passed between the application code and the IDL encoding services. These are referred to as different *buffering styles*. The different buffering styles are:

- Incremental encoding

  The incremental encoding style requires that you provide an **allocate** routine which creates an empty buffer into which IDL encoding services can place encoded data, and a **write** routine which IDL encoding services will call when the buffer is full or all the parameters of the operation have been encoded. The IDL encoding services call the **allocate** and **write** routines repeatedly until the encoding of all of the parameters has been delivered to the user code. See the **idl_es_encode_incremental(3rpc)** reference page for a description of the required parameters for the **allocate** and **write** routines.

- Fixed buffer encoding

  The fixed buffer encoding style requires that the application supply a single buffer into which all the encoded data is to be placed. The buffer must have an address that is 8-byte aligned and must be a multiple of 8 bytes in size. It must also be large enough to hold an encoding of all the data, together with an encoding header for each operation whose parameters are being encoded; 56 bytes should be allowed for each encoding header.

- Dynamic buffer encoding

  With the dynamic buffer encoding style, the IDL encoding services build a single buffer containing all the encoded data and deliver the buffer to application code. The buffer is allocated by whatever client memory management mechanism has been put in place by the application code. The default for this is **malloc**(). When the application code no longer needs the buffer, it should release the memory resource.

The dynamic buffer encoding style has performance implications. The IDL encoding services will usually allocate a number of intermediate buffers, then allocate the buffer to be delivered to the application code, copy data into it from the intermediate buffers, and release the intermediate buffers.

- Incremental decoding

  The incremental decoding buffering style requires that you provide a **read** routine which, when called, delivers to the IDL encoding services a buffer that contains the next part of the data to be decoded. The IDL encoding services will call the **read** routine repeatedly until all of the required data has been decoded. See the **idl_es_encode_incremental(3rpc)** reference page for a description of the required parameters for the **read** routine.

- Buffer decoding

  The buffer decoding style requires that you supply a single buffer containing all the encoded data. Where application performance is important, note that, if the supplied buffer is not 8-byte aligned, the IDL encoding services allocate a temporary aligned buffer of comparable size and copy data from the user-supplied buffer into it before performing the requested decoding.

17.7.3 IDL Encoding Services Handles

When an application's encoding or decoding operation is invoked, the handle passed to it must be an IDL encoding services handle (the **idl_es_handle_t** type). The IDL encoding services handle indicates whether encoding or decoding is required, and what style of buffering is to be used. The IDL encoding services provides a set of routines to enable the application code to obtain encoding and decoding handles to the IDL encoding services. The IDL encoding services handle-returning routine you call depends on the buffering style you have chosen:

- If you have selected the incremental encoding style, you call the **idl_es_encode_incremental()** routine, which returns an incremental encoding handle.

- If you have selected the fixed buffer encoding style, you call the **idl_es_encode_fixed_buffer()** routine, which returns a fixed buffer encoding handle.

- If you have selected dynamic buffer encoding, you call the **idl_es_encode_dyn_buffer()** routine, which returns a dynamic buffer encoding handle.
- If you have selected incremental decoding as your buffering style, you call the **idl_es_decode_incremental()** routine, which returns an incremental decoding handle.
- If you have selected the buffer decoding style, you call the **idl_es_decode_buffer()** routine, which returns a buffer decoding handle.

When the encoding or decoding for which an IDL encoding services handle was required is completed, the application code should release the handle resources by calling the **idl_es_handle_free()** routine. See the *DCE 1.2.2 Application Development Reference* for a complete description of the IDL encoding service routines.

It is an error to call an operation for which **encode** or **decode** has been specified by using an RPC binding handle, and it is an error to call an RPC operation by using an IDL encoding services handle.

The following restrictions apply to the use of IDL encoding services handles:

- An operation can be called with an encoding handle only if the operation has been given the **encode** ACF attribute.
- An operation can be called with a decoding handle only if the operation has been given the **decode** ACF attribute.
- The **auto_handle** ACF attribute cannot be used with the IDL encoding services.
- The **implicit_handle** ACF attribute cannot be used with the IDL encoding services.
- Customized handles cannot be used with the IDL encoding services.
- An **in** context handle does not contain the handle information needed by the IDL encoding services.

17.7.4 Programming Example

The following example uses the IDL encoding service features described in the preceding sections. The example verifies that the results of a number of decoding operations are the same as the parameters used to create the corresponding encodings.

The interface definition for this example is as follows:

```
[uuid(20aac780-5398-11c9-b996-08002b13d56d), version(0)]
interface es_array
{
    const long N = 5000;

    typedef struct
    {
        byte b;
        long l;
    } s_t;

    typedef struct
    {
        byte b;
        long a[7];
    } t_t;

    void in_array_op1([in] handle_t h, [in] long arr[N]);
    void out_array_op1([in] handle_t h, [out] long arr[N]);

    void array_op2([in] handle_t h, [in,out] s_t big[N]);

    void array_op3([in] handle_t h, [in,out] t_t big[N]);
}
```

The attribute configuration file for the example is as follows:

```
interface es_array
{
    [encode] in_array_op1();
    [decode] out_array_op1();
    [encode, decode] array_op2();
    [encode, decode] array_op3();
}
```

The test code for the example is as follows:

```
#include <dce/pthread_exc.h>
#include "rpcexc.h"
#include <stdio.h>
#include <stdlib.h>
#include <file.h>
#include <sys/file.h>
#include "es_array.h"

/*
*  User state for incremental encode/decode
*/
typedef struct es_state_t {
idl_byte *malloced_addr;
int file_handle;
} es_state_t;

static es_state_t es_state;

#define OUT_BUFF_SIZE 2048
static idl_byte out_buff[OUT_BUFF_SIZE];
static idl_byte *out_data_addr;
static idl_ulong_int out_data_size;

/*
*  User allocate routine for incremental encode
*/
void es_allocate(state, buf, size)
idl_void_p_t state;
idl_byte **buf;
```

```
idl_ulong_int *size;
{
idl_byte *malloced_addr;
es_state_t *p_es_state = (es_state_t *)state;

malloced_addr = (idl_byte *)malloc(*size);
p_es_state->malloced_addr = malloced_addr;
*buf = (idl_byte *)(((malloced_addr - \
(idl_byte *)0) + 7) & (~7));
*size = (*size - (*buf - malloced_addr)) & (~7);
}

/*
*  User write routine for incremental encode
*/
void es_write(state, buf, size)
idl_void_p_t state;
idl_byte *buf;
idl_ulong_int size;
{
es_state_t *p_es_state = (es_state_t *)state;

write(p_es_state->file_handle, buf, size);
free(p_es_state->malloced_addr);
}

/*
*  User read routine for incremental decode
*/
void es_read(state, buf, size)
idl_void_p_t state;
idl_byte **buf;
idl_ulong_int *size;
{
es_state_t *p_es_state = (es_state_t *)state;

read(p_es_state->file_handle, out_data_addr, out_data_size);
*buf = out_data_addr;
*size = out_data_size;
}
```

```
static ndr_long_int arr[N];
static ndr_long_int out_arr[N];
static s_t sarr[N];
static s_t ref_sarr[N];
static s_t out_sarr[N];
static t_t tarr[N];
static t_t ref_tarr[N];
static t_t out_tarr[N];
static ndr_long_int (*oarr)[M];

#define FIXED_BUFF_STORE (8*N+64)
static idl_byte fixed_buff_area[FIXED_BUFF_STORE];

/*
*  Test Program
*/
main()
{
idl_es_handle_t es_h;
idl_byte *fixed_buff_start;
idl_ulong_int fixed_buff_size, encoding_size;
idl_byte *dyn_buff_start;
error_status_t status;
int i,j;

for (i = 0; i < N; i++)
{
arr[i] = random()%10000;
sarr[i].b = i & 0x7f;
sarr[i].l = random()%10000;
ref_sarr[i] = sarr[i];
tarr[i].b = i & 0x7f;
for (j = 0; j < 7; j++) tarr[i].a[j] = random()%10000;
ref_tarr[i] = tarr[i];
}

/*
*Incremental encode/decode
*/
```

```
/* Encode data using one operation */
es_state.file_handle = open("es_array_1.dat", \
O_CREAT|O_TRUNC|O_WRONLY,  0777);
if (es_state.file_handle < 0)
{
printf("Can't open es_array_1.dat\n");
exit(0);
}
idl_es_encode_incremental((idl_void_p_t)&es_state, es_allocate, \
es_write, &es_h, &status);
if (status != error_status_ok)
{
printf("Error %08x from idl_es_encode_incremental\n", status);
exit(0);
}
in_array_op1(es_h, arr);
close(es_state.file_handle);
idl_es_handle_free(&es_h, &status);
if (status != error_status_ok)
{
printf("Error %08x from idl_es_handle_free\n", status);
exit(0);
}
/* Decode the data using another operation with                */
/* the same signature                                          */
out_data_addr =
(idl_byte *)(((out_buff - (idl_byte *)0) + 7) & (~7));
out_data_size =
(OUT_BUFF_SIZE - (out_data_addr - out_buff)) & (~7);
es_state.file_handle = open("es_array_1.dat", O_RDONLY, 0);
if (es_state.file_handle < 0)
{
printf("Can't open es_array_1.dat for reading\n");
exit(0);
}
idl_es_decode_incremental((idl_void_p_t)&es_state, es_read,
&es_h, &status);
if (status != error_status_ok)
{
printf("Error %08x from idl_es_decode_incremental\n", status);
```

```
exit(0);
}
out_array_op1(es_h, out_arr);
close(es_state.file_handle);
idl_es_handle_free(&es_h, &status);
if (status != error_status_ok)
{
printf("Error %08x from idl_es_handle_free\n", status);
exit(0);
}

/* Check the input and output are the same */
for (i = 0; i < N; i++)
{
if (out_arr[i] != arr[i])
{
printf("out_arr[%d] - found %d - expecting %d\n",
i, out_arr[i], arr[i]);
}
}

/*
* Fixed buffer encode/decode
*/
fixed_buff_start = (idl_byte *)(((fixed_buff_area - \
(idl_byte *)0) + 7)
& (~7));
fixed_buff_size = (FIXED_BUFF_STORE - \
(fixed_buff_start - fixed_buff_area))
& (~7);
idl_es_encode_fixed_buffer(fixed_buff_start, fixed_buff_size,
&encoding_size, &es_h, &status);
if (status != error_status_ok)
{
printf("Error %08x from idl_es_encode_fixed_buffer\n", status);
exit(0);
}
    array_op2(es_h, sarr);
idl_es_handle_free(&es_h, &status);
if (status != error_status_ok)
```

```
{
printf("Error %08x from idl_es_handle_free\n", status);
exit(0);
}
idl_es_decode_buffer
(fixed_buff_start, encoding_size, &es_h, &status);
if (status != error_status_ok)
{
printf("Error %08x from idl_es_decode_buffer\n", status);
exit(0);
}
array_op2(es_h, out_sarr);
idl_es_handle_free(&es_h, &status);
if (status != error_status_ok)
{
printf("Error %08x from idl_es_handle_free\n", status);
exit(0);
}
for (i = 0; i < N; i++)
{
if (out_sarr[i].b != ref_sarr[i].b)
{
printf
("array_op2 - out_sarr[%d].b = %c\n", i, out_sarr[i].b);
}
if (out_sarr[i].l != ref_sarr[i].l)
{
printf
("array_op2 - out_sarr[%d].l = %d\n", i, out_sarr[i].l);
}
}

/*
* Dynamic buffer encode - fixed buffer decode
*/
idl_es_encode_dyn_buffer
(&dyn_buff_start, &encoding_size, &es_h, \ &status);
if (status != error_status_ok)
{
printf("Error %08x from idl_es_encode_dyn_buffer\n", status);
```

```
exit(0);
}
array_op3(es_h, tarr);
idl_es_handle_free(&es_h, &status);
if (status != error_status_ok)
{
printf("Error %08x from idl_es_handle_free\n", status);
exit(0);
}
    idl_es_decode_buffer(dyn_buff_start, encoding_size, &es_h, &status);
if (status != error_status_ok)
{
printf("Error %08x from idl_es_decode_buffer\n", status);
exit(0);
}
array_op3(es_h, out_tarr);
rpc_ss_free (dyn_buff_start);
idl_es_handle_free(&es_h, &status);
if (status != error_status_ok)
{
printf("Error %08x from idl_es_handle_free\n", status);
exit(0);
}
for (i = 0; i < N; i++)
{
if (out_tarr[i].b != ref_tarr[i].b)
{
printf("array_op3 - out_tarr[%d].b = %c\n", i, out_tarr[i].b);
}
for (j=0; j<7; j++)
{
if (out_tarr[i].a[j] != ref_tarr[i].a[j])
{
printf("array_op3 - out_tarr[%d].a[%d] = %d\n",
i, j, out_tarr[i].a[j]);
}
}
}

printf("Test Complete\n");
```

```
}
```

17.7.5 Performing Multiple Operations on a Single Handle

Multiple operations can be performed using one encoding handle before the handle is released. In this case, all the encoded data is part of the same buffer system.

A single decoding handle is used to obtain the contents of the encoded data. Decoding operations must be called in the same order the encoding operations were called to create the encoded data.

The definition of the user client memory management functions, and any memory allocated by IDL encoding services using the client memory allocator, must not be modified between operations for which the same encoding handle is used.

17.7.6 Determining the Identity of an Encoding

Applications can use the **idl_es_inq_encoding_id()** routine to determine the identity of an encoding operation, for example, before calling their decoding operations.

Chapter 18

Interface Definition Language

This chapter describes how to construct an Interface Definition Language (IDL) file. First, it describes the IDL syntax notation conventions and lexical elements. It then describes the interface definition structure and the individual language elements supported by the IDL compiler.

18.1 The Interface Definition Language File

The IDL file defines all aspects of an interface that affect data passed over the network between a caller (client) and a callee (server). An interface definition file has the suffix **.idl**. In order for a caller and callee to interoperate, they both need to incorporate the same interface definition.

18.2 Syntax Notation Conventions

In addition to the documentation conventions described in the Preface of this guide, the IDL syntax uses the special notation described in the following subsections.

18.2.1 Typography

IDL documentation uses the following typefaces:

Bold — **Bold** typeface indicates a literal item. Keywords and literal punctuation are represented in bold typeface. Identifiers used in a particular example are represented in bold typeface when mentioned in the text.

Italic — *Italic* typeface indicates a symbolic item for which you need to substitute a particular value. In IDL syntax descriptions, all identifiers that are not keywords are represented in italic typeface.

`Constant width` — `Constant width` typeface is used for source code examples (in IDL or in C) that are displayed separately from regular text.

18.2.2 Special Symbols

IDL documentation uses the following symbolic notations:

[item] — *Italic* brackets surrounding an item, which may include brackets in regular typeface, indicate that the item contained within them is optional.

[*item*] — Brackets shown in regular typeface surrounding a variable *item* indicate that the brackets are a required when the item is included, whether or not the item itself is required.

item ... — Ellipsis points following an item indicate that the item may occur one or more times.

item, *...* — If an item is followed by a literal punctuation character and then by ellipsis points, the item may occur either once without the punctuation character or more than once with the punctuation character separating each instance.

...	If ellipsis points are shown on a line by themselves, the item or set of items in the preceding line may occur any number of additional times.
item | *item*	If several items are shown separated by vertical bars, exactly one of those items must occur.

18.3 IDL Lexical Elements

The following subsections describe these IDL lexical elements:

- Identifiers
- Keywords
- Punctuation characters
- Whitespace
- Case sensitivity

18.3.1 Identifiers

The character set for IDL identifiers comprises the alphabetic characters A to Z and a to z, the digits 0 to 9, and the _ (underscore) character. An identifier must start with an alphabetic character.

No IDL identifier can exceed 31 characters. In some cases, an identifier has a shorter maximum length because the IDL compiler uses the identifier as a base from which to construct other identifiers; we identify such cases as they occur.

18.3.2 Keywords

IDL reserves some identifiers as keywords. In the text of this chapter, keywords are represented in **bold** typeface, and identifiers chosen by application developers are represented in *italic* typeface.

18.3.3 Punctuation Characters

IDL uses the following graphic characters:

```
" ' ( ) * , . / : ; | = [ \ ] { }
```

The **{** (left brace) and **}** (right brace) characters are national replacement set characters that may not be available on all keyboards. Wherever IDL specifies a left brace, the **??<** trigraph may be substituted. Wherever IDL specifies a right brace, the **??>** trigraph may be substituted.

Use of these trigraph sequences adds the following punctuation characters to the set in the preceding list:

```
< > ?
```

18.3.4 Whitespace

Whitespace is used to delimit other constructs. IDL defines the following whitespace constructs:

- A space
- A carriage return
- A horizontal tab
- A form feed at the beginning of a line
- A comment
- A sequence of one or more of the preceding whitespace constructs

A keyword, identifier, or number not preceded by a punctuation character must be preceded by whitespace. A keyword, identifier, or number not followed by a punctuation character must be followed by whitespace. Unless we note otherwise, any punctuation character may be preceded and/or followed by whitespace.

When enclosed in **""** (double quotes) or **’’** (single quotes), whitespace constructs are treated literally. Otherwise, they serve only to separate other lexical elements and are ignored.

Just as in C, the character sequence **/*** (slash and asterisk) begins a comment, and the character sequence ***/** (asterisk and slash) ends a comment. For example:

```
/* all natural */
import "potato.idl";  /* no preservatives */
```

Comments do not nest.

18.3.5 Case Sensitivity

The IDL compiler does not force the case of identifiers in the generated code.

The only case sensitivity issue that you have to be aware of is the implications involved in calling generated stubs from languages other than C.

18.4 IDL Versus C

IDL resembles a subset of ANSI C. The major difference between IDL and C is that there are no executable statements in IDL.

18.4.1 Declarations

An interface definition specifies how operations are called, not how they are implemented. IDL is therefore a purely declarative language.

18.4.2 Data Types

To support applications written in languages other than C, IDL defines some data types that do not exist in C and extends some data types that do exist in C. For example, IDL defines a Boolean data type.

Some C data types are supported by IDL only with modifications or restrictions. For example, unions must be discriminated, and all arrays must be accompanied by bounds information.

18.4.3 Attributes

The stub modules that are generated from an interface definition require more information about the interface than can be expressed in C. For example, stubs must know whether an operation parameter is an input or an output.

The additional information required to define a network interface is specified via IDL attributes. IDL attributes can apply to types, to structure members, to operations, to operation parameters, or to the interface as a whole. Some attributes are legal in only one of the preceding contexts; others are legal in more than one context. An attribute is always represented in **[ ]**(brackets) before the item to which it applies. For example, in an operation declaration, inputs of the operation are preceded by the **in** attribute and outputs are preceded by the **out** attribute:

```
void arith_add (
     [in] long a,
     [in] long b,
     [out] long *c,
     );
```

18.5 Interface Definition Structure

An interface definition has the following structure:

[*interface_attribute***, ...] interface** *interface_name*
{
declarations
}

The portion of an interface definition that precedes the **{** (left brace) is the interface header. The remainder of the definition is the interface body. Interface header syntax and interface body syntax are described separately in the following two subsections.

18.5.1 Interface Definition Header

The interface header comprises a list of interface attributes enclosed in **[ ]**(brackets), the keyword **interface**, and the interface name:

[*interface_attribute***, ...] interface** *interface_name*

Interface names, together with major and minor version numbers, are used by the IDL compiler to construct identifiers for interface specifiers, entry point vectors, and entry point vector types. If the major and minor version numbers are single digits, the interface name can be up to 17 characters long.

For C++ output, the interface header can also inherit an interface by using the inheritance operator (:) as follows:

[*interface_attribute***, ...] interface** *interface_name* **:** *inherited_interface*

18.5.2 Interface Definition Body

The *declarations* in an interface definition body are one or more of the following:

import_declaration
constant_declaration

type_declaration
operation_declaration

A **;** (semicolon) terminates each declaration, and **{ }** (braces) enclose the entire body.

Import declarations must precede other declarations in the interface body. Import declarations specify the names of other IDL interfaces that define types and constants used by the importing interface.

Constant, type, and operation declarations specify the constants, types, and operations that the interface exports. These declarations can be coded in any order, provided any constant or type is defined before it is used.

18.6 Overview of IDL Attributes

Table 18-1 lists the attributes allowed in interface definition files and specifies the declarations in which they can occur.

Table 18–1. IDL Attributes

Attribute	**Where Used**
uuid	Interface definition headers
version	
endpoint	
exceptions	
pointer_default	
local	
broadcast	Operations
maybe	
idempotent	
reflect_deletions	
in	Parameters

Attribute	**Where Used**
out	
ignore	Structures
max_is	Arrays
min_is	
size_is	
first_is	
last_is	
length_is	
string	Arrays
ptr	Pointers
ref	
unique	
handle	Customized handles
context_handle	Context handles
transmit_as	Type declarations

18.7 Interface Definition Header Attributes

The following subsections describe in detail the usage and semantics of the IDL attributes that can be used in interface definition headers. The attributes provided for interface definition headers are as follows:

- **uuid**
- **version**
- **endpoint**
- **exceptions**
- **pointer_default**

- **local**

18.7.1 The uuid Attribute

The **uuid** attribute specifies the Universal Unique Identifier (UUID) that is assigned to an interface. The **uuid** attribute takes the following form:

uuid (*uuid_string*)

A *uuid_string* is the string representation of a UUID. This string is typically generated as part of a skeletal interface definition by the utility **uuidgen**. A *uuid_string* contains one group of 8 hexadecimal digits, three groups of 4 hexadecimal digits, and one group of 12 hexadecimal digits, with hyphens separating the groups, as in the following example:

```
01234567-89ab-cdef-0123-456789abcdef
```

A new UUID should be generated for any new interface. If several versions of one interface exist, all versions should have the same interface UUID but different version numbers. A client and a server cannot communicate unless the interface imported by the client and the interface exported by the server have the same UUID. The client and server stubs in an application must be generated from the same interface definition or from interface definitions with identical **uuid** attributes.

Any remote interface must have the **uuid** attribute. An interface must have either the **uuid** attribute or the **local** attribute, but cannot have both.

The **uuid** attribute can appear at most once in an interface.

The following example illustrates use of the **uuid** attribute:

```
uuid(4ca7b4dc-d000-0d00-0218-cb0123ed9876)
```

18.7.2 The version Attribute

The **version** attribute specifies a particular version of a remote interface. The **version** attribute takes the following form:

version (*major* [**.** *minor*])

A version number can be either a pair of integers (the major and minor version numbers) or a single integer (the major version number). If both major and minor version numbers are supplied, the integers should be separated by a period without whitespace. If no minor version number is supplied, 0 (zero) is assumed.

The following examples illustrate use of the **version** attribute:

```
version (1.1)   /* major and minor version numbers */

version (3)     /* major version number only */
```

The **version** attribute can be omitted altogether, in which case the interface is assigned 0.0 as the default version number.

A client and a server can communicate only if the following requirements are met:

- The interface imported by the client and the interface exported by the server have the same major version number.
- The interface imported by the client has a minor version number less than or equal to that of the interface exported by the server.

You must increase either the minor version number or the major version number when you make any compatible change to an interface definition. You must not decrease the minor version number unless you simultaneously increase the major version number.

You must increase the major version number when you make any incompatible change to an interface definition. (See the definition of compatible changes that follows.) You cannot decrease the major version number.

The following are considered compatible changes to an interface definition:

- Adding operations to the interface, if and only if the new operations are declared after all existing operation declarations in the interface definition.
- Adding type and constant declarations, if the new types and constants are used only by operations added at the same time or later. Existing operation declarations cannot have their signatures modified.

The *major* and *minor* integers in the **version** attribute can range from 0 to 65,535, inclusive. However, these typically are small integers and are increased in increments of one.

The following are considered incompatible changes to an interface definition:

- Changing the signature of an existing operation
- Changing the order of existing operations
- Adding a new operation other than at the end

The **version** attribute can appear at most once in an interface.

18.7.3 The endpoint Attribute

The **endpoint** attribute specifies the well-known endpoint or endpoints on which servers that export the interface will listen. The **endpoint** attribute takes the following form:

endpoint (*endpoint_spec***, ...)**

Each *endpoint_spec* is a string in the following form:

" *family* **: [***endpoint***] "**

The *family* identifies a protocol family. The following are accepted values for *family*:

- **ncacn_ip_tcp**: NCA Connection over Internet Protocol: Transmission Control Protocol (TCP/IP)

- **ncadg_ip_udp**: NCA Datagram over Internet Protocol: User Datagram Protocol (UDP/IP)

The *endpoint* identifies a well-known endpoint for the specified *family*. The values accepted for *endpoint* depend on the *family* but typically are integers within a limited range. IDL does not define valid *endpoint* values.

Well-known endpoint values are typically assigned by the central authority that ''owns'' a protocol. For example, the Internet Assigned Numbers Authority assigns well-known endpoint values for the IP protocol family.

At compile time, the IDL compiler checks each *endpoint_spec* only for gross syntax. At runtime, stubs pass the *family* and *endpoint* strings to the RPC runtime, which validates and interprets them.

Most applications should not use well-known endpoints and should instead use dynamically assigned opaque endpoints. Most interfaces designed for use by applications should therefore not have the **endpoint** attribute.

The following example illustrates use of the **endpoint** attribute:

```
endpoint ("ncacn_ip_tcp:[1025]", "ncadg_ip_udp:[6677]")
```

The **endpoint** attribute can appear at most once in an interface.

18.7.4 The exceptions Attribute

The **exceptions** attribute specifies a set of user-defined exceptions that can be generated by the server implementation of the interface. The **exceptions** attribute takes the following form:

exceptions (*exception_name* **[,***exception_name***] ...)**

The following is a sample declaration of an **exceptions** attribute:

```
[uuid(06255501-08AF-11CB-8C4F-08002B13D56D),
version (1.1),
  exceptions (
      exc_e_exquota,
      binop_e_aborted,
      binop_e_too_busy,
      binop_e_shutdown)
] interface binop
  {
      long binop_add(
           [in] long a,
           [in] long b
           );
   }
```

See Chapter 17 for more information on using exceptions.

18.7.5 The pointer_default Attribute

IDL supports two kinds of pointer semantics. The **pointer_default** attribute specifies the default semantics for pointers that are declared in the interface definition. The **pointer_default** attribute takes the following form:

pointer_default (*pointer_attribute***)**

Possible values for *pointer_attribute* are **ref, unique,** and **ptr**.

The default semantics established by the **pointer_default** attribute apply to the following usages of pointers:

- A pointer that occurs in the declaration of a member of a structure or a union.
- A pointer that does not occur at the top level of an operation parameter declared with more than one pointer operator. A top-level pointer is one that is not the target of another pointer and is not a field of a data structure that is the target of a pointer. (See Section 18.14.7.2 for more information on top-level pointers.)

Note that the **pointer_default** attribute does not apply to a pointer that is the return value of an operation because this is always a full pointer.

The default semantics can be overridden by pointer attributes in the declaration of a particular pointer. If an interface definition does not specify **pointer_default** and contains a declaration that requires default pointer semantics, the IDL compiler will issue a warning. For additional information on pointer semantics, refer to Section 18.14.7.1.

The **pointer_default** attribute can appear at most once in an interface.

18.7.6 The local Attribute

The **local** attribute indicates that an interface definition does not declare any remote operations and that the IDL compiler should therefore generate only header files, not stub files. The **local** attribute takes the following form:

local

An interface containing operation definitions must have either the **local** attribute or the **uuid** attribute. No interface can have both.

The **local** attribute can appear at most once in an interface.

18.7.7 Rules for Using Interface Definition Header Attributes

An interface cannot have both the **local** attribute and the **uuid** attribute. In an interface definition that contains any operation declarations, either **local** or **uuid** must be specified. In an interface definition that contains no operation declarations, both **local** and **uuid** can be omitted.

The **local**, **uuid**, and **version** attributes cannot be coded more than once. If the **endpoint** or the **pointer_default** attribute is coded more than once, the IDL compiler issues a warning and, where conflicts exist, the IDL compiler accepts the last value specified.

18.7.8 Examples of Interface Definition Header Attributes

The following example uses the **uuid** and **version** attributes:

```
[uuid(df961f80-2d24-11c9-be74-08002b0ecef1), version(1.1)]
interface my_interface_name
```

The following example uses the **uuid**, **endpoint**, and **version** attributes:

```
[uuid(0bb1a080-2d25-11c9-8d6e-08002b0ecef1),
endpoint("ncacn_ip_tcp:[1025]", "ncacn_ip_tcp:[6677]"),
version(3.2)]
interface my_interface_name
```

18.8 Import Declarations

The IDL *import_declaration* specifies interface definition files that declare types and constants used by the importing interface. It takes the following form:

import ***file*,... ;**

The *file* argument is the pathname, enclosed in double quotes, of the interface definition you are importing. This pathname can be relative; the **-I** option of the IDL compiler allows you to specify a directory from which to resolve import pathnames.

The effect of an import declaration is as if all constant, type, and import declarations from the imported file occurred in the importing file at the point where the import declaration occurs. Operation declarations are not imported.

For example, suppose that the interface definition **aioli.idl** contains a declaration to import the definitions for the **garlic** and **oil** interfaces:

```
import "garlic.idl", "oil.idl";
```

The IDL compiler will generate a C header file named **aioli.h** that contains the following **#include** directives:

```
#include "garlic.h"
#include "oil.h"
```

The stub files that the compiler generates will not contain code for any **garlic** and **oil** operations.

Importing an interface many times has the same effect as importing it once.

18.9 Constant Declarations

The IDL *constant_declaration* can take any one of the following forms:

const *integer_type_spec identifier* = *integer* | *value* | *integer_const_expression***;**
const boolean *identifier* = **TRUE** | **FALSE** | *value***;**
const char *identifier* = *character* | *value***;**
const char* *identifier* = *string* | *value***;**
const void* *identifier* = **NULL** | *value***;**

The *integer_type_spec* is the data type of the integer constant you are declaring. The *identifier* is the name of the constant. The *integer*, *integer_const_expression*, *character*, *string*, or *value* specifies the value to be assigned to the constant. A *value* can be any previously defined constant.

IDL provides only integer, Boolean, character, string, and null pointer constants.

Following are examples of constant declarations:

```
const short TEN = 10;
const boolean FAUX = FALSE;
```

```
const char* DSCH = "Dmitri Shostakovich";
```

18.9.1 Integer Constants

An *integer_type_spec* is a *type_specifier* for an integer, except that the *int_size* for an integer constant cannot be **hyper**.

An *integer* is the decimal representation of an integer. IDL also supports the C notation for hexadecimal, octal, and long integer constants.

You can specify any previously defined integer constant as the *value* of an integer constant.

You can specify any arithmetic expression as the *integer_const_expression* that evaluates to an integer constant.

18.9.2 Boolean Constants

A Boolean constant can take one of two values: TRUE or FALSE.

You can specify any previously defined Boolean constant as the *value* of a Boolean constant.

18.9.3 Character Constants

A *character* is an ASCII character enclosed in single quotes. A white space character is interpreted literally. The **** (backslash) character introduces an escape sequence, as defined in the ANSI C standard. The **'**(single quote) character can be coded as the *character* only if it is escaped by a backslash.

You can specify any previously defined character constant as the *value* of a character constant.

18.9.4 String Constants

A *string* is a sequence of ASCII characters enclosed in double quotes. Whitespace characters are interpreted literally. The **** (backslash) character introduces an escape sequence, as defined in the ANSI C standard. The **"** (double quote) character can be coded in a *string* only if it is escaped by a backslash.

You can specify any previously defined string constant as the *value* of a string constant.

18.9.5 NULL Constants

A **void*** constant can take only one literal value: NULL.

You can specify any previously defined **void*** constant as the *value* of a **void*** constant.

18.10 Type Declarations

The IDL *type_declaration* enables you to associate a name with a data type and to specify attributes of the data type. It takes the following form:

typedef *[***[***type_attribute***, ...]***] type_specifier type_declarator***, ... ;**

A *type_attribute* specifies characteristics of the type being declared.

The *type_specifier* can specify a base type, a constructed type, a predefined type, or a named type. A function pointer can be specified if the **local** attribute has been specified.

Each *type_declarator* is a name for the type being defined. Note, though, that a *type_declarator* can also be preceded by an ***** (asterisk), followed by **[]** (brackets), and can include **( )** (parentheses) to indicate the precedence of its components.

18.10.1 Type Attributes

A *type_attribute* can be any of the following:

- **handle**: The type being declared is a user-defined, customized-handle type.
- **context_handle**: The type being declared is a context-handle type.
- **transmit_as**: The type being declared is a *presented type*. When it is passed in remote procedure calls, it is converted to a specified *transmitted type*.
- **ref**: The type being declared is a reference pointer.
- **ptr**: The type being declared is a full pointer.
- **unique**: The type being declared is a unique pointer.
- **string**: The array type being declared is a string type.

18.10.2 Base Type Specifiers

IDL base types include integers, floating-point numbers, characters, a **boolean** type, a **byte** type, a **void** type, and a primitive handle type.

Table 18-2 lists the IDL base data type specifiers. Where applicable, the table shows the size of the corresponding transmittable type and the type macro emitted by the IDL compiler for resulting declarations.

Table 18–2. Base Data Type Specifiers

Specifier				Type Macro
(sign)	**(size)**	**(type)**	**Size**	**Emitted by idl**
	small	**int**	8 bits	**idl_small_int**
	short	**int**	16 bits	**idl_short_int**
	long	**int**	32 bits	**idl_long_int**
	hyper	**int**	64 bits	**idl_hyper_int**
unsigned	**small**	**int**	8 bits	**idl_usmall_int**

Specifier				Type Macro
(sign)	(size)	(type)	Size	Emitted by idl
unsigned	**short**	**int**	16 bits	**idl_ushort_int**
unsigned	**long**	**int**	32 bits	**idl_ulong_int**
unsigned	**hyper**	**int**	64 bits	**idl_uhyper_int**
		float	32 bits	**idl_short_float**
		double	64 bits	**idl_long_float**
		char	8 bits	**idl_char**
		boolean	8 bits	**idl_boolean**
		byte	8 bits	**idl_byte**
		void	—	**idl_void_p_t**
		handle_t	—	—

The base types are described individually later in this chapter.

Note that you can use the **idl_** macros in the code you write for an application to ensure that your type declarations are consistent with those in the stubs, even when the application is ported to another platform. The **idl_** macros are especially useful when passing constant values to RPC calls. For maximum portability, all constants passed to RPC calls declared in your network interfaces should be cast to the appropriate type because the size of integer constants (like the size of the **int** data type) is ambiguous in the C language.

The **idl_** macros are defined in **dce/idlbase.h**, which is included by header files that the IDL compiler generates.

18.10.3 Constructed Type Specifiers

IDL constructed types include structures, unions, enumerations, pipes, arrays, and pointers. (In IDL, as in C, arrays and pointers are specified via declarator constructs rather than type specifiers.) Following are the keywords used to declare constructed type specifiers:

struct
union
enum
pipe

Constructed types are described in detail later in this chapter.

18.10.4 Predefined Type Specifiers

While IDL per se does not have any predefined types, DCE RPC IDL implicitly imports **nbase.idl**, which does predefine some types. Specifically, **nbase.idl** predefines an error status type, several international character data types, and many other types. Following are the keywords used to declare these *predefined* type specifiers:

error_status_t
ISO_LATIN_1
ISO_MULTI_LINGUAL
ISO_UCS

The error status type and international characters are described in detail later in this chapter.

18.10.5 Type Declarator

An IDL *type_declarator* can be either a simple declarator or a complex declarator.

A simple declarator is just an identifier.

A complex declarator is an identifier that specifies an array, a function pointer, or a pointer.

18.11 Operation Declarations

The IDL *operation_declaration* can take the following forms:

*[***[***operation_attribute***, ...]***] [***static***] type_specifier operation_identifier* **(***parameter_declaration***, ...);**

*[***[***operation_attribute***, ...]***] [***static***] type_specifier operation_identifier* **(***[***void***]***);**

Use the first form for an operation that has one or more parameters; use the second form for an operation that has no parameters. Use the **static** keyword if the operation is a static member function of the interface class (C++ output only).

An *operation_attribute* can take the following forms:

- **idempotent**: The operation is idempotent.
- **broadcast**: The operation is always to be broadcast.
- **maybe**: The caller of the operation does not require and will not receive any response.
- **reflect_deletions**: If **rpc_ss_free()** is applied by application code on the server side to memory used for the referent of a full pointer that is part of an **[in]** parameter, the storage occupied by that referent on the client side is released.
- **ptr**: The operation returns a full pointer. This attribute must be supplied if the operation returns a pointer result and reference pointers are the default for the interface.
- **context_handle**: The operation returns a context handle.
- **string**: The operation returns a string.

The *type_specifier* in an operation declaration specifies the data type that the operation returns, if any. This type must be either a scalar type or a previously defined type. If the operation does not return a result, its *type_specifier* must be **void** .

For information on the semantics of pointers as operation return values, refer to the discussion of pointers in Section 18.14.7.

The *operation_identifier* in an operation declaration is an identifier that names the operation.

Each *parameter_declaration* in an operation declaration declares a parameter of the operation. A *parameter_declaration* takes the following form:

[*parameter_attribute***, ...]** *type_specifier parameter_declarator*

Parameter declarations and the parameter attributes are described separately in the following sections.

18.11.1 Operation Attributes

Operation attributes determine the semantics to be applied by the RPC client and server protocol when an operation is called.

18.11.2 Operation Attributes: Execution Semantics

The **idempotent** attribute specifies that an operation is idempotent; that is, it can safely be executed more than once.

The **broadcast** attribute specifies that an operation is to be broadcast to all hosts on the local network each time the operation is called. The client receives output arguments from the first reply to return successfully, and all subsequent replies are discarded.

An operation with the **broadcast** attribute is implicitly idempotent.

Note that the broadcast capabilities of RPC runtime have a number of distinct limitations:

- Not all systems and networks support broadcasting. In particular, broadcasting is not supported by the RPC connection-oriented protocol.
- Broadcasts are limited to hosts on the local network.
- Broadcasts make inefficient use of network bandwidth and processor cycles.
- The RPC runtime library does not support **at-most-once** semantics for broadcast operations; it applies **idempotent** semantics to all such operations.

- The input arguments for broadcast calls are limited to 944 bytes.

The **maybe** attribute specifies that the caller of an operation does not expect any response. An operation with the **maybe** attribute cannot have any output parameters and cannot return anything. Delivery of the call is not guaranteed.

An operation with the **maybe** attribute is implicitly idempotent.

18.11.3 Operation Attributes: Memory Management

Use the **reflect_deletions** attribute to mirror the release of memory from server pointer targets to client pointer targets. When you use the **reflect_deletions** attribute, memory occupied by pointer targets on the client will be released when the corresponding pointer targets on the server are released. This is only true for pointer targets that are components of **[in]** parameters of the operation. By default, the mechanism used by RPC to release the pointer targets is the C language **free()** function unless the client code is executing as part of RPC server application code, in which case the **rpc_ss_free**() function is used. You can override the default by calling **rpc_ss_set_client_alloc_free**() or **rpc_ss_swap_client_alloc_free**() before the call to the remote operation.

18.12 Parameter Declarations

A *parameter_declaration* is used in an operation declaration to declare a parameter of the operation. A *parameter_declaration* takes the following form:

[*parameter_attribute***, ...]** *type_specifier parameter_declarator*

If an interface does not use implicit handles or use interface-based binding, the first parameter must be an explicit handle that gives the object UUID and location. The handle parameter can be of a primitive handle type, **handle_t**, or a nonprimitive user-defined handle type.

A *parameter_attribute* can be any of the following:

- *array_attribute*: One of several attributes that specifies the characteristics of arrays.
- **in**: The parameter is an input attribute.
- **out**: The parameter is an output attribute.
- **ref**: The parameter is a reference pointer; it cannot be NULL and cannot be an aliased pointer.
- **ptr**: The parameter is a full pointer; it can be NULL and can be an aliased pointer.
- **unique**: The parameter is a unique pointer; it can be NULL.
- **string**: The parameter is a string.
- **context_handle**: The parameter is a context handle.
- **switch_is**:

The directional attributes **in** and **out** specify the directions in which a parameter is to be passed. The **in** attribute specifies that the parameter is passed from the caller to the callee. The **out** attribute specifies that the parameter is passed from the callee to the caller.

An output parameter must be passed by reference and therefore must be declared with an explicit * (asterisk). (Note that an array is implicitly passed by reference and so an output array does not require an explicit *.) At least one directional attribute must be specified for each parameter of an operation.

An explicit handle parameter must have at least the **in** attribute.

The **ref, unique,** and **ptr** attributes are described later in Section 18.14.7. The **string** attribute is described in Section 18.14.6. The **context_handle** attribute is described in Section 18.14.9.1.

The *type_specifier* in a parameter declaration specifies the data type of the parameter.

The *declarator* in a parameter declaration can be any simple or complex declarator.

A parameter with the **out** attribute must be either an array or an explicitly declared pointer. An explicitly declared pointer is declared by a *pointer_declarator*, rather than by a *simple_declarator* with a named pointer type as its *type_specifier*.

For information on the semantics of pointers as operation parameters, refer to the discussion of pointers in Section 18.14.7.

18.13 Basic Data Types

The following subsections describe the basic data types provided by IDL and the treatment of international characters within IDL. The basic data types are as follows:

- Integer types
- Floating-point types
- The **char** type
- The **boolean** type
- The **byte** type
- The **void** type
- The **handle_t** type
- The **error_status_t** type

Section 18.14 describes the constructed data types that are built on the basic data types.

18.13.1 Integer Types

IDL provides four sizes of signed and unsigned integer data types, specified as follows:

*int_size [***int***]*
unsigned *int_size [***int***]*
int_size **unsigned** *[***int***]*

The *int_size* can take the following values:

hyper
long
short
small

The **hyper** types are represented in 64 bits. A **long** is 32 bits. A **short** is 16 bits. A **small** is 8 bits.

The keyword **int** is optional and has no effect. The keyword **unsigned** denotes an unsigned integer type; it can occur either before or after the size keyword.

18.13.2 Floating-Point Types

IDL provides two sizes of floating-point data types, specified as follows:

float
double

A **float** is represented in 32 bits. A **double** is represented in 64 bits.

18.13.3 The char Type

The IDL character type is specified as follows:

*[***unsigned***]* **char**

A **char** is unsigned and is represented in 8 bits.

The keyword **unsigned** is optional and has no effect. IDL does not support a signed character type. IDL provides the **small** data type for representing signed 8-bit integers.

18.13.4 The boolean Type

The IDL **boolean** type is specified as follows:

boolean

A **boolean** is represented in 8 bits. A **boolean** is a logical quantity that assumes one of two values: TRUE or FALSE. Zero is FALSE and any nonzero value is TRUE.

18.13.5 The byte Type

The IDL **byte** type is specified as follows:

byte

A **byte** is represented in 8 bits. The data representation format of **byte** data is guaranteed not to change when the data is transmitted by the RPC mechanism.

The IDL integer, character, and floating-point types (and hence any types constructed from these) are all subject to format conversion when they are transmitted between hosts that use different data representation formats. You can protect data of any type from format conversion by transmitting that type as an array of **byte**.

18.13.6 The void Type

The IDL **void** type is specified as follows:

void

The **void** type may be used to do the following:

- Specify the type of an operation that does not return a value

- Specify the type of a context handle parameter, which must be **void***
- Specify the type of a NULL pointer constant, which must be **void***

18.13.7 The handle_t Type

The IDL primitive handle type is specified as follows:

handle_t

A **handle_t** is a primitive handle type that is opaque to application programs but meaningful to the RPC runtime library. Section 18.14.8 discusses primitive and nonprimitive handle types.

18.13.8 The error_status_t Type

IDL provides the following predefined data type to hold RPC communications status information:

error_status_t

The values that can be contained in the **error_status_t** data type are compatible with the **unsigned long** and **unsigned32** IDL data types. These data types are used for status values in the DCE.

The **error_status_t** data type contains an additional semantic to indicate that this particular **unsigned long** contains a DCE format error status value. This additional semantic enables the IDL compiler to perform any necessary translation when moving the status value between systems with differing hardware architectures and software operating systems. If you are using status codes that are not in the DCE error status format or if you do not require such conversion, use an **unsigned long** instead of **error_status_t**.

18.13.9 International Characters

The implicitly imported **nbase.idl** provides predefined data types to support present and emerging international standards for the representation of characters and strings:

ISO_LATIN_1
ISO_MULTI_LINGUAL
ISO_UCS

Data of type **char** is subject to ASCII-EBCDIC conversion when transmitted by the RPC mechanism. The predefined international character types are constructed from the base type **byte** and are thereby protected from data representation format conversion.

The **ISO_LATIN_1** type is represented in 8 bits and is predefined as follows:

```
typedef byte ISO_LATIN_1;
```

The **ISO_MULTI_LINGUAL** type is represented in 16 bits and is predefined as follows:

```
typedef struct {
     byte row, column;
     } ISO_MULTI_LINGUAL;
```

The **ISO_UCS** type is represented in 32 bits and is predefined as follows:

```
typedef struct {
     byte group, plane, row, column;
     } ISO_UCS;
```

18.14 Constructed Data Types

The following subsections describe the constructed data types that are provided by IDL. The constructed types are built on the basic data types, which are described in Section 18.13. The constructed data types are as follows:

- Structures
- Unions
- Enumerations
- Pipes
- Arrays
- Strings

In IDL, as in C, arrays and pointers are specified via declarator constructs. The other constructed types are specified via type specifiers.

18.14.1 Structures

The *type_specifier* for a structure type can take the following forms:

```
struct [tag]
{
struct_member;
...
}
```

```
struct tag
```

A *tag*, if supplied in a specifier of the first form, becomes a shorthand form for the set of member declarations that follows it. Such a *tag* can subsequently be used in a specifier of the second form.

A *struct_member* takes the following form:

*[***[***struct_member_attribute***, ...]***] type_specifier declarator***, ...;**

A *struct_member_attribute* can be any of the following:

- *array_attribute*: One of several attributes that specify characteristics of arrays.
- **ignore**: An attribute indicating that the pointer member being declared is not to be transmitted in remote procedure calls.
- **ref**: An attribute indicating that the pointer member being declared is a reference pointer; it cannot be NULL and cannot be an alias.
- **ptr**: An attribute indicating that the pointer member being declared is a full pointer; it can be NULL and can be an alias.
- **unique**: An attribute indicating that the pointer member being declared is a unique pointer.
- **string**: An attribute indicating that the array member being declared is a string.
- **switch_is**:

A structure can contain a conformant array (conformant structure) only as its last member. And such a structure can be contained by another structure only as its last member, and so on. A conformant structure cannot be returned by an operation as its value and cannot be simply an **out** parameter. Note that a structure can contain any number of *pointer to* conformant arrays. Structure fields defined as pointers to an array base type and with one or more of the array size attributes define pointers to conformant arrays. Since the size of the pointer field in the structure is fixed, the structure itself is not conformant, although the array that it points to is conformant.

A structure cannot contain a pipe or context handle.

The **ignore** attribute specifies that the pointer is not to be transmitted in remote procedure calls. Note that the **ignore** attribute can be applied only to a pointer that is a member of a structure. The **ignore** attribute is not allowed in a type declaration that defines a pointer type.

18.14.2 Unions

IDL provides two types of unions: encapsulated and nonencapsulated. An IDL union must be discriminated. In an encapsulated union, the discriminator is part of the union. In a nonencapsulated union, the discriminator is not part of the union.

The following *type_specifier* can be used to indicate either kind of union.

union *[tag]*

A definition of the union identified by *tag* must appear elsewhere in the interface definition.

18.14.2.1 Encapsulated Unions

To define an encapsulated union, use the following syntax:

union *[tag]* **switch** *(disc_type_spec discriminator) [union_name]*
{
case
...
[default_case]
}

If a *tag* is supplied, it can be used in a *type_specifier* of the form shown in Section 18.14.2.

The *disc_type_spec* indicates the type of the *discriminator*, which can be an integer, a character, a **boolean**, or an enumeration.

The *union_name* specifies a name to be used in C code generated by the IDL compiler. When the IDL compiler generates C code to represent an IDL union, it embeds the union and its discriminator in a C structure. The name of the IDL union becomes the name of the C structure. If you supply a *union_name* in your type declaration, the

compiler assigns this name to the embedded C union; otherwise, the compiler assigns the generic name **tagged_union**.

A *case* contains one or more labels and may contain a member declaration:

case *constant***:**
...
*[union_member]***;**

Each label in a *case* specifies a constant. The *constant* can take any of the forms accepted in an integer, character, or Boolean constant declaration, each of which is described earlier in this chapter.

A *default_case* can be coded anywhere in the list of cases:

default:
*[union_member]***;**

A *union_member* takes the following form:

*[***[***union_member_attribute***, ...]***] type_specifier declarator***;**

A *union_member_attribute* can be any of the following:

- **ptr**: An attribute indicating that the pointer member being declared is a full pointer; it can be NULL and can be an alias.
- **string**: An attribute indicating that the character array member being declared is a string.

In any union, the type of the discriminator and the type of all constants in all case labels must resolve to the same type. At the time the union is used, the value of the discriminator selects a member, as follows:

- If the value of the discriminator matches the constant in any label, the member associated with the label is selected.

- If there is no label whose constant matches the value of the discriminator and there is a default case, the default member is selected.
- If there is no label whose constant matches the value of the discriminator and there is no default case, no member is selected and the exception **rpc_x_invalid_tag** is raised.

Note that IDL prohibits duplicate constant label values.

A *union_member* can contain only one declarator. If no *union_member* is supplied, the member is NULL; if that member is selected when the union is used, no data is passed. But note that the discriminator is always passed.

A union cannot contain a pipe, a conformant array, a varying array, or any structure that contains a conformant or varying array. A union also cannot contain a **ref** or **unique** pointer or any structure that contains a **ref** or **unique** pointer.

The following is an example of an encapsulated union.

```
/* IDL construct /*

   typedef
       union fred switch (long a) ralph {
            case 1: float b;
            case 2: long c;
       } bill;

/* becomes in the generated header file /*

  typedef
      struct fred {
          long a;
          union {
              float b;
              long c;
          } ralph;
      } bill;
```

18.14.2.2 Nonencapsulated Unions

To define a nonencapsulated union, use the following syntax:

[switch_type(datatype)] **union** *[tag]*
{
case
...
[default_case]
}

If a *tag* is supplied, it can be used in a *type_specifier* of the form shown in Section 18.14.2.

A parameter or a structure field that is a nonencapsulated union must have an attribute attached to it. This attribute has the following form:

switch_is(*attr_var***)**

where *attr_var* is the name of the parameter or structure field that is the discriminator for the union.

If a nonencapsulated union is used as a structure field, the discriminator of the union must be a field of the same structure. If a nonencapsulated union is used as a parameter of an operation, the discriminator must be another parameter of the same operation.

The following example shows uses of a nonencapsulated union.

```
typedef
  [switch_type(long)] union {
    [case (1,3)] float a_float;
    [case (2)] short b_short;
    [default] ; /* An empty arm.  Nothing is shipped. */
  } n_e_union_t;
```

```
typedef
  struct {
    long a; /* The discriminant for the    */
     /* union later in this struct. */
    [switch_is (a)] n_e_union_t b;
  } a_struct;

/* Note switch can follow union in operation */
void op1 (
   [in] handle_t h,
   [in,switch_is (s)] n_e_union_t u,
   [in] long s  );
```

18.14.3 Enumeration

An IDL enumeration provides names for integers. It is specified as follows:

enum **{***identifier[= integer], ...***}**

Each identifier in an enumeration is assigned an integer, either explicitly in the interface or automatically by the IDL compiler. If all the identifiers are unassigned, the IDL compiler begins assigning 0 (zero) to the first identifier, 1 to the next identifier, and so on. If an unassigned identifier follows an assigned one, the compiler restarts number assignment with the next consecutive integer. An enumeration can have up to 32,767 identifiers.

Assignments can be made in any order, and multiple identifiers can have the same value. For example:

```
typedef  enum {
 SHOVEL = 9, AX, MATTOCK = 3, PITCHFORK, SPADE = 9
 } yard_tools;
/* values assigned: SHOVEL:9, AX:10, MATTOCK:3, PITCHFORK:4, */
/* SPADE:9                                                   */
```

18.14.4 Pipes

IDL supports pipes as a mechanism for transferring large quantities of typed data. An IDL pipe is an open-ended sequence of elements of one type. A pipe permits application-level optimization of bulk data transfer by allowing the overlap of communication and processing. Applications that process a stream of data as it arrives, rather than simply storing the data in memory, can make efficient use of the pipe mechanism.

A pipe is specified as follows:

pipe *type_specifier*

The *type_specifier* specifies the type for the elements of the pipe. This type cannot be a pointer type, a type that contains a pointer, a conformant type, a context handle, a **handle_t** element type, or a data type that is declared as **transmit_as**.

A pipe type can be used to declare only the type of an operation parameter. IDL recognizes three kinds of pipes, based on the three operation parameters:

- An **in** pipe is for transferring data from a client to a server. It allows the callee (server) to pull an open-ended stream of typed data from the caller (client).
- An **out** pipe is for transferring data from a server to a client. It allows the callee (server) to push the stream of data to the caller (client).
- An **in,out** pipe provides for two-way data transfer between a client and server by combining the behavior of **in** and **out** pipes.

A pipe can be defined only through a **typedef** declaration. Anonymous pipe types are not supported.

At the interface between the stub and the application-specific code (for both the client and server), a pipe appears as a simple callback mechanism. To the user code, the processing of a pipe parameter appears to be synchronous. The IDL implementation of pipes in the RPC stub and runtime allows the apparent callbacks to occur without requiring actual remote callbacks. As a result, pipes provide an efficient transfer mechanism for large amounts of data.

Note however, that pipe data communications occur at about the same speed as arrays. Pipes can improve latency and minimum memory utilization, but not throughput. Pipes are intended for use where the receiver can process the data in some way as it arrives, for example by writing it to a file or passing it to a consumer thread. If the intent is to store the data in memory for later processing, pipes offer no advantage over arrays.

18.14.4.1 IDL Pipes Example

To illustrate the IDL implementation of pipes, consider the following IDL fragment:

```
typedef
   pipe element_t pipe_t;
```

When the code containing this fragment is compiled, the IDL compiler will generate the following declarations in the derived header file:

```
typedef struct pipe_t {
    void (* pull)(
       rpc_ss_pipe_state_t state,
       element_t *buf,
       idl_ulong_int esize,
       idl_ulong_int *ecount
    );
   void (* push)(
      rpc_ss_pipe_state_t state,
      element_t *buf,
      idl_ulong_int  ecount
   );
   void (* alloc)(
      rpc_ss_pipe_state_t state,
      idl_ulong_int bsize,
      element_t **buf,
      idl_ulong_int *bcount
   );
   rpc_ss_pipe_state_t state;
```

```
} pipe_t;
```

The pipe data structure specifies pointers to three separate routines and a pipe state. The client application has to implement these routines for the client stub to call, and the server manager must call the associated routines generated in the server stub.

The **pull** routine is used for an input pipe. It pulls the next chunk of data from the client application into the pipe. The input parameters include the pipe **state**, the buffer (***buf**) containing a chunk of data, and the size of the buffer (**esize**) in terms of the number of pipe data elements. The output parameter is the actual count (***ecount**) of the number of pipe data elements in the buffer.

The **push** routine is used for an output pipe. It pushes the next chunk of data from the pipe to the client application. The input parameters include the pipe **state**, the buffer (***buf**) containing a chunk of data, and a count (**ecount**) of the number of pipe data elements in the buffer.

The **alloc** routine allocates a buffer for the pipe data. The input parameters include the pipe **state** and the requested size of the buffer (**bsize**) in bytes. The output parameters include a pointer to the allocated buffer (****buf**), and the actual count (**bcount**) of the number of bytes in the buffer. The routine allocates memory from which pipe data can be marshalled or into which pipe data can be marshalled. If less memory is allocated than requested, the RPC runtime uses the smaller memory and makes more callbacks to the user. If the routine allocates more memory than requested, the excess memory is not used.

Finally, the **state** is used to coordinate between these routines.

For more on how to write the code for the client and server manager, see Chapter 17.

18.14.4.2 Rules for Using Pipes

Observe the following rules when defining pipes in IDL:

- Pipe types must only be parameters. In other words, pipes of pipes, arrays of pipes, and structures or unions containing pipes as members are illegal.
- A pipe cannot be a function result.
- The element type of a pipe cannot be a pointer or contain a pointer.

- The element type of a pipe cannot be a **context_handle** or **handle_t** type.
- A pipe type cannot be used in the definition of another type. For example, the following code fragment is illegal:

```
typedef
   pipe char pipe_t;

typedef
   pipe_t * pipe_p_t;
```

- A pipe type cannot have the **transmit_as** attribute.
- The element type of a pipe cannot have the **transmit_as** attribute.
- A pipe parameter can be passed by value or by reference. A pipe that is passed by reference (that is, has an * (asterisk)) cannot have the **ptr** or **unique** parameter attributes.
- Pipes that pass data from the client to the server must be processed in the order in which they occur in an operation's signature. All such pipes must be processed before data is sent from the server to the client.
- Pipes that pass data from the server to the client must be processed in the order in which they occur in an operation's signature. No such pipes must be processed until all data has been sent from the client to the server.
- Manager routines must reraise RPC pipe and communications exceptions so that client stub code and server stub code continue to execute properly.

  For example, consider an interface that has an **out** pipe along with other **out** parameters. Suppose that the following sequence of events occurs:

  — The manager routine closes the pipe by writing an empty chunk whose length is 0 (zero).

  — The manager routine attempts to write another chunk of data to the pipe.

  — The generated **push** routine raises the exception **rpc_x_fault_pipe_closed**.

  — The manager routine catches the exception and does not reraise it.

  — The manager routine exits normally.

  — The server stub attempts to marshall the **out** parameters.

After this sequence, neither the server stub nor the client stub can continue to execute properly.

To avoid this situation, you *must* reraise the exception.

- A pipe cannot be used in an operation that has the **broadcast** or **idempotent** attribute.
- The element type of a pipe cannot be a conformant structure.
- The maximum length of pipe type IDs is 29 characters.

18.14.5 Arrays

IDL supports the following types of arrays:

- Fixed: The size of the array is defined in IDL and all of the data in the array is transferred during the call.
- Conformant: The size of the array is determined at runtime. At least one bound of the array is determined at runtime by a value referenced through a **min_is**, **max_is**, or **size_is** attribute. All of the data in the array is transferred during the call.
- Varying: The size of the array is defined in IDL but the part of its contents transferred during the call is determined by the values of fields or parameters named in one or more data limit attributes. The data limit attributes are **first_is**, **length_is** , and **last_is**.

An array can also be both conformant and varying (or, as it is sometimes termed, *open*). In this case, the size of the array is determined at runtime by the value of the field or parameter referenced by the **min_is** , **max_is** or **size_is** attributes. The part of its contents transferred during the call is determined by the values of fields or parameters named in one or more of the data limit attributes.

An IDL array is declared via an *array_declarator* construct whose syntax is as follows:

array_identifier array_bounds_declarator **...**

An *array_bounds_declarator* must be specified for each dimension of an array.

18.14.5.1 Array Bounds

The *array_bounds_declarator* for the first dimension of an array can take any of the following forms:

[*lower* **..***upper***]**
The lower bound is *lower*. The upper bound is *upper*.

[*size***]** The lower bound is 0 (zero). The upper bound is *size* − 1.

[*] The lower bound is 0 (zero). The upper bound is determined by a **max_is** or **size_is** attribute.

[ ] The lower bound is 0 (zero). The upper bound is determined by a **max_is** or **size_is** attribute.

[*lower***..]** The lower bound is *lower*. The upper bound is determined by a **max_is** or **size_is** attribute.

[* .. *upper***]** The lower bound is determined by a **min_is** attribute. The upper bound is *upper*.

[* .. *] The lower bound is determined by a **min_is** attribute. The upper bound is determined by a **size_is** or **max_is** attribute.

18.14.5.2 Conformance in Dimensions Other Than the First

If a multidimensional array is conformant in a dimension other than the first, the C description for this array, which is located in the header (**.h**) file generated by the IDL compiler, will be a one-dimensional conformant array of the appropriate element type. This occurs because there is no ‘‘natural’’ C binding for conformance in dimensions other than the first.

The following examples show how IDL type definitions and parameter declarations that contain bounds in dimensions other than the first are translated into their C equivalents at runtime.

IDL Type Definition:

```
typedef struct {
    long a;
    long e;
    [max_is(,,e),min_is(a)] long g7[*..1][2..9][3..*];
} t3;
```

C Translation:

```
typedef struct  {
  idl_long_int a;
  idl_long_int e;
  idl_long_int g7[1];
```

IDL Parameter Declaration:

```
[in,out,max_is(,,e),min_is(a)] long g7[*..1][2..9][3..*];
```

C Translation:

```
/* [in, out] */ idl_long_int g7[]
```

Arrays that have a nonzero first lower bound and a first upper bound that is determined at runtime are translated into the equivalent C representation of a conformant array, as shown in the following IDL type definition and parameter declaration examples:

IDL Type Definition:

```
typedef struct  {
           long s;
           [size_is(s)] long fa3[3..*][-4..1][-1..2];
} t1;
```

C Translation:

```
typedef struct  {
  idl_long_int s;
  idl_long_int fa3[1][6][4];
} t1;
```

IDL Parameter Declaration:

```
[in,out,size_is(s)] long fa3[3..*][-4..1][-1..2]
```

C Translation:

```
/* [in, out] */ idl_long_int fa3[][6][4]
```

18.14.5.3 Array Attributes

Array attributes specify the size of an array or the part of an array that is to be transferred during a call. An array attribute specifies a variable that is either a field in the same structure as the array or a parameter in the same operation as the array.

An *array_attribute* can take the following forms:

min_is (*[*] variable*)
max_is (*[*] variable*)
size_is (*[*] variable*)
last_is (*[*] variable*)
first_is (*[*] variable*)
length_is (*[*] variable*)

where *variable* specifies a variable whose value at runtime will determine the bound or element count for the associated dimension. A pointer variable is indicated by preceding the variable name with an ***** (asterisk).

If the array is a member of a structure, any referenced variables must be members of the same structure. If the array is a parameter of an operation, any referenced variables must be parameters of the same operation.

Only the **..._is(***variable* **)**form is allowed when the array is a field of a structure. In this case, the **..._is(****variable* **)**form is not allowed.

Note that an array with an array attribute (that is, a conformant or varying array) is not allowed to have the **transmit_as** attribute.

18.14.5.3.1 The **min_is** Attribute

The **min_is** attribute is used to specify the variable(s) from which the values of one or more lower bounds of the array will be obtained at runtime. If any dimension of an array has an unspecified lower bound, the array must have a **min_is** attribute. A variable must be identified for each such dimension. The following examples show the syntax of the **min_is** attribute:

```
/* Assume values of variables are as follows
    long a = -10;
    long b = -20;
    long c = -30;
*/

long [min_is(a)] g1[*..10];           /* g1[-10..10]          */
long [min_is(a)] g2[*..10][4];        /* g2[-10..10[0..3]     */
long [min_is(a,b)] g3[*..10][*..20];  /* g3[-10..10][-20..20] */
long [min_is(,b)] g4[2][*..20];       /* g4[0..1][-20..20]    */
long [min_is(a,,c)] g5[*..7][2..9][*..8];
                               /* g5[-10..7][2..9][-30..8]    */
long [min_is(a,b,)] g6[*..10][*..20][3..8];
                             /* g6[-10..10][-20..20][3..8]    */
```

The following examples show the **min_is** attribute being applied to the first dimension of an array in an IDL type definition and parameter declaration, and how the definition or parameter is translated into its C equivalent:

IDL Type Definition:

```
typedef struct {
        long n;
  [min_is(n)] long fa3[*..10][-4..1][-1..2]
} t2;
```

C Translation:

```
typedef struct  {
  idl_long_int n;
  idl_long_int fa3[1][6][4];
} t2;
```

IDL Parameter Declaration:

```
[in,out,min_is(n)] long fa3[*..10][-4..1][-1..2]
```

C Translation:

```
/* [in, out] */ idl_long_int fa3[][6][4]
```

18.14.5.3.2 The **max_is** Attribute

The **max_is** attribute is used to specify the variables from which the values of one or more upper bounds of the array are obtained at runtime. If any dimension of an array has an unspecified upper bound, the array must have a **max_is** or **size_is** attribute. A variable must be identified for each dimension in which the upper bound is unspecified. In a **max_is** attribute, the value in the identified variable specifies the maximum array index in that dimension. An array with one or more unspecified upper bounds may have a **max_is** attribute or a **size_is** attribute, but not both.

The **max_is** attribute is for use with conformant arrays. The following is an example of the **max_is** attribute:

```
/* Assume values of variables are as follows:
long a = 10;
long b = 20;
long c = 30;
*/

long [max_is(a)] f1[];           /* f1[0..10] /*
long [max_is(a)] f2[][4];        /* f2[0..10][0..3]  */
long [max_is(a,b)] f3[][];       /* f3[0..10][0..20] */
long [max_is(,b)] f4[2][];       /* f4[0..1][0..20] */
long [max_is(a,,c)] f5[1..*][2..9][3..*];  /* f5[1..10][2..9][3..30] */
long [max_is(a,b,)] f6[1..*][2..*][3..8];  /* f6[1..10][2..20][3..8] */
```

18.14.5.3.3 The **size_is** Attribute

The **size_is** attribute is used to specify the variables from which the values of the element counts for one or more dimensions of the array are obtained at runtime. If any dimension of an array has an unspecified upper bound, the array must have a **max_is** or **size_is** attribute. A variable must be identified for each dimension in which the upper bound is unspecified. In a **size_is** attribute, the value in the identified variable specifies the number of elements in that dimension. An array with one or more unspecified upper bounds may have a **max_is** attribute or a **size_is** attribute, but not both.

The size of a dimension is defined as the upper bound, minus the lower bound, + 1.

The **size_is** attribute is for use with conformant arrays. The following is an example of the **size_is** attribute:

```
/* Assume the following values for the referenced variables:
   n3 = 5;
   x2 = 12;
```

```
   x3 = 14;
   z2 = 9;
   z3 = 10;
*/

/* The following declaration */

int [min_is(,,n3),max_is(,x2,x3)] hh[3..13,4..*,*..*];

/* specifies the same data to be  */
/* transmitted as the declaration */

int [min_is(,,n3),size_is(,z2,z3)] hh[3..13,4..*,*..*];
```

18.14.5.3.4 The **last_is** Attribute

The **last_is** attribute is one of the attributes that can be used to allow the amount of data in an array that will be transmitted to be determined at runtime. Each **last_is** attribute specifies an upper data limit, which is the highest index value in that dimension for the array elements to be transmitted. If the entry in a **last_is** attribute for a dimension is empty, the effect is as if the upper bound in that dimension had been specified.

An array can have either the **last_is** attribute or the **length_is** attribute, but not both.

When an array with the **last_is** attribute is used in a remote procedure call, the elements actually passed in the call can be a subset of the maximum possible.

The **last_is** attribute is for use with varying arrays. The following is an example of the **last_is** attribute:

```
/* Assume the following values for the referenced variables:
long a = 1;
long b = 2;
long c = 3;
long e = 25;
long f = 35;
*/
```

```
long [last_is(a,b)] bb1[10][20]; /* transmit bb1[0..1][0..2] */
long [last_is(a,b)] bb2[-1..10][-2..20][-3..30];
/* transmit bb2[-1..1][-2..2][-3..30]*/
long [last_is(a,,c)] bb3[-1..10][-2..20][-3..30];
/* transmit bb3[-1..1][-2..20][-3..3]*/
long [last_is(,b,c),max_is(,e)] cc1[10][][30];
/* transmit cc1[0..9][0..2][0..3] */
long [last_is(a,b),max_is(,e,f)] cc2[-4..4][][];
/* transmit cc2[-4..1][0..2][0..35] */
```

18.14.5.3.5 The **first_is** Attribute

The **first_is** attribute is one of the attributes that can be used to allow the amount of data in an array that will be transmitted to be determined at runtime. Each **first_is** attribute specifies a lower data limit, which is the lowest index value in that dimension for the array elements to be transmitted. If the entry in a **first_is** attribute for a dimension is empty, the effect is as if the lower bound in that dimension had been specified.

When an array with the **first_is** attribute is used in a remote procedure call, the elements actually passed in the call can be a subset of the maximum possible.

The **first_is** attribute is for use with varying arrays. The following is an example of the **first_is** attribute:

```
/* Assume the following values for the referenced variables:
long p = -1;
long q = -2;
long r = -3;
long t = -25;
long u = -35;
long x = 1;
long y = 2;
long z = 3;
*/

long [first_is(p)] dd1[-10..10];            /* transmit dd1[-1..10] */
long [first_is(p),last_is(x)] dd2[-10..10];  /* transmit dd2[-1..1] */
```

```
long [first_is(p,q)] ee1[-10..10][-20..20];
/* transmit ee1[-1..10][-2..20] */
long [first_is(p,q)] ee2[-10..10][-20..20][-30..30];
/* transmit ee2[-1..10][-2..20][-30..30] */
long [first_is(p,q,r),last_is(,,z)] ee3[-10..10][-20..20][-30..30]:
/* transmit ee3[-1..10][-2..20[-3..30] */
double [first_is(,q,r),min_is(,t)] ff1[10][*..2][-30..30];
/* transmit ff1[0..9][-2..2][-3..30] */
double [first_is(p,q),min_is(,t,u)] ff2[-4..4][*..2][*..35];
/* transmit ff2[-1..4][-2..2][-35..35] */
double [max_is(x,,z),min_is(,t,u),first_is(p,,r)]ff3[-20..*][*..30][*..*]
/* transmit ff3[-1..1][-25..30][-3..3] */
```

18.14.5.3.6 The **length_is** Attribute

The **length_is** attribute is one of the attributes that can be used to allow the amount of data in an array that will be transmitted to be determined at runtime. Each **length_is** attribute specifies the number of elements in that dimension to be transmitted. If the entry in a **length_is** attribute for a dimension is empty, the effect is for the highest index value in that dimension for the elements to be transmitted to be determined from the upper bound in that dimension.

An array can have either the **last_is** attribute or the **length_is** attribute, but not both.

When an array with the **length_is** attribute is used in a remote procedure call, the elements actually passed in the call can be a subset of the maximum possible.

The **length_is** attribute is for use with varying arrays. The following is an example of the **length_is** attribute:

```
/* Assume the following values for the referenced variables:
    n3 = 5;
    f2 = 10;
    a1 = 11;
    a2 = 12;
    a3 = 14;
    e1 = 9;
```

```
    e2 = 3;
    e3 = 10;
*/

/* The following declaration: */

int [min_is(,,n3),first_is(,f2,),last_is(a1,a2,a3)] \
  gg[3..13,4..14,*..15];

/* specifies the same data to be   */
/* transmitted as the declaration: */

int [min_is(,,n3),first_is(,f2,),length_is(e1,e2,e3)] \
  gg[3..13,4..14,*..15];
```

18.14.5.4 Rules for Using Arrays

Observe the following rules when defining arrays in IDL:

- A structure can contain only one conformant array, which must be the last member in the structure.
- Conformant arrays are not valid in unions.
- A structure parameter containing a conformant array can be passed only by reference.
- Arrays that have the **transmit_as** attribute cannot be conformant or varying arrays.
- The structure member or parameter referenced in an array attribute cannot be defined to have either the **represent_as** or **transmit_as** attribute.
- Array bounds must be integers. Array attributes can reference only structure members or parameters of integer type.
- A parameter that is referenced by an array attribute on a conformant array must have the **in** attribute.
- Array elements cannot be context handles or pipes, or conformant arrays or conformant structures.

18.14.6 Strings

IDL implements strings as one-dimensional arrays to which the **string** attribute is assigned. The element type of the array must resolve to one of the following:

- Type **char**
- Type **byte**
- A structure all of whose members are of type **byte** or of a named type that resolves to **byte**
- A named type that resolves to one of the previous three types
- Type **unsigned short**
- Type **unsigned long**
- A named type that resolves to **unsigned short** or **unsigned long**

Strings built from **byte** or **char** data types are referred to as *byte-string types* while strings built from **unsigned short** or **unsigned long** types are called *integer-string types*. Integer string types allow for multioctet character sets whose characters are represented by 16-bit or 32-bit quantities, rather than as groups of bytes. For example:

```
/* A structure that contains a fixed string */
/* and a conformant string */
typedef unsigned long PRIVATE_CHAR_32;
typedef struct {
   [string] PRIVATE_CHAR_32 fixed[27];
   [string] PRIVATE_CHAR_32 conf[];
} two_strings;


/* A structure that contains pointers to two strings */
typedef unsigned short PRIVATE_CHAR_16;
typedef struct {
   [string] PRIVATE_CHAR_16 *astring;
   [string] PRIVATE_CHAR_16 *bstring;
} stringptrs;
```

Integer-string types use the array element zero (0) to specify the string terminator, while byte-string types use the NULL character. Both byte-type and integer-type strings conform to the same usage rules.

An array with the **string** attribute represents a string of characters. The **string** attribute does not specify the format of the string or the mechanism for determining its length. Implementations of IDL provide string formats and mechanisms for determining string lengths that are compatible with the programming languages in which applications are written. For DCE RPC IDL, the number of characters in a **string** array includes the NULL terminator (for byte-string types) or the zero (0) terminator (for integer-string types), and the entire terminated string is passed between stubs.

The *array_bounds_declarator* for a **string** array determines the maximum number of characters in the array. Note that, when you declare a string, you must allocate space for one more than the maximum number of characters the string is to hold. For instance, if a string is to store 80 characters, the string must be declared with a size of 81:

```
/* A string type that holds 80 characters */
typedef
   [string] char string_t [81];
```

If an array has the **string** attribute or if the type of an array has the **string** attribute, the array cannot have the **first_is**, the **last_is**, or the **length_is** attribute.

18.14.7 Pointers

Use the following syntax to declare an IDL pointer:

******[*]...pointer_identifier*

The ***** (asterisk) is the pointer operator, and multiple asterisks indicate multiple levels of indirection.

18.14.7.1 Pointer Attributes

Pointers are used for several purposes, including implementing a parameter passing mechanism that allows a data value to be returned, and building complex data structures.

IDL offers three classes of pointers: reference pointers, full pointers, and unique pointers. The attributes that indicate these pointers are as follows:

- **ref**: Indicates reference pointers. This is the default for top-level pointers used in parameters.
- **ptr**: Indicates full pointers.
- **unique**: Indicates unique pointers.

Pointer attributes are used in parameters, in structure and union members, and in type definitions. In some instances, IDL infers the applicable pointer class from its usage. However, most pointer declarations require that you specify a pointer class by using one of the following methods:

- Use the **ref**, **ptr**, or **unique** attribute in the pointer declaration.
- Use the **pointer_default** attribute in the IDL interface heading. The default pointer class is determined by the **pointer_default** attribute.

Pointer attributes are applied only to the top-level pointer within the declaration. If multiple pointers are declared in a single declaration, the **pointer_default** established applies to all but the top-level pointer. (See Section 18.14.7.2, which describes pointer attributes in parameters.)

Examples of pointers are shown at the end of this section.

18.14.7.1.1 Reference Pointers

A reference pointer is the least complex form of pointer. The most common use for this class of pointer is as a passing mechanism; for example, passing an integer by reference. Reference pointers have significantly better performance than full pointers, but are restrictive; you cannot create a linked list by using a reference pointer because a reference pointer cannot have a NULL value, and the list cannot be terminated.

A reference pointer has the following characteristics:

- It always points to valid storage; it can never have a NULL value.
- Its value does not change during a call; it always points to the same storage on return from the call as it did when the call was made.
- It does not support aliasing; it cannot point to a storage area that is pointed to by any other pointer used in a parameter of the same operation.

When a manager routine is entered, all the reference pointers in its parameters will point to valid storage, except those reference pointers that point neither to targets whose size can be determined at compile time nor to values that have been received from the client.

In the following example, the size of the targets of the reference pointers can be calculated at compilation time:

```
typedef [ref] long *rpl;

void op1( [in] long f,
          [in] long l,
          [in,first_is(f),last_is(l)] rpl rpla[10] );
```

For this example, when the manager is entered, all the pointers in **rpla** will point to usable storage, although only ***rpla[f]** through ***rpla[l]** will be the values received from the client.

Conversely, the size of the targets of the reference pointers cannot be calculated at compile time in the following example:

```
typedef [ref,string] char *rps;

void op1( [in] long f,
          [in] long l,
          [in,first_is(f),last_is(l)] rps rpsa[10] );
```

In this case, only **rpsa[f]** through **rpsa[l]** , which point to values received from the client, will point to usable storage.

18.14.7.1.2 Full Pointers

A full pointer is the most complex form of pointer. It supports all capabilities associated with pointers. For example, by using a full pointer you can build complex data structures such as linked lists, trees, queues, or arbitrary graphs.

A full pointer has the following characteristics:

- Its value can change during a call; it can change from a NULL to non-NULL value, non-NULL to NULL, or from one non-NULL value to another non-NULL value.
- It supports aliasing; it can point to a storage area that is also pointed to by any other full pointer used in a parameter of the same operation. However, all such pointers must point to the beginning of the structure. There is no support for pointers to substructures or to overlapping storage areas. For example, if the interface definition code contains the following:

```
[uuid(0e256080-587c-11ca-878c-08002b111685), version(1.0)]
interface overlap
{
  typedef struct {
          long bill;
          long charlie;
  } foo;
  typedef struct {
          long fred;
          foo ken;
  } bar;

  void op ( [in] foo *f, [in] bar *b );
}
```

  and the client application code includes the following:

```
bar bb;
 .
 .
```

```
.
op ( &bb.ken, &bb );
```

then the server stub treats these two separate parameters as distinct, and the manager application code does not see them as overlapping storage.

- It allows dynamically allocated data to be returned from a call.

Note that you might need to take some extra steps if you use large linked lists in your application. Linked lists are marshalled and unmarshalled using recursion which can cause the stack size to grow. Linked lists usually do not cause problems in simple clients that do not spawn threads for remote procedure calls. In this case, the stack can grow as needed.

Large linked lists can cause problems in servers because the server's thread-stack usually cannot grow automatically. Large lists can overrun the stack, causing the server to crash.

DCE offers several ways to avoid this server memory problem while using large linked lists.

One method is to increase the server stack size using the **rpc_mgmt_set_server_stack_size()** routine. This method is useful when you suspect that the linked list is just slightly larger than the server stack. For information about using the **rpc_mgmt_set_server_stack_size()** routine, refer to the *DCE 1.2.2 Application Development Reference*.

If you suspect that the list size is much greater than the stack, you can convert the list to an array using the **transmit_as** idl attribute. Servers handle arrays by allocating memory from the heap rather than from the stack. For information about using the **transmit_as** idl attribute, refer to Chapter 19 in this guide.

18.14.7.1.3 Unique Pointers

A unique pointer is more flexible than a reference pointer. However, both types of pointers share several important characteristics.

A unique pointer has the following characteristics:

- It can have a NULL value.

- It can change from NULL to non-NULL during a call. This change results in memory being allocated on return from the call, whereby the result is stored in the allocated memory.
- It can change from non-NULL to NULL during a call. This change can result in the orphaning of the memory pointed to on return from the call. Note that, if a unique pointer changes from one non-NULL value to another non-NULL value, the change is ignored.
- It does not identify particular extents of memory, but only extents of memory that are suitable for storing the data. If it is important to know that the data is being stored in a specific memory location, then you should use a full pointer.
- If it has a value other than NULL, output data is placed in existing storage.

Unique pointers are similar to reference pointers in the following ways:

- No storage pointed to by a unique pointer can be reached from any other name in the operation. That is, a unique pointer does not allow aliasing of data within the operation.
- Data returned from the called subroutine is written into the existing storage specified by the unique pointer, if the pointer did not have the value NULL.

With regard to performance, unique pointers have an advantage over full pointers because unique pointers do not support the referencing of common data by more than one pointer (aliasing), and they are significantly more flexible than reference pointers because they can have a value of NULL.

Unique pointers are particularly suitable for creating optional parameters (because you can specify them as NULL) and for simple tree or singly linked-list data structures. You specify the three different levels of pointers by attributes, as follows:

[ref] Reference pointers

[unique] Unique pointers

[ptr] Full pointers

The following example shows how a unique pointer can be used:

```
[
    uuid(D37A0E80-5D23-11C9-B199-08002B13D56D)
```

```
] interface Unique_ptrs
{
    typedef [ref]    long *r_ptr;
    typedef [unique] long *u_ptr;
    typedef [ptr]    long *f_ptr;

    void op1 (
      [ref,in,out,string]  char *my_rname,
      [unique,in,out,string] char *my_uname,
      [ptr,in,out,string]  char *my_pname
      );
}
```

18.14.7.2 Pointer Attributes in Parameters

A pointer attribute can be applied to a parameter only if the parameter contains an explicit pointer declaration (*).

By default, a single pointer (*) operator in a parameter list of an operation declaration is treated as a reference pointer. To override this, specify a pointer attribute for the parameter. When there is more than one pointer operator, or multiple levels of indirection in the parameter list, the rightmost pointer is the top-level pointer; all pointers to the left of the rightmost pointer are of a lower level. The top-level pointer is treated as a reference pointer by default; the lower-level pointers have the semantics specified by the **pointer_default** attribute in the interface.

The following example illustrates the use of top- and lower-level pointers:

```
void op1 ([in] long **p_p_l)
```

In this example, **p_p_l** is a pointer to a pointer to a long integer. The first or leftmost pointer (*) signifies that the pointer to the long integer is a lower-level pointer, and the second or rightmost pointer (*) signifies that the pointer to the pointer is a top-level pointer.

Any pointer attribute you specify for the parameter applies to the top-level pointer only. Note that unless you specify a pointer attribute, the top-level explicit

pointer declaration in a parameter defaults to a reference pointer even if the **pointer_default(ptr)** interface attribute is specified.

Using a reference pointer improves performance but is more restrictive. For example, the pointer declared in the following operation, for the parameter **int_value**, is a reference pointer. An application call to this operation can never specify NULL as the value of **int_value**.

```
void op ([in] long *int_value);
```

To pass a NULL value, use a full pointer. The following two methods make **int_value** into a full pointer:

- Applying the **ptr** attribute to the declaration of the parameter, **int_value**:

```
void op ([in, ptr] long *int_value);
```

- Using the **pointer_default (ptr)** attribute in an interface header :

```
[uuid(135e7f00-1682-11ca-bf61-08002b111685,
 pointer_default(ptr),
 version(1.0)] interface full_pointer
{
typedef long *long_ptr;
void op ([in] long_ptr int_value);
}
```

A NULL pointer can also be passed via a unique pointer.

18.14.7.3 Array Attributes on Pointers

To apply array attributes to pointers, use the **max_is** or **size_is** attributes. When applied to a pointer, the **max_is** and **size_is** attributes convert the pointer from a single element

of a certain type to a pointer to an array of elements of that type. The number of elements in the array is determined by the variable in the **max_is** and **size_is** attributes.

18.14.7.4 Pointer Attributes in Function Results

Function results that are pointers are always treated as full pointers. The **ptr** attribute is allowed on function results but it is not mandatory. The **ref** pointer attribute is never allowed on function results.

A function result that is a pointer always indicates new storage. A pointer parameter can reference storage that was allocated before the function was called, but a function result cannot.

18.14.7.5 Pointers in Structure Fields and Union Case

If a pointer is declared in a member of a structure or union, its default is determined by the **pointer_default** attribute you specify for the interface. To override this, specify a pointer attribute for the member.

18.14.7.6 Resolving a Possible Pointer Ambiguity

A declaration of the following form raises a possible ambiguity about the type of *myarray*:

```
void op ([in, out] long s, [in, out, size_is(s)] long **myarray);
```

IDL defines *myarray* in this case to be an array of pointers to **longs**, not a pointer to an array of **longs**. The **max_is** and **size_is** attributes always apply to the top-level, or rightmost, * (asterisk) in the IDL signature of a parameter.

18.14.7.7 Rules for Using Pointers

Use the following rules when developing code in IDL:

- Do not use the full pointer attribute on the following:
  - The parameter in the first parameter position, when that parameter is of type **handle_t** or is of a type with the **handle** attribute.
  - Context handle parameters.
  - A parameter that has the output attribute (**out**), but not the input attribute (**in**).
- The element type of a pipe must not be a pointer or a structure containing a pointer.
- A member of a union or a structure contained in a union cannot contain a reference pointer.
- A reference pointer must point to valid storage at the time the call is made.
- A parameter containing a varying array of reference pointers must have all array elements initialized to point to valid storage even if only a portion of the array is input, since the manager code (the application code supporting an interface on a server) may use the remaining array elements. (Recall that a varying array is one to which any of the array attributes **first_is, last_is, length_is** is applied).
- The type name in a declaration that defines a pointer type must have no more than 28 characters.

18.14.7.8 Memory Management for Pointed-to Nodes

A full pointer can change its value across a call. Therefore, stubs must be able to manage memory for the pointed-to nodes. Managing memory involves allocating and freeing memory for user data structures.

18.14.7.8.1 Allocating and Freeing Memory

Manager code within RPC servers usually uses the **rpc_ss_allocate()** routine to allocate storage. Storage that is allocated by **rpc_ss_allocate()** is released by the server stub after any output parameters have been marshalled by the stubs. Storage allocated

by other allocators is not released automatically but must be freed by the manager code. When the manager code makes a remote call, the default memory management routines are **rpc_ss_allocate()** and **rpc_ss_free()**.

The syntax of the **rpc_ss_allocate()** routine is as follows:

idl_void_p_t rpc_ss_allocate (idl_size_t *size***);**

The *size* parameter specifies the size of the memory allocated.

Note: In ANSI standard C environments, **idl_void_p_t** is defined as **void *** and in other environments is defined as **char ***.

Use **rpc_ss_free()** to release storage allocated by **rpc_ss_allocate()**. You can also use the **rpc_ss_free()** routine to release storage pointed to by a full pointer in an input parameter and have the freeing of the memory reflected on return to the calling application by specifying the **reflect_deletions** attribute as an *operation_attribute*. See Section 18.4.1 for more information.

The syntax of the routine is as follows:

void rpc_ss_free (idl_void_p_t *node_to_free***);**

The *node_to_free* parameter specifies the location of the memory to be freed.

18.14.7.8.2 Enabling and Disabling Memory Allocation

It may be necessary to call manager routines from different environments; for example, when the application is both a client and a server of the same interface. In this case, the same routine may be called both from server manager code and from client code. The **rpc_ss_allocate()** routine, when used by the manager code to allocate memory, must be initialized before its first use. The stub performs the initialization automatically. Code, other than stub code, that calls a routine, which in turn calls **rpc_ss_allocate()**, first calls the **rpc_ss_enable_allocate()** routine.

The syntax of the routine is as follows:

```
void rpc_ss_enable_allocate (void);
```

The environment set up by the **rpc_ss_enable_allocate()** routine is released by calling the **rpc_ss_disable_allocate()** routine. This routine releases all memory allocated by calls to **rpc_ss_allocate()** since the call to **rpc_ss_enable_allocate()** was made. It also releases memory that was used by the memory management mechanism for internal bookkeeping.

The syntax of the **rpc_ss_disable_allocate()** routine is as follows:

```
void rpc_ss_disable_allocate (void);
```

18.14.7.9 Advanced Memory Management Support

Memory management may also involve setting and swapping the mechanisms used for allocating and freeing memory. The default memory management routines are **malloc()** and **free()**, except when the remote call occurs within manager code, in which case the default memory management routines are **rpc_ss_allocate()** and **rpc_ss_free()**.

18.14.7.9.1 Setting the Client Memory Mechanism

Use the **rpc_ss_set_client_alloc_free()** routine to establish the routines used in allocating and freeing memory.

The syntax of the routine is as follows:

```
void rpc_ss_set_client_alloc_free (
     idl_void_p_t (*p_allocate) (
        idl_size_t size),
      void (*p_free) (
         idl_void_p_t ptr)
      );
```

The *p_allocate* parameter points to a routine that has the same procedure declaration as the **malloc()** routine, and is used by the client stub when performing memory allocation. The *p_free* parameter points to a routine that has the same procedure declaration as the **free()** routine, and is used by the client stub to free memory.

18.14.7.9.2 Swapping Client Memory Mechanisms

This routine exchanges the current client allocation and freeing mechanism for one supplied in the call. The primary purpose of this routine is to simplify the writing of modular routine libraries in which RPC calls are made. To preserve modularity, any dynamically allocated memory returned by a modular routine library must be allocated with a specific memory allocator. When dynamically allocated memory is returned by an RPC call that is then returned to the user of the routine library, use **rpc_ss_swap_client_alloc_free()** , before making the RPC call, to make sure the desired memory allocator is used. Prior to returning, the modular routine library calls **rpc_ss_set_client_alloc_free()** to restore the previous memory management mechanism.

The syntax of the routine is as follows:

```
void rpc_ss_swap_client_alloc_free (
    idl_void_p_t (*p_allocate) (
      idl_size_t size),
    void (*p_free) (
      idl_void_p_t ptr),
    idl_void_p_t (**p_p_old_allocate) (
      idl_size_t size),
    void (**p_p_old_free) (
      idl_void_p_t ptr)
    );
```

The *p_allocate* parameter points to a routine that has the same procedure declaration as the **malloc()** routine, and is used by the client stub when performing memory allocation. The *p_free* parameter points to a routine that has the same procedure declaration as the **free()** routine, and is used by the client stub to free memory. The *p_p_old_allocate* parameter points to a pointer to a routine that has the same procedure declaration as the **malloc()** routine, and is the default routine used for memory allocation in the client stub. The *p_p_old_free* parameter points to a pointer

to a routine that has the same procedure declaration as the **free()** routine, and is used for memory release in the client.

18.14.7.10 Use of Thread Handles in Memory Management

There are two situations where control of memory management requires the use of thread handles. The more common situation is when the manager thread spawns additional threads. The less common situation is when a program transitions from being a client to being a server, then reverts to being a client.

18.14.7.10.1 Spawning Threads

When a remote procedure call invokes the manager code, the manager code may wish to spawn additional threads to complete the task for which it was called. To spawn additional threads that are able to perform memory management, the manager code must first call the **rpc_ss_get_thread_handle()** routine to get its thread handle and then pass that thread handle to each spawned thread. Each spawned thread that uses the **rpc_ss_allocate()** and **rpc_ss_free()** routines for memory management first calls the **rpc_ss_set_thread_handle()** routine by using the handle obtained by the original manager thread.

These routine calls allow the manager and its spawned threads to share a common memory management environment. This common environment enables memory allocated by the spawned threads to be used in returned parameters, and causes all allocations in the common memory management environment to be released when the manager thread returns to the server stub.

The main manager thread must not return control to the server stub before all the threads it spawned complete execution; otherwise, unpredictable results may occur.

The listener thread can cancel the main manager thread if the remote procedure call is orphaned or if a cancellation occurs on the client side of the application. You should code the main manager thread to terminate any spawned threads before it exits. The code should anticipate exits caused by an unexpected exception or by being canceled.

Your code can handle all of these cases by including a **TRY/FINALLY** block to clean up any spawned threads if a cancellation or other exception occurs. If

unexpected exceptions do not concern you, then your code can perform two steps. They are disabling cancelability before threads are spawned followed by enabling cancelability after the join operation finishes and after testing for any pending cancel operations. Following this disable/enable sequence prevents routine **pthread_join()** from producing a cancel point in a manager thread that has spawned threads which, in turn, share thread handles with the manager thread.

18.14.7.10.2 Transitioning from Client to Server to Client

Immediately before the program changes from a client to a server, it must obtain a handle on its environment as a client by calling **rpc_ss_get_thread_handle()**. When it reverts from a server to a client, it must reestablish the client environment by calling the **rpc_ss_set_thread_handle()** routine, supplying the previously obtained handle as a parameter.

18.14.7.10.3 Syntax for Thread Routines

The syntax for the **rpc_ss_get_thread_handle()** routine is as follows:

```
rpc_ss_thread_handle_t  rpc_ss_get_thread_handle(void);
```

The syntax for the **rpc_ss_set_thread_handle()** routine is as follows:

```
void rpc_ss_set_thread_handle (
    rpc_ss_thread_handle_t id
    );
```

The **rpc_ss_thread_handle_t()** value identifies the thread to the RPC stub support library. The *id* parameter indicates the thread handle passed to the spawned thread by its creator, or the thread handle returned by the previous call to **rpc_ss_get_thread_handle()**.

18.14.7.11 Rules for Using the Memory Management Routines

You can use the **rpc_ss_allocate()** routine in the following environments:

- The manager code for an operation that has a full pointer in its argument list
- The manager code for an operation to which the **enable_allocate** ACF attribute is applied
- Code that is not called from a server stub but that has called the **rpc_ss_enable_allocate()** routine
- A thread, spawned by code of any of the previous three types, that has made a call to the **rpc_ss_set_thread_handle()** routine using a thread handle obtained by this code

18.14.7.12 Examples Using Pointers

The examples in this subsection contain the following files, listed here with the function of each file:

STRING_TREE.IDL
Defines data types and interfaces

CLIENT.C User of the interface

MANAGER.C
Server code that implements the procedure

SERVER.C Declares the server; enables the client code to find the interface it needs

STRING_TREE.OUTPUT
Shows the output

The STRING_TREE.IDL Example

```
[uuid(0144d600-2d28-11c9-a812-08002b0ecef1), version(0)]
interface string_tree
{
  /*
   * Maximum length of a string in the tree
```

```
     */
    const long int st_c_name_len = 32;

    /*
     * Definition of a node in the tree.
     */
    typedef struct node
    {
        [string] char name[0..st_c_name_len];
        [ptr] struct node *left;
        [ptr] struct node *right;
    } st_node_t;

    /*
     * Operation that prunes the left subtree of the specified
     * tree and returns it as the value.
     */
    st_node_t *st_prune_left (
        [in, out] st_node_t *tree /* root of tree by ref */
        );
}
```

The CLIENT.C Example

```
#include <stdio.h>
#include "string_tree.h"

#include <stdlib.h>

/*
** Routine to print a depiction of the tree
*/
void st_print_tree (tree, indent)
  st_node_t *tree;
  int  indent;
{
  int i;
  if (tree == NULL) return;
```

```
  for (i = 0; i < indent; i++) printf("    ");
  printf("%s\n",tree->name);
  st_print_tree(tree->left, indent + 1);
  st_print_tree(tree->right, indent + 1);
}

/*
** Create a tree with a few nodes
*/
st_node_t *st_make_tree()
{
  st_node_t *root = (st_node_t *)malloc(sizeof(st_node_t));
  strcpy(root->name,"Root Node");

  /* left subtree node */
  root->left =  (st_node_t *)malloc(sizeof(st_node_t));
  strcpy(root->left->name,"Left subtree");

  /* left subtree children */
  root->left->right = NULL;
  root->left->left = (st_node_t *)malloc(sizeof(st_node_t));
  strcpy(root->left->left->name,"Child of left subtree");
  root->left->left->left = NULL;
  root->left->left->right = NULL;

  /* right subtree node */
  root->right =  (st_node_t *)malloc(sizeof(st_node_t));
  strcpy(root->right->name,"Right subtree");
  root->right->left = NULL;
  root->right->right = NULL;

  return root;
}

main()
{
  st_node_t *tree;
  st_node_t *subtree;

  /* setup and print original tree */
```

```
  tree = st_make_tree();
  printf("Original Tree:\n");
  st_print_tree(tree, 1);

  /* call the prune routine */
  subtree = st_prune_left (tree);

  /* print the resulting trees */
  printf("\nPruned Tree:\n");
  st_print_tree(tree, 1);

  printf("\nPruned subtree:\n");
  st_print_tree(subtree, 1);
  }
```

The MANAGER.C Example

```
#include <stdio.h>
#include "string_tree.h"

/*
** Prune the left subtree of the specified tree and return
** it as the function value.
*/
st_node_t *st_prune_left (tree)
/* [in,out] */  st_node_t *tree;
{
st_node_t *left_sub_tree = tree->left;
tree->left = (st_node_t *)NULL;
return left_sub_tree;
}
```

The SERVER.C Example

```
#include <stdio.h>
#include "string_tree.h"  /* header created by idl compiler */
#define check_error(s, msg) if(s != rpc_s_ok) \
{fprintf(stderr, "%s", msg); exit(1);}

main ()
{
unsigned32              status;   /* error status (nbase.h) */
rpc_binding_vector_p_t  binding_vector;
/* set of binding handles (rpc.h) */

rpc_server_register_if(   /* register interface with RPC runtime */
string_tree_v0_0_s_ifspec,
/* interface specification (string_tree.h) */
NULL,
NULL,
&status                                  /* error status */
);
check_error(status, "Can't register interface\n");

rpc_server_use_all_protseqs(     /* establish protocol sequences */
rpc_c_protseq_max_calls_default,
/* concurrent calls server takes (rpc.h) */
&status
);
check_error(status, "Can't establish protocol sequences\n");

  rpc_server_inq_bindings(
/* get set of this server's binding handles*/
&binding_vector,
&status
);
check_error(status, "Can't get binding handles\n");

  rpc_ep_register(
/* register addresses in endpoint map database */
string_tree_v0_0_s_ifspec,          /* interface specification */
binding_vector,  /* (string_tree.h) the set of binding handles */
NULL,
"",
```

```
&status
);
check_error(status, "Can't add address to the endpoint database\n");

rpc_ns_binding_export(                  /* establish namespace entry */
rpc_c_ns_syntax_dce,          /* syntax of the entry name (rpc.h) */
"string_tree",                 /* entry name in directory service */
&string_tree_v0_0_s_ifspec,            /* interface specification */
binding_vector,     /* (string_tree.h) the set of binding handles */
NULL,
&status
);
check_error(status, "Can't export to directory service\n");

rpc_binding_vector_free(             /* free set of binding handles */
&binding_vector,
status
);
check_error(status, "Can't free binding handles and vector\n");

rpc_server_listen(                       /* listen for remote calls */
rpc_c_listen_max_calls_default,
/* concurrent calls server executes (rpc.h) */
&status
);
check_error(status, "rpc listen failed\n");
}
```

The STRING_TREE.OUTPUT Example

```
Original Tree:
    Root Node
       Left subtree
           Child of left subtree
       Right subtree
Pruned Tree:
    Root Node
        Right subtree
```

```
Pruned subtree:
    Left subtree
        Child of left subtree
```

18.14.8 Customized Handles

The **handle** attribute specifies that the type being declared is a user-defined, nonprimitive handle type, and is to be used in place of the predefined primitive handle type **handle_t**. The term *customized handle* is used to denote a nonprimitive handle.

The following example declares a customized handle type **filehandle_t**, a structure containing the textual representations of a host and a pathname:

```
typedef [handle] struct {
     char host[256];
     char path[1024];
     } filehandle_t;
```

If the handle parameter is the first parameter in the list, then it is a customized handle that is used to determine the binding for the call, and it must have the **in** attribute or the **in,out** attributes. A handle parameter that is not the first parameter in the parameter list need not have the **in** or **in,out** attributes.

Note that a **handle_t** parameter that is the first parameter in the list must not have the **transmit_as** attribute.

To build an application that uses customized handles, you must write custom binding and unbinding routines, and you must link those routines with your application client code. At runtime, each time the client calls an operation that uses a customized handle, the client stub calls the custom binding routine before it sends the remote procedure call request, and the client stub calls the custom unbinding routine after it receives a response.

The following paragraphs specify C prototypes for customized binding and unbinding routines; in these prototypes, *CUSTOM* is the name of the customized handle type.

The custom binding routine *CUSTOM*_**bind** generates a primitive binding handle from a customized handle and returns the primitive binding handle:

handle_t *CUSTOM*_**bind** **(***CUSTOM c-handle***)**

The custom unbinding routine *CUSTOM*_**unbind** takes two inputs, a customized handle and the primitive binding handle that was generated from it, and has no outputs:

void *CUSTOM*_**unbind (**
*CUSTOM c-handle***,**
handle_t *rpc-handle***)**

A custom unbinding routine typically frees the primitive binding handle and any unneeded resources associated with the customized handle, but it is not required to do anything.

Because the **handle** attribute can occur only in a type declaration, a customized handle must have a named type. Because customized handle type names are used to construct custom binding and unbinding routine names, these names cannot exceed 24 characters.

A customized handle can be coded either in a parameter list as an explicit handle or in an interface header as an implicit handle.

18.14.9 Context Handles

Manager code often maintains state information for a client. A handle to this state information is passed to the client in an output parameter or as an operation result. The client passes the unchanged handle-to-the-state information as an input or input/output parameter of a subsequent manager operation that the client calls to manipulate that data structure. This handle-to-the-state information is called a *context handle*. A context handle is implemented as an untyped pointer or a pointer to a structure by tag name.

The manager causes the untyped pointer or the structure pointer to point to the state information it will need the next time the client asks the manager to manipulate the context. For the client, the context handle is an opaque pointer (**idl_void_p_t** or an opaque structure tag). The client receives or supplies the context handle by means of the parameter list but does not perform any transformations on it.

The RPC runtime maintains the context handle, providing an association between the client and the address space running the manager and the state information within that address space.

If a manager supports multiple interfaces, and a client obtains a context handle by performing an operation from one of these interfaces, the client can then supply the context handle to an operation from another of these interfaces.

A context handle can only be exchanged between the server process that created it and the client process for which it was created. No other client except the one that obtained the context handle can use it without causing an application error.

18.14.9.1 The context_handle Attribute

Specify a context handle by one of the following methods:

- Use the **context_handle** attribute on a parameter of type **void ***.
- Use the **context_handle** attribute on a type that is defined as **void ***.
- Use the **context_handle** attribute on a type that is defined as a pointer to a structure by tag name.

For example, in the IDL file, you can define a context handle within a type declaration as follows:

```
typedef [context_handle] void * my_context;
```

or within a parameter declaration as follows:

```
[in, context_handle] void * my_context;
```

You can also define a context handle within a type declaration as a forward reference to a structure type by tag, as follows:

```
typedef [context_handle] struct opaque_struct * opaque_ch_t;
```

Note that you do not need to define the structure type in the IDL file; it is a forward reference to a structure whose definition can be included into the server code, either from a private **.h** file or from a server IDL file. As a result, the structure type is opaque to the client. This method of defining a context handle provides type checking and permits the server code to avoid extensive casting when manipulating the context handle.

A structure type in a context handle type definition must be referenced by tag name and not by type name. So, for example, the first of the following declarations is valid, while the second is not:

```
typedef [context_handle] struct struct_tag * valid_ch_t;
                                                  /* valid */

typedef [context_handle] struct_type * invalid_ch_t;
                                                  /* error */
```

The following example illustrates context handles defined as untyped pointers and as pointers to structures by tag name.

```
/* A context handle implemented as untyped pointer */
typedef [context_handle] void * void_ch_t;

/* A context handle implemented as a  */
/* pointer to a structure by tag name */
typedef [context_handle] struct opaque_struct * opaque_ch_t;

/* Operations using both types of context handles */
void ch_oper(
     [in] void_ch_t v1,
     [in,out] void_ch_t *v2,
```

```
     [out] void_ch_t *v3,
     [in] opaque_ch_t *o2,
     [out] opaque_ch_t *o3
);

void_ch_t void_ch_oper ([in] handle_t h);

opaque_ch_t opaque_ch_oper([in] handle_t h);
```

It is possible to define a structure type in a context handle in the IDL file; for example, the following structure definition can either precede or follow the definition of **valid_ch_t** in the example previously shown:

```
typedef struct struct_tag {long l;} struct_type;
```

This practice is not recommended, however, since it violates the opaqueness of the context handle type.

The type name in a context handle declaration must be no longer than 23 characters.

The first operation on a context creates a context handle that the server procedure passes to the client. The client then passes the unmodified handle back to the server in a subsequent remote call. The called procedure interprets the context handle. For example, to specify a procedure that a client can use to obtain a context handle, you can define the following:

```
typedef [context_handle] void * my_context;
void op1(
   [in]handle_t h,
   [out] my_context * this_object);
```

To specify a procedure that a client can call to make use of a previously obtained context handle, you can define the following:

```
void op2([in] my_context this_object);
```

To close a context, and to clean the context on the client side, you can define the following:

```
[in, out, context_handle] void * my_context;
```

The resources associated with a context handle are reclaimed when, and only when, the manager changes the value of the **in,out** context handle parameter from non-NULL to NULL.

18.14.9.2 The Context Rundown Procedure

Some uses of context handles may require you to write a context rundown procedure in the application code for the server. If communications between the client and server are broken while the server is maintaining context for the client, RPC invokes the context rundown procedure on the server to recover the resources represented by the context handle. If you declare a context handle as a named type, you must supply a rundown procedure for that type.

When a context requires a context rundown procedure, you must define a named type that has the **context_handle** attribute. For each different context handle type, you must provide a context rundown procedure as part of the manager code.

The format for the rundown procedure name is as follows:

*context_type_name*_**rundown**

A rundown procedure takes one parameter, the handle of the context to be run down, and delivers no result. For example, if you declare the following:

```
typedef [context_handle] void * my_context;
```

then the rundown procedure is as follows:

```
void my_context_rundown (my_context this_object);
```

Server application code that uses a certain context handle may be executing in one or more server threads at the time that RPC detects that communications between the server and the client that is using that context have broken. The context rundown routine will not be invoked until a return of control to the server stub has happened in each of the threads that were using the context handle.

If application code in any of these threads destroys the context before returning control to the server stub from which it was called, your context rundown procedure will not be executed.

18.14.9.3 Creating New Context

When a client makes its first request to the manager to manipulate context, the manager creates context information and returns this information to the client through a parameter of the type **context_handle**. This parameter must be an output parameter or an input/output parameter whose value is NULL when the call is made. A context handle can also be a function result.

18.14.9.4 Reclaiming Client Memory Resources for the Context Handle

In the event that a communications error causes the context handle to be unusable, the resources that maintain the context handle must be reclaimed. Use the **rpc_ss_destroy_client_context()** routine in the client application to reclaim the client-side resources and to set the context handle value to NULL.

The syntax of the routine is as follows:

void rpc_ss_destroy_client_context(
    void ***p_unusable_context_handle);*

18.14.9.5 Relationship of Context Handles and Binding

For the client, the context handle specifies the state within a server and also contains binding information. If an operation has an input context handle or input/output context handle that is not NULL, it is not necessary to supply any other binding information. A context handle that has only the **in** attribute cannot be NULL. If an operation has **in,out** context handle parameters but no **in** context handle parameters, at least one of the **in,out** context handle parameters cannot be NULL. However, if the only context handle parameters in an operation are output, they carry no binding information. In this case, you must use another method to bind the client to a server.

If you specify multiple context handles in an operation, all active context handles must map to the same remote address space on the same server or the call fails. (A context handle is active while it represents context information that the server maintains for the client. It is inactive if no context has yet been created, or if the context is no longer in use.)

18.14.9.6 Rules for Using Context Handles

The following rules apply to using context handles:

- A context handle can be a parameter or a function result. You cannot use context handles as an array element, as a structure or union member, or as the element type of a pipe.
- A context handle cannot have the **transmit_as** or **ptr** attributes.
- An input-only context handle cannot be NULL.
- A context handle cannot be pointed to, except by a top-level reference pointer.

18.14.9.7 Examples Using Context Handles

The following examples show a sample IDL file that uses context handles and a sample context rundown procedure file.

Example of an IDL File That Uses a Context Handle

```
/*
 * Filename: context_handle.idl
 */
[uuid(f38f5080-2d27-11c9-a96d-08002b0ecef1),
 pointer_default(ref), version (1.0)]
interface files
{
/* File context handle type */
typedef [context_handle] void * file_handle_t;
/* File specification type */
typedef [string] char * filespec_t;
/* File read buffer type */
typedef [string] char buf_t[*];

 /*
  * The file_open call requires that the client has located a
  * file server interface files and that an RPC handle that is
  * bound to that server be passed as the binding parameter h.
  *
  * Operation to OPEN a file; returns context handle for that
  * file.
  */
file_handle_t file_open
(
 /* RPC handle bound to file server */
    [in] handle_t h,
 /* File specification of file to open */
    [in] filespec_t fs
);

 /*
  * The file_read call is able to use the context handle
  * obtained from the file_open as the binding parameter,
  * thus an RPC handle is not necessary.
  *
  * Operation to read from an opened file; returns true if
  * not end-of-file
  */
boolean file_read
(
```

```
 /* Context handle of opened file */
    [in] file_handle_t fh,
 /* Maximum number of characters to read */
    [in] long buf_size,
 /* Actual number of characters of data read */
    [out] long *data_size,
 /* Buffer for characters read */
    [out, size_is(buf_size), length_is(*data_size)] \
      buf_t buffer
);
 /* Operation to close an opened file */
void file_close
(
 /* Valid file context handle goes [in]. On successful close,
  * null is returned.
  */
    [in,out] file_handle_t *fh
);
}
```

Example of a Context Rundown Procedure

```
/*
 * fh_rundown.c:  A context rundown procedure.
 */

#include <stdio.h>
#include "context_handle.h"   /* IDL-generated header file */

void file_handle_t_rundown
(
    file_handle_t file_handle   /* Active context handle */
                                 * (open file handle)    */
)

{
    /*
     * This procedure is called by the RPC runtime on the
     * SERVER side when communication is broken between the
```

```
     * client and server.  This gives the server the
     * opportunity to reclaim resources identified by the
     * passed context handle.  In this case, the passed
     * context handle identifies a file, and simply closing
     * the file cleans up the state maintained by the context
     * handle, that is "runs down" the context handle.  Note
     * that the file_close manager operation is not used here;
     * perhaps it could be, but it is more efficient to use
     * the underlying file system call to do the close.
     *
     * File handle is void*, it must be cast to FILE*
     */
    fclose((FILE *)file_handle);
}
```

18.15 IDL Support for C++

Most of the IDL features apply to both C and C++ applications. However, just as C++ is an extension to C, this section describes additional IDL features required to use IDL effectively with C++.

When the IDL compiler compiles an interface definition, it typically generates a header file and one or more intermediate stub files in C or C++, and then it invokes the appropriate compiler to generate object stub files. The IDL Compiler generates C language intermediate stub files by default, but you can use the **- lang cxx** option to cause it to generate C++ files instead.

This section describes the following topics:

- The **idl**-generated class hierarchy

  This is important for a basic understanding of how to integrate the interface into an object-oriented application.

- Interface inheritance

  One interface can be derived from another, just as classes are derived from other classes.

- Static operations

Static operations specify member functions that are called independently from an object. All other operations specify nonstatic member functions which are only invoked with respect to an existing object.

- Reference parameters

  Reference parameters are passed by reference instead of being passed by value.

- **idl**-generated member functions

  Several member functions are generated by IDL and made part of the interface class. These functions perform useful operations for all interfaces.

18.15.1 The idl-generated Class Hierarchy

For C++ applications, the interface definition specifies a public interface class. This means that IDL data types specify public data members of the interface class, and IDL operations specify member functions. The IDL compiler generates this *interface class* within C++ class hierarchies for both the client and server. The RPC network mechanisms are encapsulated in a class above the interface class. Clients use (and servers implement) the objects of classes below the interface class.

18.15.1.1 The rpc_object_reference Base Class

Because C++ makes it easy to hide information, the IDL compiler generates an **rpc_object_reference** *base class* for identifying, distributing, and tracking objects. All interface classes inherit the **rpc_object_reference** class, which encapsulates the following information:

- Object binding information, including server binding information and an object UUID representing the object on the particular server
- Transport protocol information for the server
- A name identifying an optional location in the namespace for the object's binding information
- A location flag indicating whether the object is on the local system or a remote system
- A reference count to keep track of how many clients currently access the object

18.15.1.2 The Interface Class

For each interface, the IDL compiler generates and places in the header file the interface class derived from the **rpc_object_reference** class. The class name generated is the interface name specified in the interface definition. For example, the compiler generates the following class:

class *interface_name* **: public virtual rpc_object_reference**

This is an abstract class that contains public functions for all the operations specified in the IDL interface. The member functions that are not static object creator functions are defined as pure virtual functions. In C++, an abstract class contains at least one pure virtual function, which means that the implementation is postponed until a later, derived class. Therefore, object instances cannot be created for abstract classes, and thus the interface class is not implemented but is only a declaration. Other classes must be derived from the interface class so that objects can be created for clients and servers.

No constructor operations are allowed in the interface definition, and the IDL compiler does not generate one because no objects are created for the interface class. No destructor operations are allowed in the interface definition, but the compiler generates one automatically for the interface class.

18.15.1.3 The Client's Proxy Class

The IDL compiler places in the header file a *proxy class* derived from the interface class. An instance of a proxy class is also known as an *object reference*, which clients use to access a remote object. This class provides proxy (or surrogate) objects on the client whose member functions (or methods) transparently perform the RPCs that invoke the actual remote object's member functions on the server. The proxy class name is generated from the interface name and the word **Proxy**, as follows:

class *interface_name***Proxy : public** *interface_name*

Implementations of the proxy class's member functions are automatically generated in the client stub and represent the client's implementation of the interface's operations.

18.15.1.4 The Server's Manager Class

A *manager class* is required for servers to implement the interface. The class is generated by the IDL compiler and derived from the interface class as follows:

```
class  interface_name_Mgr : public  interface_name  {
public:
     .
     .
     .
}
```

The class is placed in a header file whose name is based on the IDL file and an **_mgr** suffix. When generated, the manager class contains empty functions of all the nonstatic member functions of the interface class. The member function implementations and other implementation details of this class are called *manager code*.

18.15.2 The Interface Inheritance Operator

An interface definition can inherit properties of a previously defined interface, just as a C++ class can inherit properties of previously defined classes. You can modify an interface definition to inherit an interface by using the inheritance operator (**:**) in the interface header, as follows:

[*interface_attribute, ...***] interface** *interface_name [: inherited_interface]*

This **idl**-generated header file contains the inherited interface's data types and interface class. The interface definition must also declare the information in the inherited interface's header file by using an **import** declaration in the body of the interface. The following example shows how the **derived** interface inherits another interface and

imports that interface's definition file. The inherited interface definition file is named **inherit.idl**, and the interface it contains is named **inherit**.

```
interface derived : inherit
{
 import "inherit.idl";
  .
  .
  .
}
```

A interface may inherit only one interface; that is, multiple interface inheritance is not allowed.

18.15.3 The static Keyword for Operations

In C++ applications, the interface definition operations specify the member functions of the interface class. The majority of the member functions are invoked by an existing object, but some operations are intended to work regardless of whether an object invokes them or not. Static member functions are invoked independently from any object and are good for such things as object creator functions and for obtaining a class's static data; that is, data that is class-wide and independent from a specific object.

Static member functions may be specified in an interface definition by using the **static** keyword in front of the operation, in one of the following ways:

static *return_type operation_identifier*(**...**);

[*operation_attribute*, **...**] **static** *return_type operation_identifier*(**...**);

Instead of using the **static** keyword in the interface definition, you can use the **cxx_static** attribute in an ACF.

Since non-static member functions are invoked by an object for which the application must already have a binding, nonstatic operations cannot have a binding handle parameter. If you want to use explicit binding for an interface, only static operations can have a binding handle as the first parameter.

18.15.4 The C++ Reference Operator (&) on Parameters

C++ passes arguments by value; however, to override this and cause a member function argument to be passed by reference, apply the reference operator (**&**) to the parameter in the interface definition. Specify a reference parameter as follows:

[*parameter_attribute,...***]** *parameter_type* **&***parameter*

Using the reference operator on a parameter is the same as applying the reference pointer attribute (**[ref]**) to a pointer parameter.

18.15.5 Functions Generated by IDL

The IDL compiler generates some additional member functions for an interface class. For clients, these functions include overloaded static member functions to bind to remote named objects in various ways and a member function to set security information. For servers, additional member functions exist to advertise named objects and get the binding handle on which a member function was called from within the member function implementation.

Four overloaded functions for binding clients to known objects are named **bind()**. The functions otherwise differ by the type of parameter passed in. Three of these functions are intended for use with named objects and one is used to swap between interfaces when an object supports more than one interface. Each **bind()** function obtains an *object reference* (instance of a proxy class) by returning a pointer to the interface class. These functions are described in the following sections.

18.15.5.1 The bind() Function for Binding by an Object's Name

A client can bind to a named object (an object whose name is advertised in a name service) by calling the **idl**-generated **bind()** static member function with the name service name as an argument. The function's prototype is as follows:

interface_class * *interface_class*::**bind(unsigned_char_t *)**

This function takes a pointer argument of type **unsigned_char_t** that points to a name service name. The function returns a pointer to the interface class. For example:

```
char *CDS_name = "/.:/object_name";
IF_class * object = IF_class::bind( (unsigned_char_t *) CDS_name);
```

If the entry contains more than one binding, one is returned at random. The function obtains a full binding (the binding information includes a server's endpoint.)

Before a client uses this function, a persistent object on a server typically places its name and binding information in the name service by using the **idl**-generated **register_named_object()** member function.

18.15.5.2 The bind() Function for Binding by an Object's UUID

A client can bind to a named object by using the object's UUID as an argument to the **idl**-generated **bind()** static member function. This function's prototype is as follows:

interface_class * **interface_class::bind(uuid_t &)**

This function takes an argument of type **uuid_t** that is the UUID of a named object. The function returns a pointer to the interface class. For example:

```
uuid_t objectUUID;
interface_class * object = interface_class::bind(objectUUID);
```

The search in the namespace for an entry that contains the matching UUID begins with the default entry named in the **RPC_DEFAULT_ENTRY** environment variable. The binding obtained is fully bound.

18.15.5.3 The bind() Function for Binding by Binding Handle

A client can bind to a known object directly by using a binding handle as an argument to the **idl**-generated **bind()** static member function. This function's prototype is as follows:

interface_class ***** *interface_class***::bind(rpc_binding_handle_t)**

This function takes an argument of type **rpc_binding_handle_t** that is a binding handle to an object. The function returns a pointer to the interface class. For example:

```
rpc_binding_handle_t bindingHandle;
interface_class * object = interface_class::bind(bindingHandle);
```

This function does not use the name service because the client obtains the binding information and binding handle prior to the call. The binding handle can be either partially or fully bound. If the binding handle is partially bound, it becomes fully bound when the object calls a member function.

18.15.5.4 The bind() Function for Binding by Object Reference

Depending on the application, objects can have the behavior of more than one interface class. However, your code can access only one interface's member functions at a time. A client uses the **idl**-generated **bind()** static member function with an existing object reference as an argument to bind to a different interface. This function's prototype is as follows:

different_interface_class ***** *different_interface_class***::bind(rpc_object_reference *)**

This function takes a pointer argument of type **rpc_object_reference** that is an existing object reference to an interface class. The function returns a pointer to a different interface class that the object also supports. The original object is obtained through a previous **bind()** call, an object creator function, or an output parameter of a member function. For example:

```
rpc_binding_handle_t bindingHandle;
interface_class * object = interface_class::bind(bindingHandle);
diff_if_class * new_object = diff_if_class::bind(object);
```

18.15.5.5 The secure() Function for Setting Object Security

Objects use the **idl**-generated **secure()** member function to set their authorization and authentication information from the client. This sets the information for all the binding handles encapsulated in the client proxy object. The **secure()** function is a public member function of the **rpc_object_reference** class. This function's prototype is as follows:

```
void   interface_class::secure(
    [unsigned_char_t  *  server_principal_name = 0 , ]
    [unsigned32     protection_level     =  rpc_c_protect_level_default , ]
    [unsigned32     authentication_protocol = rpc_c_authn_default , ]
    [rpc_auth_identity_handle_t  authorization_identity = NULL , ]
    [unsigned32     authorization_policy  =  rpc_c_authz_name]
)
```

The following code shows an example of how to use the **secure()** member function:

```
Matrix          *m;

cout << "creating a remote matrix" << endl;
m = Matrix::createMatrix(1, 2, 3, 4);
```

```
cout << "calling set() operation without authorization" << endl;
m->set(0,0,99);
// Without authorization, operation should have not changed anything.
assert(m->get(0,0) == 1);

cout << "setting security privileges on object" << endl;
m->secure(
 (unsigned_char_t *) "refmon_test", // server principal name
 rpc_c_protect_level_pkt_integ, // protection level
 rpc_c_authn_dce_secret,  // authentication protocol
 NULL,    // inherited login context
 rpc_c_authz_name  // authorization policy
);

// since we now have set security flags, the set() operation
// should work
m->set(0,0,99);
assert(m->get(0,0) == 99);
```

The example shows that unauthorized use of a matrix's member function will not change values (**m->get(0,0,99);**). However, after setting the appropriate authorization and authentication information with **secure()**, the member function will work as expected. All parameters to the **secure()** function are optional, but it is recommended that you specify values rather than depend on the default values.

18.15.5.6 The SetRebind( )Function

A client can automatically rebind to an object if the client first sets a rebind policy by using the **SetRebind()** function. This allows a degree of fault tolerance in an application. For example, if a server goes down and is restarted, the client can re-establish communications with the new server. In another example, if a server provides access over multiple protocols or addresses and one of those links fails, the client can choose another link automatically. Finally, if multiple servers support the same object and one server exits, clients can still access the object via another server.

The format of the function is as follows:

```
void interface_class::SetRebind(
      DCERebindPolicy policy,
      [ unsigned32 * n = 0 ]
)
```

The second argument is optional and only used when the rebind policy is **attempt_rebind_n**. The valid policies include the following:

attempt_rebind_n
: If a communication fails, try to communicate with the object by selecting another binding until successful or until *n* attempts have been tried.

wait_on_rebind
: If a communication fails, try to communicate with the object by selecting another binding until successful or until the calling thread is canceled.

attempt_rebind
: If a communication fails, try to communicate with the object by selecting another binding, if possible. If all handles have been tried, return an error. This is the default policy.

never_rebind
: If a communication fails, return an error.

18.15.5.7 The register_named_object() Function

Persistent objects can name and register themselves from the server by using the **idl**-generated **register_named_object()** member function. This function performs the following tasks:

- Creates the name service entry (if it doesn't already exist) and adds the server's binding information so clients can find the server's host
- Replaces or adds the object's binding information in this host's endpoint map so clients can find this server

This function's prototype is as follows:

```
void interface_class::register_named_object(
          unsigned_char_t * name_service_name
```

```
        [, boolean32  replace_endpoint = TRUE  ]
)
```

The function takes a pointer argument of type **unsigned_char_t**, representing the name to use for the name service entry. The function has an optional second argument of type **boolean32** to indicate whether to replace or add the object's binding information to the host's endpoint map. If the second argument is not used (or is set to **TRUE**) and the object's binding information already exists, this function replaces the information. If the second argument is set to **FALSE**, the object's binding information is added to the endpoint map (not replaced). You should add the binding information rather than replace it in circumstances where a single host has more than one server that offers the same interface. The function does not return a value.

18.15.5.8 The get_binding_handle() Function

Server manager code uses the **idl**-generated **get_binding_handle()** function to obtain the binding handle used to invoke the call. The function's prototype is as follows:

```
rpc_binding_handle_t   get_binding_handle();
```

Member functions (that are not static) cannot have an explicit binding handle argument since the handle is encapsulated in the **rpc_object_reference** base class. A member function implementation uses this function to obtain the binding handle to verify security information, among other things.

18.16 Associating a Data Type with a Transmitted Type

The **transmit_as** attribute associates a transmitted type that stubs pass over the network with a presented type that clients and servers manipulate. The specified transmitted type must be a named type defined previously in another type declaration.

There are two primary uses for this attribute:

- To pass complex data types for which the IDL compiler cannot generate marshalling and unmarshalling code.

- To pass data more efficiently. An application can provide routines to convert a data type between a sparse representation (presented to the client and server programs) and a compact one (transmitted over the network).

To build an application that uses presented and transmitted types, you must write routines to perform conversions between the types and to manage storage for the types, and you must link those routines with your application code. At runtime, the client and server stubs call these routines before sending and after receiving data of these types.

The following paragraphs specify C prototypes for generic binding and unbinding routines; in these prototypes, *PRES* is the name of the presented type and *TRANS* is the name of the transmitted type.

The *PRES*_**to_xmit()** routine allocates storage for the transmitted type and converts from the presented type to the transmitted type:

void *PRES*_**to_xmit (***PRES* ******presented*, *TRANS* *******transmitted***)**

The *PRES*_**from_xmit()** routine converts from the transmitted type to the presented type and allocates any storage referenced by pointers in the presented type:

void *PRES*_**from_xmit (***TRANS* ******transmitted*, *PRES* ******presented***)**

The *PRES*_**free_inst()** routine frees any storage referenced by pointers in the presented type by *PRES* **_from_xmit()**:

void *PRES*_**free_inst (***PRES* ******presented***)**

Suppose that the **transmit_as** attribute appears either on the type of a parameter or on a component of a parameter and that the parameter has the **out** or **in,out** attribute. Then, the *PRES*_**free_inst()** routine will be called automatically for the data item that has the **transmit_as** attribute.

Suppose that the **transmit_as** attribute appears on the type of a parameter and that the parameter has only the **in** attribute. Then, the *PRES*_**free_inst()** routine will be called automatically.

Finally, suppose that the **transmit_as** attribute appears on a component of a parameter and that the parameter has only the **in** attribute. Then, the *PRES*_**free_inst()** routine will not be called automatically for the component; the manager application code must release any resources that the component uses, possibly by explicitly calling the *PRES* **_free_inst()** routine.

The *PRES*_**free_xmit()** routine frees any storage that has been allocated for the transmitted type by *PRES* **_to_xmit()**:

void *PRES*_**free_xmit (***TRANS* ******transmitted***)**

A type with the **transmit_as** attribute cannot have other type attributes, specifically the following:

- A pipe type.
- A pipe element type.
- A type with the **context_handle** attribute.
- A type of which any instance has the **context_handle** attribute.
- A type that includes the **handle** attribute in its definition cannot be used, directly or indirectly, in the definition of a type with the **transmit_as** attribute. Nor can a type that includes the **transmit_as** attribute in its definition be used, directly or indirectly, in the definition of a type with the **handle** attribute.
- A conformant array type.
- A varying array type.
- A structure type co ntaining a conformant array.
- An array type of which any instance is varying.
- A type with the **represent_as** attribute.

The type name in a declaration for a **transmit_as** attribute is restricted to 21 characters.

A transmitted type specified by the **transmit_as** attribute must be either a base type, a predefined type, or a named type defined via **typedef**. A transmitted type cannot be a conformant array type or a conformant structure type if any instance of that type is an **in** parameter or an **in, out** parameter.

The following is an example of **transmit_as**. Assuming the following declarations:

```
typedef
   struct tree_node_t {
      data_t data;
      struct tree_node_t * left;
      struct tree_node_t * right;
   } tree_node_t;

typedef
   [transmit_as(tree_xmit_t)] tree_node_t *tree_t;
```

The application code must include routines that match the prototypes:

```
void tree_t_to_xmit ( tree_t *, (tree_xmit_t **) );
void tree_t_from_xmit ( (tree_xmit_t *), (tree_t *) );
void tree_t_free_inst ( tree_t *);
void tree_t_free_xmit ( (tree_xmit_t *) );
```

18.17 IDL Grammar Synopsis

This section summarizes IDL syntax, in extended Backus-Naur Format (BNF) notation.

```
<interface> ::= <interface_header> "{" <interface_body> "}"

<interface_header> ::=
"[" <interface_attributes> "]" "interface" <identifier> \
[ ":" <identifier> ]
```

```
<interface_attributes> ::=
<interface_attribute> [ "," <interface_attribute> ] ...

<interface_attribute> ::= "uuid" "(" <uuid_rep> ")"
| "version" "(" <major> [ "." <minor> ] ")"
| "endpoint" "(" <endpoint_spec> [ "," <endpoint_spec> ] ... ")"
| "pointer_default" "(" <pointer_attribute> ")"
| "local"
| "exceptions" "(" <excep_name> ["," <excep_name>] ... ")"

<excep_name> ::= <Identifier>

<major> ::= <integer>

<minor> ::= <integer>

<endpoint_spec> ::=
""" <family_string> ":" "[" <endpoint_string> "]" """

<family_string> ::= <identifier>

<endpoint_string> ::= <identifier>

<interface_body> ::= [ <import> ] ... [ <export> ] ...

<export> ::= <const_declaration> ";"
| <type_declaration> ";"
| <op_declaration> ";"

<import> ::= import <import_files> ";"

<import_files> ::= <filename> [ "," <filename> ] ... ";"

<filename> ::= """ <character> ... """

<const_declaration> ::=
"const" <const_type_spec> <identifier> "=" <const_exp>

<const_type_spec> ::=
```

```
<integer_type> | "char" | "char" "*" | "boolean" | "void" "*"

<const_exp> ::=
<integer_const_exp> | <character_const> | <string_const>
| <identifier> | "TRUE" | "FALSE" | "NULL"

<integer_const_exp> ::= <conditional_exp>

<conditional_exp> ::= <logical_or_exp>
| <logical_or_exp> "?" <integer_const_exp> ":" <conditional_exp>

<logical_or_exp> ::= <logical_and_exp>
| <logical_or_exp> "||" <logical_and_exp>

<logical_and_exp> ::= <inclusive_or_exp>
| <logical_and_exp> "&&" <inclusive_or_exp>

<inclusive_or_exp> ::= <exclusive_or_exp>
| <inclusive_or_exp> "|" <exclusive_or_exp>

<exclusive_or_exp> ::= <and_exp>
| <and_exp> "^" <and_exp>

<and_exp> ::= <equality_exp>
| <and_exp> "&" <equality_exp>

<equality_exp> ::= <relational_exp>
| <equality_exp> "==" <relational_exp>
| <equality_exp> "!=" <relational_exp>

<relational_exp> ::= <shift_exp>
| <relational_exp> "<" <shift_exp>
| <relational_exp> ">" <shift_exp>
| <relational_exp> "<=" <shift_exp>
| <relational_exp> ">=" <shift_exp>

<shift_exp> ::= <additive_exp>
| <shift_exp> "<<" <additive_exp>
| <shift_exp> ">>" <additive_exp>
```

```
<additive_exp> ::= <multiplicative_exp>
| <additive_exp> "+" <multiplicative_exp>
| <additive_exp> "-" <multiplicative_exp>

<multiplicative_exp> ::= <unary_exp>
| <multiplicative_exp> "*" <unary_exp>
| <multiplicative_exp> "/" <unary_exp>
| <multiplicative_exp> "%" <unary_exp>

<
unary_exp> ::= <primary_exp>
| "+" <primary_exp>
| "-" <primary_exp>
| "~" <primary_exp>
| "!" <primary_exp>

<primary_exp> ::= <integer_literal>
| <identifier>

<character_const> ::= "'" <character> "'"

<string_const> ::= """ [ <character> ] ... """

<type_declaration> ::=
"typedef" [ <type_attributes> ] <type_spec> <declarators>

<type_spec> ::= <simple_type_spec>
| <constructed_type_spec>

<simple_type_spec> ::= <base_type_spec>
| <predefined_type_spec>
| <identifier>

<declarators> ::= <declarator> [ "," <declarator> ] ...

<declarator> ::= <simple_declarator>
| <complex_declarator>

<simple_declarator> ::= <identifier>
```

```
<complex_declarator> ::= <array_declarator>
| <function_ptr_declarator>
| <ptr_declarator>
| <ref_declarator>

<ref_declarator> ::= "&" <identifier>

<tagged_declarator> ::= <tagged_struct_declarator>
| <tagged_union_declarator>

<base_type_spec> ::= <integer_type>
| <floating_type>
| <char_type>
| <boolean_type>
| <byte_type>
| <void_type>
| <handle_type>

<floating_type> ::= "float" | "double"

<integer_type> ::= <signed_int> | <unsigned_int>

<signed_int> ::= <int_size> [ "int" ]

<
unsigned_int> ::= <int_size> "unsigned" [ "int" ]
| "unsigned" <int_size> [ "int" ]

<int_size> ::= "hyper" | "long" | "short" | "small"

<char_type> ::= [ "unsigned" ] "char"

<boolean_type> ::= "boolean"

<byte_type> ::= "byte"

<void_type> ::= "void"

<handle_type> ::= "handle_t"
```

```
<constructed_type_spec> ::= <struct_type>
| <union_type>
| <tagged_declarator>
| <enumeration_type>
| <pipe_type>

<tagged_struct_declarator> ::= "struct" <tag>
| <tagged_struct>

<struct_type> ::= "struct" "{" <member_list> "}"

<tagged_struct> ::= "struct" <tag> "{" <member_list> "}"

<tag> ::= <identifier>

<member_list> ::= <member> [ <member> ] ...

<member> ::= <field_declarator> ";"

<field_declarator> ::= [ <field_attribute_list> ]
<type_spec> <declarators>

<field_attribute_list> ::= "[" <field_attribute> [ ","
<field_attribute>] ... "]"

<tagged_union_declarator> ::= "union" <tag>
| <tagged_union>

<union_type> ::= "union" <union_switch> "{" <union_body>
"}" | "union" "{" <union_body_n_e> "}"

<union_switch> ::= "switch" "(" <switch_type_spec> <identifier> ")"
[ <union_name> ]

<
switch_type_spec> ::= <integer_type>
| <char_type>
| <boolean_type>
| <enumeration_type>
<tagged_union_declarator> ::= "union" <tag>
```

```
| <tagged_union>

<union_type> ::= "union" <union_switch> "{" <union_body> "}"
| "union" "{" <union_body_n_e> "}"

<union_switch> ::= "switch" "(" <switch_type_spec> \
<Identifier> ")" [ <union_name> ]

<switch_type_spec> ::= <primitive_integer_type>
| <char_type>
| <boolean_type>
| <enumeration_type>

<tagged_union> ::= "union" <tag> <union_switch> "{" <union_body> "}"
| "union" <tag> "{" <union_body_n_e> "}"

<union_name> ::= <Identifier>

<union_body> ::= <union_case> [  <union_case> ] ...

<union_body_n_e> ::=  <union_case_n_e> [ <union_case_n_e> ] ...

<union_case> ::= <union_case_label>  \
[ <union_case_label> ] ... <union_arm> | <default_case>

<union_case_n_e> ::= <union_case_label_n_e> <union_arm>
| <default_case_n_e>

<union_case_label> ::= "case" <const_exp> ":"

<union_case_label_n_e> ::= "[" "case" "(" <const_exp> \
[ , <const_exp>] ...")" "]"

<default_case> ::= "default" ":" <union_arm>

<default_case_n_e> ::= "[" "default" "]" <union_arm>

<union_arm> ::= [ <field_declarator> ] ";"

<union_type_switch_attr> ::= "switch_type" "(" \
```

```
<switch_type_spec> ")"

<union_instance_switch_attr> ::= "switch_is" "(" <attr_var> ")"

<enumeration_type> ::=

<enum_identifier> ::= <identifier> [ "=" <const_exp> ]

<pipe_type> ::= "pipe" <type_spec> <pipe_declarators>

<array_declarator> ::= <identifier> <array_bounds_list>

<array_bounds_list> ::= <array_bounds_declarator>
[ <array_bounds_declarator> ] ...

<array_bounds_declarator> ::= "[" [ <array_bound> ] "]"
| "[" <array_bounds_pair> "]"

<array_bounds_pair> ::= <array_bound> ".." <array_bound>

<array_bound> ::= "*"
| <integer_literal>
| <identifier>

<type_attribute> ::= "transmit_as" "(" <xmit_type> ")"
| "handle"
| <usage_attribute>
| <union_type_switch_attr>
| <ptr_attr>

<usage_attribute> ::= "string"
| "context_handle"

<xmit_type> ::= <simple_type_spec>

<field_attribute> ::= "first_is" "(" <attr_var_list> ")"
| "last_is" "(" <attr_var_list> ")"
| "length_is" "(" <attr_var_list> ")"
| "max_is" "(" <attr_var_list> ")"
| "min_is" "(" <attr_var_list> ")"
```

```
| "size_is" "(" <attr_var_list> ")"
| <usage_attribute>
| <union_instance_switch_attr>
| "ignore"
| <ptr_attr>

<attr_var_list> ::= <attr_var> [ "," <attr_var> ] ...

<attr_var> ::= [ ["*"]<identifier> ]

<ptr_declarator> ::= "*"<identifier>

<ptr_attr> ::= "ref"
| "unique"
| "full"

<op_declarator> ::= [ <operation_attributes> ]
<simple_type_spec> <identifier> <parameter_declarators>

<
operation_attributes> ::=  "[" <operation_attribute> [ "static" ]
[ "," <operation_attribute> ] ... "]"

<
operation_attribute> ::= "idempotent"
| "broadcast"
| "maybe"
| "reflect_deletions"
| <usage_attribute>
| <ptr_attr>

<param_declarators> ::= "(" "void" ")"
| "(" [ <param_declarator> [ "," <param_declarator> ] ... ] ")"

<param_declarator> ::= <param_attributes> <type_spec> <declarator>

<param_attributes> ::=
"[" <param_attribute> [ "," <param_attribute> ] ... "]"

<param_attribute> ::= <directional_attribute>
```

```
| <field_attribute>

<directional_attribute> ::= "in" [ "(" "shape" ")" ]
| "out" [ "(" "shape" ")" ]

<function_ptr_declarator> ::= <simple_type_spec>
"(" "*"<identifier> ")" <param_declarators>

<predefined_type_spec> ::= "error_status_t"
| <international_character_type>

<international_character_type> ::= ISO_LATIN_1
| ISO_MULTI_LINGUAL
| ISO_UCS

<pipe_declarators> ::= <pipe_declarator> \
[ "," <pipe_declarator> ] ...

<pipe_declarator> ::= <simple_declarator>
| <ptr_declarator>
| <ref_declarator>
```

Chapter 19

Attribute Configuration Language

The Attribute Configuration Language is used for writing an Attribute Configuration File (ACF). Use the attributes in the ACF to modify the interaction between the application code and stubs without affecting the client/server network interaction.

19.1 Syntax Notation Conventions

The syntax of the Attribute Configuration Language is similar to the syntax of IDL. For syntax information, see the syntax notation conventions for the IDL.

The use of **[ ]** (brackets) can be either a required part of the syntax or can denote that a string is optional to the syntax. To differentiate this, brackets that are required are shown as [ ] (plain square brackets). Brackets that contain optional strings are shown as *[ ]* (italicized square brackets).

A **|** (vertical bar) denotes a logical OR.

19.2 Attribute Configuration File

The ACF changes the way the IDL compiler interprets the interface definition, written in IDL. The IDL file defines a means of interaction between a client and a server. For new server implementations to be compatible across the network with existing servers, the interaction between the client and server must not be modified. If the interaction between an application and a specific stub needs to change, you must provide an ACF when you build this stub.

The ACF affects only the interaction between the generated stub code and the local application code; it has no effect on the interaction between local and remote stubs. Therefore, client and server writers are likely to have different attribute configuration files that they can modify as desired.

19.2.1 Naming the ACF

To name the ACF, replace the extension of the IDL file (**.idl**) with the extension of the ACF (**.acf**). For example, the ACF associated with *my_idl_filename***.idl** is *my_idl_filename***.acf**.

19.2.2 Compiling the ACF

When you issue the **idl** command, naming the IDL file to compile, it searches for a corresponding ACF and compiles it along with the IDL file. The compiler also searches for any ACF (there can be more than one) associated with any imported IDL files. The stubs that the compiler creates contain the appropriate modifications.

19.2.3 ACF Features

The following list contains the ACF attributes and the features associated with the attributes:

- **include** statement: Includes header files in the generated code

- **auto_handle**, **explicit_handle**, **implicit_handle**, **binding_callout**: Controls binding
- **comm_status**, **fault_status**: Indicates parameters to hold status conditions occurring in the call
- **cs_char**, **cs_tag_rtn**, **cs_stag**, **cs_drtag**, **cs_rtag**: Controls the transmission of international (non-PCS) characters
- **code**, **nocode**: Controls which operations of the IDL file are compiled
- **encode**, **decode**: Controls the generation of IDL encoding services stubs to perform encoding or decoding operations
- **extern_exceptions**: Indicates user-defined parameters to hold status conditions occurring in the call
- **represent_as**: Controls conversion between local and network data types
- **enable_allocate**: Forces the initialization of the memory management routines
- **heap**: Specifies objects to be allocated from heap memory
- **cxx_lookup, cxx_delegate, cxx_new, cxx_static**: Specifies C++ features

19.3 Structure

The structure of the ACF is as follows:

interface_header
{
interface_body
}

Follow these structural rules when creating an ACF:

- The basename of the ACF must be the same as the basename of the IDL file although the extensions are different.
- The interface name in the ACF must be the same as the interface name in the corresponding IDL file.

- With a few exceptions, any type, parameter, or operation names in the ACF must be declared in the IDL file, or defined in files included by use of the **include** statement, as the same class of name.
- Except for additional status parameters, any parameter name that occurs within an operation in the ACF must also occur within that operation in the IDL file.

19.3.1 ACF Interface Header

The ACF interface header has the following structure:

*[***[***acf_attribute_list***]***]* **interface** *idl_interface_name*

The *acf_attribute_list* is optional. The interface header attributes can include one or more of the following attributes, entered within brackets. If you use more than one attribute, separate them with commas and include the list within a single pair of brackets. (Note that some of these attributes can be used in the ACF body also. See Section 19.3.2 for more information.)

- **code**
- **nocode**
- **implicit_handle(***handle_type handle_name* **)**
- **auto_handle**
- **explicit_handle**
- **encode**
- **decode**
- **binding_callout(***routine_name* **)**
- **extern_exceptions(***exception_name[***,***exception_name]...* **)**
- **cs_tag_rtn(***tag_set_routine* **)**
- **cxx_lookup**(*function_name*)
- **cxx_delegate**(*class_name*)

The following example shows how to use more than one attribute in the ACF interface header:

```
[auto_handle, binding_callout(rpc_ss_bind_authn_client)] \
  interface phone_direct
{
}
```

19.3.2 ACF Interface Body

The ACF interface body can contain the elements in the following list. Note that some of the attributes listed here can also be used in the ACF header, as described in Section 19.3.1. If you use more than one attribute, separate them with commas and include the list within a single pair of brackets.

- An **include** statement
- A declared type

  typedef *[***[represent_as** **(***local_type_name***)]** | **[heap]** |
  [cs_char **(***local_type_name***)]***] type_name***;**

- An operation

  *[***[explicit_handle]** | **[comm_status]** | **[fault_status]** |
  [code] | **[nocode]** | **[enable_allocate]** |
  [cxx_new(*manager_class***)]** | **[cxx_static]** | **[cxx_static(***local_function***)]** |
  [encode] | **[decode]** | **[cs_tag_rtn** **(***tag_set_routine***)]***]*
  operation_name **(***[parameter_list]***);**

  A *parameter_list* is a list of zero or more parameter names as they appear in the corresponding operation definition of the IDL file. You do not need to use all the parameter names that occur in the IDL operation definition; use only those to which you attach an ACF attribute. If you use more than one parameter name, the names must be separated by commas.

- A parameter within an operation

*[***[comm_status]** | **[fault_status]** | **[heap]** |
[cs_stag] | **[cs_drtag]** | **[cs_rtag]***]* *parameter_name*

19.3.3 The include Statement and the C++ Attributes cstub and sstub

The **include** statement specifies any additional header files you want included in the generated stub code. You can specify more than one header file. The **include** statement is placed in the body of the ACF and has the following syntax:

include "*filename***"** *[***,"***filename***"***]* **...;**

[**[sstub | cstub | sstub, cstub]***]* **include "***filename***";**

Do not specify the directory name or file extension when you use the **include** statement. The compiler appends the **.h** extension. If you want to specify the directory name(s), use the **-cc_opt** or **-I** IDL compiler command options.

Use the **include** statement whenever you use the **represent_as, implicit_handle, cs_char, cxx_static, cxx_new, cxx_lookup**, or **cxx_delegate** attributes and the specified type is not defined or imported in the IDL file.

The **sstub** and **cstub** attributes are optional. By default, the IDL compiler places directives only in the **idl**-generated header file when neither the **sstub** nor **cstub** attributes are used. These attributes restrict where **#include** compiler directives are placed in order to include application-specific header files in C++ client and server stub files. In C++ applications, local and remote versions of operations are included together by linking in both the client and server stubs. C++ applications need to control **#include** compiler directives so that the operations for local objects can be easily renamed to avoid name conflicts with the operations for remote objects.

The following table shows to which output file the IDL compiler places the **#include** compiler directive for the application-specific file. Note, that the idl-generated header file is always included automatically in each stub.

ACF Statement	Header File	Client Stub	Server Stub
include "*file*";	**X**		
[cstub] include "*file*";		**X**	
[sstub] include "*file*";			X
[cstub, sstub] include " *file*";		**X**	X

19.3.4 The auto_handle Attribute

This attribute causes the client stub and RPC runtime to manage the binding to the server by using a directory service. Any operation in the interface that has no parameter containing binding information is bound automatically to a server so the client does not have to specify a binding to a server.

When an operation is automatically bound, the client does not have to specify the server on which an operation executes. If you make a call on an operation without explicit binding information in an interface for which you have specified **auto_handle**, and no client/server binding currently exists, the client stub selects an available server and establishes a binding. This binding is used for this call and subsequent calls to all operations in the interface that do not include explicit binding information, while the server is still available.

When a client uses the automatic binding method, DCE must use the name service to obtain binding information. However, the client host must have a starting entry from which to begin the namespace search. If the **RPC_DEFAULT_ENTRY** environment variable is defined on the client host, DCE uses the entry in that variable to obtain binding information. If **RPC_DEFAULT_ENTRY** is not defined, DCE looks for binding information from the host's name service profile.

Server termination, network failure, or other problems can cause a break in binding. If this occurs during the execution of an automatically bound operation, the client stub issues the call to another server, provided one is available and the operation is idempotent, or it determines that the call did not start to run on the server. Similarly,

if a communications or server failure occurs between calls, the client stub binds to another server for the next call, if a server is available.

If the client stub is unable to find a server to run the operation, it reports this by returning the status code **rpc_s_no_more_bindings** in the **comm_status** parameter, or by raising the exception **rpc_x_no_more_bindings** if the operation does not use the **comm_status** attribute for error reporting. Note that, if a binding breaks, the search for another server begins at the directory service entry following the one where the binding broke. This means that, even if a server earlier in the list becomes available, it is not treated as a candidate for binding. After the RPC runtime tries each server in the list, it reinitializes the list of server candidates and tries again. If the second attempt is unsuccessful, the RPC runtime reports the status code **rpc_s_no_more_bindings**. The next call on an operation in the interface starts from the top of the list when looking for a server to bind to.

The **auto_handle** attribute can occur at most once in the ACF.

If an interface uses the **auto_handle** attribute, the presence of a binding handle or context handle parameter in an operation overrides **auto_handle** for that operation.

The **auto_handle** attribute declaration has the following syntax. (See the example at the end of this section.)

[auto_handle] interface *interface_name*

You cannot use **auto_handle** if you use **implicit_handle** or if you use **explicit_handle** in the interface header. You also cannot use **auto_handle** if you use the **encode** or **decode** ACF attributes.

Example Using the auto_handle Attribute

ACF

```
[auto_handle] interface math_1
{
}
```

IDL File

```
[uuid(b3c86900-2d27-11c9-ab09-08002b0ecef1)]
interface math_1
{
/* This operation has no handle parameter,
 * therefore, uses automatic binding.
 */
long add([in] long a,
         [in] long b);

/*
 * This operation has an explicit handle parameter, h,
 * that overrides the [auto_handle] ACF attribute.
 * Explicit handles also override [implicit_handle].
 */
long subtract ([in] handle_t h,
               [in] long a,
               [in] long b);
}
```

19.3.5 The explicit_handle Attribute

This attribute allows the application program to manage the binding to the server. The **explicit_handle** attribute indicates that a binding handle is passed to the runtime as an operation parameter.

The **explicit_handle** attribute has the following syntax. (See the example at the end of this section.)

For an interface:

[explicit_handle] interface *interface_name*

For an operation:

[explicit_handle] *operation_name* **(***[parameter_list]***);**

When used as an ACF interface attribute, the **explicit_handle** attribute applies to all operations in the IDL file. When used as an ACF operation attribute, this attribute applies to only the operation you specify.

If you use the **explicit_handle** attribute as an ACF interface attribute, you must not use the **auto_handle** or **implicit_handle** attributes. Also, you cannot use the **encode** and **decode** attributes if you use **explicit_handle**.

Using the **explicit_handle** attribute on an interface or operation has no effect on operations in IDL that have explicit binding information in their parameter lists.

Example Using the explicit_handle Attribute

ACF

```
[explicit_handle] interface math_2
{

  /* This causes the operation, as called by the client, to
   * have the parameter handle_t IDL_handle, at the start of
   * the parameter list, before the parameters specified here
   * in the IDL file.
   */
}
```

IDL File

```
[uuid(41ce5b80-0ba7-11ca-87ba-08002b111685)]
interface math_2
{
long add([in] long a,
         [in] long b);
}
```

19.3.6 The implicit_handle Attribute

This attribute allows the application program to manage the binding to the server. You specify the data type and name of the handle variable as part of the **implicit_handle** attribute. The **implicit_handle** attribute informs the compiler of the name and type of the global variable through which the binding handle is implicitly passed to the client stub. A variable of this type and name is defined in the client stub code, and the application initializes the variable before making a call to this interface.

The **implicit_handle** attribute declaration has the following syntax. (See the example at the end of this section.)

For an interface:

[implicit_handle (*handle_type handle_name***)] interface** *interface_name*

If an interface uses the **implicit_handle** attribute, the presence of a binding handle or **in** or **in,out** context handle parameter in an operation overrides the implicit handle for that operation.

The **implicit_handle** attribute can occur at most once in the ACF.

You cannot use the **implicit_handle** attribute if you are using the **auto_handle** attribute or the **explicit_handle** attribute as an interface attribute. You also cannot use **implicit_handle** if you use the **encode** or **decode** ACF attributes.

If the type in the **implicit_handle** clause is not **handle_t**, then it is treated as if it has the **handle** attribute.

The ACF in the following example modifies the **math_3** interface to use an implicit handle.

Example Using the implicit_handle Attribute

ACF

```
[implicit_handle(user_handle_t global_handle)] interface math_3
{
/*
 * Since user_handle_t is not a type defined in IDL, you
 * must specify an header file that contains the definition
 */
include "user_handle_t_def";
}
```

IDL File

```
[uuid(a01d0280-2d27-11c9-9fd3-08002b0ecef1)]
interface math_3
{
long add([in] long a,
         [in] long b);
}
```

19.3.7 The client_memory Attribute

While marshalling parameters, the client stub uses built-in routines to manage memory. You can use the **client_memory** attribute to specify different memory allocation and free routines. The **client_memory** attribute has the following syntax in the ACF header:

[client_memory(*malloc_routine, free_routine***)] interface** *idl _interface_name*

The routines you specify must have the same respective procedure declarations as the system's **malloc()** and **free()** routines.

Applications need to manage memory consistently, so if your application needs to do other memory allocation, be sure to use the same routines you specified with the **client_memory** attribute.

You can use the **client_memory** attribute in conjunction with RPC stub support API routines such as **rpc_sm_set_client_alloc_free()** and **rpc_sm_swap_client_alloc_free**().

19.3.8 The comm_status and fault_status Attributes

The **comm_status** and **fault_status** attributes cause the status code of any communications failure or server runtime failure that occurs in a remote procedure call to be stored in a parameter or returned as an operation result, instead of being raised to the client application code as an exception.

The **comm_status** attribute causes communications failures to be reported through a specified parameter. The **fault_status** attribute causes server failures to be reported through a specified parameter. Applying both attributes causes all remote and communications failures to be reported through status. Any local exception caused by an error during marshalling, correctness checking performed by the client stubs, or an error in application routines continues to be returned as an exception.

The **comm_status** and **fault_status** attributes have the following syntax. (See the examples at the end of this section.)

For an operation:

[comm_status | fault_status] *operation_name* **(***[parameter_list]***);**

For a parameter:

operation_name **([comm_status | fault_status]** *parameter_name***);**

Note: You can apply one of each attribute to the same operation and/or parameter at the same time. Separate the attributes with a comma. (See the example at the end of this section.)

If the parameter named in a **comm_status** or **fault_status** attribute is in the parameter list for the operation in the IDL file, then it must have the **out**

attribute in the IDL file. (Additional ACF parameters do not have **in** and **out** directional attributes.)

If the status attribute occurs on the operation, the returned value result must be defined as type **error_status_t** in the IDL file. If an error occurs during execution of the operation, the error code is returned as the operation result. If the operation completes successfully, the value returned to the client is the value returned by the manager code.

Note: The **error_status_t** type is equivalent to **unsigned32**, which is the data type used by the RPC runtime for an error status. The status code **error_status_ok** is equivalent to **rpc_s_ok**, which is the RPC runtime success status code.

If the status attribute occurs on a parameter, the parameter name does not have to be defined in the IDL file, although it can be. Note the following:

- If the parameter name is one used in the IDL file, then that parameter must be an output parameter of type **error_status_t**. If the operation completes successfully, the value of this parameter is the value returned by the manager code.
- If the parameter name is different from any name defined within the operation definition in the IDL file, the IDL compiler creates an extra output parameter of type **error_status_t** in the application code after the last parameter defined in the IDL file. In a successfully completed remote call, this extra parameter has the value **error_status_ok**.

In either case, if an error occurs during the remote call, the error code is returned to the parameter that has the status attribute. (See the *DCE 1.2.2 Problem Determination Guide* for an explanation of status codes.)

If you define both additional **comm_status** and additional **fault_status** parameters, they are automatically added at the end of the procedure declaration in the order of specification in the ACF.

In the following example, there are three possible uses of the status attributes: as the operation result of **add**, as a parameter of**subtract** as defined in the IDL file, and as an additional parameter of **multiply**.

Example Using the comm_status and fault_status Attributes

ACF

```
[auto_handle] interface math_4
{
[comm_status,fault_status] add();

subtract ([comm_status,fault_status] s);

/*
 * 'sts' is not a parameter in the interface definition of
 * operation 'multiply'. This specifies that the application
 * wants a trailing parameter 'sts' that is of type
 * error_status_t, after the parameters a and b.
 */
multiply ([comm_status] c_sts,[fault_status] f_sts);
}
```

IDL File

```
[uuid(91365000-2d28-11c9-ad5a-08002b0ecef1)]
interface math_4
{
error_status_t add ([in] double a,
                    [in] double b,
                    [out] double *c);
double subtract ([in] double a,
                [in] double b,
                [out] error_status_t *s);
double multiply ([in] double a,
                 [in] double b);
}
```

server.c

```
/*
 * The three server procedures below illustrate the different
 * models of comm_status and fault_status appearing in the
 * idl and acf declarations above.
 *
```

```
 * RPC automatically passes back DCE error codes through
 * comm_status and fault_status.  These examples differ in
 * their handling of the nonerror case.
 */

error_status_t add (double a,
                    double b,
                    double * c)
{
    ...
    *c = answer;

    /*
     * comm_status and fault_status are operation attributes.
     * If no error occurs, the client will see the value that
     * the server returns.
     *
     * We return error_status_ok here for the normal
     * successful case.
     */

    return error_status_ok;
}

double subtract (double a,
                 double b,
                 error_status_t * s)
{
    /*
     * "s" appears in both the idl definition and the acf
     * specification.
     *
     * In the successful case, the client is returned the
     * value that the server puts in *s.  Therefore, assume
     * success here.
     */

    *s = error_status_ok;

    ...
```

```
    return answer;
}

double multiply (double a,
                 double b,
                 error_status_t * c_sts,
          error_status_t * f_sts)
{
    /*
     * c_sts and f_sts appear in the acf, but do not appear
     * in the idl definition.  In this case, c_sts and f_sts
     * are placed at the end of the parameter list generated
     * by the idl compiler.  To conform to the prototype
     * generated by idl, your server code must also declare
     * these parameters.
     *
     * In the successful case, c_sts and f_sts are
     * automatically returned to the client as
     * error_status_ok.  Even though c_sts and f_sts are
     * parameters to the function, the server code must not
     * modify these parameters or store through them.
     */

    ...
    return answer;
}
```

19.3.9 The code and nocode Attributes

The **code** and **nocode** attributes allow you to control which operations in the IDL file have client stub code generated for them by the compiler. These attributes affect only the generation of a client stub; they have no effect when generating the server stub.

The **code** and **nocode** attributes have the following syntax. (See the example at the end of this section.)

For an interface:

[code | nocode] interface *interface_name*

For an operation:

[code | nocode] *operation_name* **(***[parameter_list]***);**

When you specify **nocode** as an attribute on an ACF interface, stub code is not generated for the operations in the corresponding IDL interface unless you also specify **code** for the particular operation(s) for which you want stub code generated. Similarly, when you specify **code** (the default) as an attribute on an ACF interface, stub code is generated for the operations in the corresponding IDL interface unless you also specify **nocode** for the particular operations for which you do not want stub code generated.

Do *not* use **nocode** on any of the operations if the compiler is generating only server stub code because it has no effect. Server stubs must always contain generated code for all operations.

In the following example, the IDL compiler generates client stub code for the operations **open**, **read**, and **close**, but not for the operation **write**. An alternative method for specifying the same behavior is to use **[nocode] write()** in the ACF.

Example Using the code and nocode Attributes

ACF

```
[nocode,auto_handle] interface open_read_close
{
[code] open();
[code] read();
[code] close();
}
```

IDL File

```
[uuid(2166d580-0c69-11ca-811d-08002b111685)]
interface open_read_close
{
void open (...);
void read (...);
void write (...);
void close (...);
}
```

19.3.10 The represent_as Attribute

This attribute associates a local data type that your application code uses with a data type defined in the IDL file. Use of the **represent_as** attribute means that, during marshalling and unmarshalling, conversions occur between the data type used by the application code and the data type specified in the IDL.

The **represent_as** attribute has the following syntax. (See the example at the end of this section.)

typedef [represent_as (*local_type_name***)]** *net_type_name***;**

The *local_type_name* is the local data type that the application code uses. You can define it in the IDL file or in an application header file. If you do not define it in the IDL file, use the **include** statement in the ACF to make its definition available to the stubs.

The *net_type_name* is the data type that is defined in the IDL file.

The **represent_as** attribute can appear at most once in a **typedef** declaration in an ACF.

If you use the **represent_as** attribute, you must write routines that perform the conversions between the local and network types, and routines that release the memory storage used to hold the converted data. The conversion routines are part of your application code.

The suffix for the routine names, the function of each, and where they are used (client or server) appear in the following list:

- **_from_local()**: Allocates storage instance of the network type and converts from the local type to the network type (used for client and server).
- **_to_local()**: Converts from the network type to the local type (used for client and server).
- **_free_inst()**: Frees storage instance used for the network type (used by client and server).
- **_free_local()**: Frees storage used by the server for the local type (used in server). This routine frees any object pointed to by its argument but does not attempt to free the argument itself.

Suppose that the **represent_as** attribute is applied to either the type of a parameter or to a component of a parameter and that the parameter has the **out** or **in,out** attribute. Then, the **_free_local()** routine will be called automatically for the data item that has the type to which the **represent_as** attribute was applied.

Suppose that the **represent_as** attribute is applied to the type of a parameter and that the parameter has only the **in** attribute. Then, the **_free_local()** routine will be called automatically.

Finally, suppose that the **represent_as** attribute is applied to the type of a component of a parameter and that the parameter has only the **in** attribute. Then, the **_free_local()** routine will not be called automatically for the component; the manager application code must release any resources that the component uses, possibly by explicitly calling the **_free_local()** routine.

Append the suffix of the routine name to the *net_type_name*. The syntax for these routines is as follows:

void *net_type_name*_**from_local (**
(*local_type_name* ***),**
(*net_type_name* ****))**

void *net_type_name*_**to_local** (
 (*net_type_name* ***),**
 (*local_type_name* ***))**

void *net_type_name*_**free_inst** ((*net_type_name* ***))**

void *net_type_name*_**free_local** ((*local_type_name* ***))**

Example Using the represent_as Attribute

ACF

```
[auto_handle] interface phonedir
{
/*
 * You must specify an included file that contains the
 * definition of my_dir_t.
 */
include "user_types";

/*
 * The application code wants to pass data type my_dir_t
 * rather than dir_t.  The [represent_as] clause allows
 * this, and you must supply routines to convert dir_t
 * to/from my_dir_t.
 */
typedef [represent_as(my_dir_t)] dir_t;
}
```

IDL File

```
[uuid(06a12100-2d26-11c9-aa24-08002b0ecef1)]
interface phonedir
{
```

```
typedef struct
    {
    short int  area_code;
    long int   phone_num;
    char       last_name[20];
    char       first_name[15];
    char       city[20];
    } dir_t;
void add ([in] dir_t *info);
void lookup ([in] char city[20],
             [in] char last_name[20],
             [in] char first_name[15],
             [out] dir_t *info);
void delete ([in] dir_t *info);
}
```

19.3.11 The enable_allocate Attribute

The **enable_allocate** attribute on an operation causes the server stub to initialize the **rpc_ss_allocate()** routine. The **rpc_ss_allocate()** routine requires initialization of its environment before it can be called. The server stub automatically initializes (enables) **rpc_ss_allocate()** if the operation uses either full pointers or a type with the **represent_as** attribute. If the operation does not meet either of these conditions, but the manager application code needs to make use of the **rpc_ss_allocate()** and **rpc_ss_free()** routines, then use the **enable_allocate** attribute to force the stub code to enable.

The **enable_allocate** attribute has the following syntax.

For an operation:

[enable_allocate] *operation_name* **(***[parameter_list]***);**

Example Using the enable_allocate Attribute

ACF

```
[auto_handle] interface phonedir
{
[enable_allocate] lookup ();
}
```

IDL File

```
[uuid(06a12100-2d26-11c9-aa24-08002b0ecef1)]
interface phonedir
{
typedef struct
    {
    short int  area_code;
    long int   phone_num;
    char       last_name[20];
    char       first_name[15];
    char       city[20];
    } dir_t;
void add ([in] dir_t *info);
void lookup ([in] char city[20],
             [in] char last_name[20],
             [in] char first_name[15],
             [out] dir_t *info);
void delete ([in] dir_t *info);
}
```

19.3.12 The heap Attribute

This attribute specifies that the server stub's copy of a parameter or of all parameters of a specified type is allocated in heap memory rather than on the stack.

The **heap** attribute has the following syntax. (See the example at the end of this section.)

For a type:

typedef [heap] *type_name***;**

For a parameter:

operation_name **([heap]** *parameter_name***);**

Any identifier occurring as a parameter name within an operation declaration in the ACF must also be a parameter name within the corresponding operation declaration in IDL.

The **heap** attribute is ignored for pipes, context handles, and scalars.

Example Using the heap Attribute

ACF

```
[auto_handle] interface galaxies
{
typedef [heap] big_array;
}
```

IDL File

```
[uuid(e61de280-0d0b-11ca-6145-08002b111685)]
interface galaxies
{
typedef long big_array[1000];
}
```

19.3.13 The extern_exceptions Attribute

By default, the IDL compiler declares and initializes all exceptions listed in an **exceptions** interface attribute in the stub code that it generates. You can use the **extern_exceptions** attribute to override this behavior; the **extern_exceptions** attribute

allows you to specify one or more exceptions listed in the exceptions interface attribute that you do not want the idl-generated stub code to declare. If the **extern_exceptions** attribute appears with no list, it has the same effect as if all IDL-defined exceptions were specified in the list.

The **extern_exceptions** attribute has the following syntax. (See the example at the end of this section.)

[extern_exceptions (*exception_name [***,***exception_name]***...)]**
interface *interface_name*

The **extern_exceptions** attribute indicates that the specified exceptions are defined and initialized in some other external manner before calling the **extern_exceptions** attribute. They may be predefined exceptions (such as **exc_e_exquota**) that were provided by another interface, or exceptions that are defined and initialized explicitly by the application itself.

Example Using the extern_exceptions Attribute

In the following example, the exception named in the list in the **extern_exceptions** attribute in the ACF is not defined or initialized in the idl-generated stub code. All of the other exceptions listed in the **exceptions** interface attribute are defined and initialized in the generated stub.

ACF

```
[extern_exceptions(exc_e_exquota)] interface binop {}
/*
 *The exc_e_exquota exception is a predefined exception
 *(provided in exc_handling.h) and so does not need
 *to be declared and initialized in the idl-generated stub.
 */
```

IDL File

```
[uuid(06255501-08af-11cb-8c4f-08002b13d56d),
version (1.1),
  exceptions (
      exc_e_exquota,
      binop_e_aborted,
      binop_e_too_busy,
      binop_e_shutdown)
] interface binop
  {
      long binop_add(
           [in] long a,
           [in] long b
           );
   }
```

19.3.14 The encode and decode Attributes

The **encode** and **decode** attributes are used in conjunction with IDL encoding services routines (**idl_es** *) to enable RPC applications to encode data types in input parameters into a byte stream and decode data types in output parameters from a byte stream without invoking the RPC runtime. Encoding and decoding operations are analogous to marshalling and unmarshalling, except that the data is stored locally and is not transmitted over the network.

The stubs that perform encoding or decoding operations are different from the stubs that perform RPC operations. The ACF attributes **encode** and **decode** direct the IDL compiler to generate encoding or decoding stubs for operations defined in a corresponding IDL interface rather than generating RPC stubs for those operations.

The **encode** and **decode** attributes have the following syntax. (See the example at the end of this section.)

For an interface:

[encode] | [decode] | [encode,decode] interface *interface_name*

For an operation:

[encode] | [decode] | [encode,decode] *operation_name* **(***[parameter_list]***);**

When used as an ACF interface attribute, the **encode** and **decode** attributes apply to all operations defined in the corresponding IDL file. When used as an ACF operation attribute, **encode** and **decode** apply only to the operation you specify. If you apply the **encode** or **decode** attribute to an ACF interface or operation, you must not use the **auto_handle** or the **implicit_handle** ACF attributes.

When you apply the **encode** or **decode** attribute to an operation, the IDL compiler generates IDL encoding services stubs that support encoding or decoding, depending on the attribute used, in the client stub code; it does not generate stub code for the operation in the server stub. To generate an IDL encoding services stub that supports both encoding and decoding, apply both attributes to the operation.

If you apply the **encode** or **decode** attribute to all of the operations in an interface, no server stub is generated. If you apply the **encode** and **decode** attributes to some, but not all, of the operations in an interface, the stubs for the operations that do not have the **encode** and **decode** attributes applied to them are generated as RPC stubs into the server stub module.

When data encoding takes place, only the operation's **in** parameters provide data for the encoding. When data decoding takes place, the decoded data is delivered only to the operation's **out** parameters.

If data is being both encoded and decoded, you generally declare all of the operation's parameters to be **in**,**out**. However, you can encode data by using the **in** parameters of one operation, and decode it by using the **out** parameters of another operation if the types and order of the **in** and **out** parameters are the same. For equivalence, the IDL encoding services treat a function result as an **out** parameter that appears after all other **out** parameters.

In the following example, the IDL compiler generates IDL encoding services stub code for the **in_array_op1**, **out_array_op1** , and **array_op2** operations, but not for the **array_op3** operation. The stub code generated for the **in_array_op1** operation supports encoding, the stub code generated for the **out_array_op1** operation supports decoding, and the stub code generated for the **array_op2** operation supports both encoding and decoding. The stub code generated for the **array_op3** is an RPC client stub. For further information on using the IDL encoding services, see Chapter 18 of this guide and the reference pages for the **idl_es_*(3rpc)** routines.

Example Using the encode and decode Attributes

ACF

```
interface es_array
{
    [encode] in_array_op1();
    [decode] out_array_op1();
    [encode, decode] array_op2();
}
```

IDL File

```
[uuid(20aac780-5398-11c9-b996-08002b13d56d), version(0)]
interface es_array
{
    void in_array_op1([in] handle_t h, [in] long arr[100]);
    void out_array_op1([in] handle_t h, [out] long arr[100]);
    void array_op2([in] handle_t h, [in,out] long big[100]);
    void array_op3([in] handle_t h, [in,out] long big[100]);
}
```

19.3.15 The cs_char Attribute

The **cs_char** attribute is intended for use in internationalized RPC applications. It is used in conjunction with the **cs_stag**, **cs_drtag**, **cs_rtag** and **cs_tag_rtn** attributes and the DCE RPC routines for automatic code set conversion to provide RPC applications with a mechanism for ensuring character and code set interoperability between clients and servers transferring international (non-PCS) characters.

The **cs_char** attribute is very similar in function to the **represent_as** attribute, in that it associates a local data type that your application code uses with a data type defined in the IDL file. The **cs_char** attribute permits the application code to use the local data type for international character data and converts between the local data type and the format specified in the IDL file when transferring international characters over the

network. The **cs_char** ACF attribute permits the conversion of characters, arrays of characters, and strings of characters between the format in which the application code requires them and the format in which they are transmitted over the network.

As with **represent_as**, use of the **cs_char** attribute means that, during marshalling and unmarshalling, conversions occur between the data type that the application code is using and the data type specified in IDL. In the case of **cs_char**, the local data type is automatically converted between the local data type in the local code set encoding and the **idl_byte** data type in the *network* code set encoding. The network code set is the code set encoding that the application code, through the use of the DCE RPC automatic code set conversion routines, has selected to use when transmitting the international characters over the network.

The **cs_char** attribute differs from the **[transmit_as]** attribute in that it does not affect the network contract between the client and server. It differs from the **[represent_as]** attribute in that multiple data items (for example, the characters of an array or string) can be converted with a single stub call to user-written conversion code, and that the conversion can modify array size and data limit information between what is transmitted over the network and what is used by application code.

The **cs_char** attribute has the following syntax. (See the examples at the end of this section.)

typedef [cs_char (*local_type_name***)]** *net_type_name***;**

The *local_type_name* is the local data type that the application code uses. You can define it in the IDL file or in an application header file. If you do not define it in the IDL file, use the **include** statement in the ACF to make its definition available to the stubs.

The *net_type_name* is the data type that is defined in the IDL file. When used with the **cs_char** attribute, this data type is always **byte** in the IDL file.

If you use the **cs_char** attribute, you must write the following stub support routines for each local type that you define:

- Routines that check the buffer storage requirements for international character data to be converted to determine whether or not more buffer space needs to be allocated to hold the converted data

- Routines to perform conversion between local and network code sets

The suffix for the routine names, the function of each, and where they are used (client or server) appear in the following list:

- *local_type_name*_**net_size()**: Calculates the necessary buffer size for code set conversion from a local code set to a network code set. Client and server stubs call this routine before they marshall any international character data.
- *local_type_name*_**local_size()**: Calculates the necessary buffer size for code set conversion from a network code set to a local code set. Client and server stubs call this routine before they unmarshall any international character data.
- *local_type_name*_**to_netcs()** : Converts international character data from a local code set to a network code set. Client and server stubs call this routine before they marshall any international character data.
- *local_type_name*_**from_netcs()** : Converts international character data from a network code set to a local code set. Client and server stubs call this routine before they unmarshall any international character data.

You specify the name for the local data type in the *local_type_name* portion of the function name. The name that you specify cannot exceed 20 characters because the entire generated name must not exceed the 31-character limit for C identifiers.

For each piece of international character data being marshalled, the **_net_size** and **_to_netcs** routines are called once each. For each piece of international character data being unmarshalled, the **_local_size** and **_from_netcs** routines are called once each.

DCE RPC provides buffer sizing and code set conversion routines for the **cs_byte** and **wchar_t** data types (the **cs_byte** type is equivalent to the **byte** type). If they meet the needs of your application, you can use these RPC routines (**cs_byte_** * and **wchar_t_***) instead of providing your own routines.

If you do provide your own routines for buffer sizing and code set conversion, they must follow a specific signature. See the reference pages for the **cs_byte_*(3rpc)** and **wchar_t_*(3rpc)** routines for a complete description of the required signatures for these routines.

When international character data is to be unmarshalled, a stub needs to have received a description of the code set being used before it receives the data. For this reason,

the **cs_char** attribute cannot be applied to the base type of a pipe or to a type used in constructing the base type of a pipe.

The **cs_char** attribute also cannot be applied to a type if there is an array that has this type as a base type and the array has more than one dimension, or if the attributes **min_is**, **max_is**, **first_is**, **last_is**, or **string** have been applied to the array. As a result, all instances of the type to which **cs_char** has been applied must be scalars or one-dimensional arrays. Only the **length_is** and/or **size_is** attributes can be applied to these arrays.

The following restrictions apply to the use of variables that appear in array attributes:

- Any parameter that is referenced by a **size_is** or **length_is** attribute of an array parameter whose base type has the **cs_char** attribute cannot be referenced by any attribute of an array parameter whose base type does not have the **cs_char** attribute.
- Any structure field that is referenced by a **size_is** or **length_is** attribute of an array field whose base type has the **cs_char** attribute cannot be referenced by any attribute of an array field whose base type does not have the **cs_char** attribute.

The **cs_char** attribute cannot interact with the **transmit_as** or **represent_as** attributes. This restriction imposes the following rules:

- The **cs_char** attribute cannot be applied to a type that has the **transmit_as** attribute, nor can it be applied to a type in whose definition a type with the **transmit_as** attribute is used.
- The **cs_char** attribute cannot be applied to a type that has the **represent_as** attribute, nor can it be applied to a type in whose definition a type with the **represent_as** attribute is used.
- The **cs_char** attribute cannot be applied to the transmitted type specified in a **transmit_as** attribute or to any type used in defining such a transmitted type.

The **cs_char** attribute cannot be applied to any type that is the type of the referent of a pointer that has a **max_is** or **size_is** attribute applied to it. It also cannot be applied to the base type of an array parameter that has the **unique** or **ptr** attribute applied to it.

An application that uses the **cs_char** ACF attribute cannot use the IDL encoding services **encode** and **decode** ACF attributes.

Examples Using the cs_char Attribute

Arrays of **cs_char** can be fixed, varying, conformant, or conformant varying. The treatment of a scalar **cs_char** is similar to that of a fixed array of one element. The following examples show the relationship between IDL declarations and declarations in the generated header file when the **cs_char** attribute has been applied. The examples assume that the ACF contains the type definition:

```
typedef [cs_char(ltype)] my_byte;
```

For a fixed array, if the IDL file contains

```
typedef struct {
    my_byte fixed_array[80];
} fixed_struct;
```

the declaration generated in the header file is

```
typedef struct {
    ltype fixed_array[80];
} fixed_struct;
```

The number of array elements in the local and network representations of the data must be the same as the array size stated in the IDL.

For a varying array, if the IDL file contains

```
typedef struct {
    long l;
    [length_is(l)] my_byte varying_array[80];
} varying_struct;
```

the declaration generated in the header file is

```
typedef struct {
    idl_long_int l;
    ltype varying_array[80];
} varying_struct;
```

Neither the number of array elements in the local representation nor the number of array elements in the network representation may exceed the array size in the IDL.

For a conformant array, if the IDL file contains

```
typedef struct {
    long s;
    [size_is(s)] my_byte conf_array[];
} conf_struct;
```

the declaration generated in the header file is

```
typedef struct {
    idl_long_int s;
    ltype conf_array[1];
} conf_struct;
```

The number of array elements in the local representation and the number of array elements in the network representation need not be the same. The conversions between these numbers are done in the user-provided **_net_size** and **_local_size** routines.

For a conformant varying array, if the IDL file contains

```
typedef struct {
    long s;
    long l;
    [size_is(s), length_is(l)] my_byte open_array[];
} open_struct;
```

the declaration generated in the header file is

```
typedef struct {
    idl_long_int s;
    idl_long_int l;
    ltype open_array[1];
} open_struct;
```

The maximum number of array elements in the local representation and the maximum number of array elements in the network representation need not be the same. The conversions between these numbers are done in the user-provided **_net_size** and **_local_size** routines.

For fixed or varying arrays, the size of the storage available to hold the local data is determined by the array size specified in IDL and the local type specified in the **cs_char** attribute. For conformant or conformant varying arrays, you must determine the transformations between local storage size and network storage size without reference to the characters being transmitted or received. Where a variable-width character set is in use, this means making the most conservative assumption about the size of the data.

19.3.16 The cs_stag, cs_drtag, and cs_rtag Attributes

The **cs_stag**, **cs_drtag**, and **cs_rtag** attributes are used in conjunction with the **cs_char** and (optionally) the **cs_tag_rtn** attributes and DCE RPC routines for automatic code set conversion to provide internationalized RPC applications with a mechanism to ensure character and code set interoperability between clients and servers handling international character data.

The **cs_stag**, **cs_drtag**, and **cs_rtag** attributes are parameter ACF attributes that correspond to the sending tag, desired receiving tag, and receiving tag parameters defined in operations in the IDL file that handle international character data. These operation parameters *tag* international characters being passed in the operation's input and output parameters with code set identifying information. The **cs_stag**, **cs_drtag**, and **cs_rtag** ACF parameter attributes declare the tag parameters in the corresponding operation definition to be special code set parameters.

The **cs_stag** attribute has the following syntax:

operation_name (**[cs_stag]** *parameter_name*)**;**

The **cs_stag** attribute identifies the code set used when the client sends international characters to the server. Operations defined in the IDL file that specify international characters in **in** parameters must use the **cs_stag** attribute in the associated ACF.

The **cs_drtag** attribute has the following syntax:

operation_name (**[cs_drtag]** *parameter_name*)**;**

The **cs_drtag** attribute identifies the code set the client would like the server to use when returning international characters.

The **cs_rtag** attribute has the following syntax:

operation_name (**[cs_rtag]** *parameter_name*)**;**

The **cs_rtag** attribute identifies the code set that is actually used when the server sends international characters to the client. Operations defined in the IDL file that specify international characters in **out** parameters must apply the **cs_rtag** attribute in the associated ACF.

Example Using the cs_stag, cs_drtag, and cs_rtag Attributes

Here is an example ACF for an IDL file in which the operation **my_op** has the tag parameters **my_stag**, **my_drtag**, and **my_rtag**, whose types are either **unsigned long** or **[ref] unsigned long**.

```
my_op( [cs_stag] my_stag, [cs_drtag] my_drtag, [cs_rtag] my_rtag);
```

For more information about the **cs_stag**, **cs_drtag**, and **cs_rtag** ACF attributes and their use in internationalized RPC applications, see Chapter 16 of this guide.

19.3.17 The cs_tag_rtn Attribute

The **cs_tag_rtn** attribute is an ACF attribute for use in RPC applications that handle international character data. This attribute specifies the name of a user-written routine that the client and server stubs will call to set an operation's code set tag parameters to specific code set values. The **cs_tag_rtn** attribute is an optional ACF attribute that you can use to provide code set tag transparency for callers of your interface's operations. If an operation that transfers international character data has the **cs_tag_rtn** attribute applied to it in the corresponding ACF, the code set tag parameters will not appear in the operation's definition within the generated header file. If the **cs_tag_rtn** attribute is not used, the operation's caller must provide appropriate values to the operation's code set tag parameters before international character data is marshalled.

The **cs_tag_rtn** attribute has the following syntax. (See the example at the end of this section.)

For an interface:

[cs_tag_rtn(*tag_set_routine***)] interface** *interface_name*

For an operation:

[cs_tag_rtn(*tag_set_routine***)]** *operation_name* **(***[parameter_list]***);**

When used as an ACF interface attribute, the **cs_tag_rtn** attribute applies to all operations defined in the corresponding IDL file. When used as an ACF operation attribute, the **cs_tag_rtn** attribute applies only to the operation you specify.

The *tag_set_routine* is the name of the stub support routine that the client and server stubs will call to set the operation's code set tag parameters. The IDL compiler will generate a function prototype for *tag_set_routine* in the generated header file.

Applications can specify the DCE RPC tag-setting routine **rpc_cs_get_tags()** if it meets their applications' needs, or they can write their own tag-setting routines. The routine name must be distinct from any type name, procedure name, constant name, or enumeration name appearing in the interface definition. It must also have

a specific calling signature. See the **rpc_cs_get_tags(3rpc)** reference page for a complete description of the required routine signature.

When the tag-setting routine is called from a client stub, it is called before any **in** parameters are marshalled. When called from a server stub, it is called before any **out** parameters are marshalled. For more information on the **cs_tag_rtn** attribute and its use in internationalized RPC applications, see Chapter 16 of this guide.

Example Using the cs_tag_rtn Attribute

As shown in the following example, the **cs_tag_rtn** attribute is used in conjunction with the **cs_char**, **cs_stag**, **cs_drtag**, and **cs_rtag** ACF attributes. In the example, the stub generated for **a_op** will call the tag-setting routine **set_tags** to set the code set tag parameters to specific values before any data is marshalled. For **b_op**, it is the responsibility of the operation's caller to ensure that the code set tag parameters are set correctly before any data is marshalled.

IDL File

```
typedef byte my_byte;

void a_op(
    [in] unsigned long stag,
    [in] unsigned long drtag,
    [out] unsigned long *p_rtag,
    [in] long s,
    [in, out] long *p_l,
    [in, out, size_is(s), length_is(*p_l)] my_byte a[]
);

void b_op(
    [in] unsigned long stag,
    [in] unsigned long drtag,
    [out] unsigned long *p_rtag,
    [in] long s,
    [in, out] long *p_l,
    [in, out, size_is(s), length_is(*p_l)] my_byte a[]
);
```

ACF

```
typedef [cs_char(ltype)] my_byte;

[cs_tag_rtn(set_tags)] a_op( [cs_stag] stag,
                         [cs_drtag] drtag,
                         [cs_rtag] p_rtag );

                     b_op( [cs_stag] stag,
                           [cs_drtag] drtag,
                           [cs_rtag] p_rtag );
```

Generated Header File

```
typedef byte my_byte;

void a_op(
    /* [in] */ idl_long_int s,
    /* [in, out] */ idl_long_int *p_l,
    /* [in, out, size_is(s), length_is(*p_l)] */ ltype a[]
);

void b_op(
    /* [in] */ idl_ulong_int stag,
    /* [in] */ idl_ulong_ing drtag,
    /* [out] */ idl_ulong_int *p_rtag,
    /* [in] */ idl_long_int s,
    /* [in, out] */ idl_long_int *p_l,
    /* [in, out, size_is(s), length_is(*p_l)] */ ltype a[]
);
```

19.3.18 The binding_callout Attribute

The **binding_callout** attribute permits you to specify the name of a routine that the client stub is to call automatically to modify a server binding handle before it initiates

a remote procedure call. This attribute is intended for use by client applications that employ the automatic binding method through the **auto_handle** ACF interface attribute. In automatic binding, it is the client stub, rather than the client application code, that obtains the binding handle to the server. The **binding_callout** attribute allows a client application using automatic binding to modify the binding handle obtained by the client stub. Without this attribute, it is impossible for the client application to modify the binding handle before the client stub attempts to initiate a remote procedure call to the selected server.

Clients typically use this attribute to augment automatic binding handles with security context, for example, so that authenticated RPC is used between client and server.

The **binding_callout** attribute has the following syntax. (See the example at the end of this section.)

[binding_callout(*routine_name***)] interface** *interface_name*

The *routine_name* specifies the name of a binding callout routine that the client stub will call to modify the server binding handle before initiating the remote procedure call to the server. The IDL compiler will generate a function prototype for *routine_name* in the generated header file.

You can specify the name of a routine that you supply, or you can specify the DCE RPC routine **rpc_ss_bind_authn_client()** to modify the binding handle if it meets the needs of your application. See the **rpc_ss_bind_authn_client(3rpc)** reference page for more information.

The binding callout routine you provide must have a specific routine signature. See the **rpc_ss_bind_authn_client(3rpc)** reference page for information about the required routine signature.

The **binding_callout** attribute can occur at most once in the ACF and applies to all of the operations in the corresponding IDL file.

A binding callout routine should return the **error_status_ok** status code when it successfully modifies the binding handle or determines that no action is necessary. This status code causes the client stub to initiate the remote procedure call.

A binding callout routine can also return error status. If it does, the client stub does not initiate the remote procedure call. Instead, if the **auto_handle** attribute has been applied in the ACF, the client stub attempts to locate another server of the interface and then calls the binding callout routine again. If **auto_handle** is not in use, the client stub invokes its normal error-handling logic. A binding callout routine for a client using **auto_handle** can return the status code **rpc_s_no_more_bindings** to prevent the client stub from searching for another server and instead invoking its error-handling logic immediately.

By default, the client stub handles an error condition by raising an exception. If a binding callout routine returns one of the **rpc_s_** status codes, the client stub raises a matching **rpc_x_** exception. However, if a binding callout routine returns any other type of status code, the client stub will most likely raise it as an ‘‘unknown status’’ exception.

If the **comm_status** parameter ACF attribute has been applied to an operation, the client stub handles an error condition by returning the error status value in the **comm_status** parameter. Consequently, a binding callout routine can return any error status value to the client application code if the **comm_status** attribute has been applied to the operation.

A binding callout routine can raise a user-defined exception, rather than return a status code, to report application-specific error conditions back to the client application code using exceptions.

Example Using the binding_callout Attribute

ACF

```
[auto_handle,binding_callout(my_bh_callout)] interface \
  bindcall
{
}
```

Generated Header File (bindcall.h)

```
void my_bh_callout(
     rpc_binding_handle_t *p_binding,
     rpc_if_handle_t interface_handle,
     error_status_t *p_st
);
```

19.3.19 The C++ Attributes cxx_new, cxx_static, cxx_lookup, and cxx_delegate

The IDL compiler uses an ACF to do the following for C++ applications:

- Declare a server's manager class and object constructor by using **cxx_new**.
- Declare interface member functions as static by using the **cxx_static** attribute, if they are not already declared in the interface definition file.
- Rename static member functions by using **cxx_static.** .
- Specify a lookup function by using the **cxx_lookup** attribute. The server calls this application-specific function automatically if a client requests a known object not currently maintained by the server.
- Specify a delegate interface class by using the **cxx_delegate** attribute. A third-party class is encapsulated by a delegate class so it can be used in RPCs without modifying the original class.
- Control in which stub files application-specific header files are included. (See also the **include** statement and the **cstub** and **sstub** attributes.)

19.3.19.1 Using cxx_new to Declare an Object Creator Function

Member functions may be specified as static object creator functions by applying the **cxx_new** attribute to the function name. An object creator function allows clients to dynamically create remote objects of an interface class. Servers require this feature to specify their implementation-specific manager class, and clients can use this feature to specify their local implementation of the interface class. The **cxx_new** attribute is applied to an operation and has the following format:

[cxx_new (*manager_class*) **]** *creator_function*(**);**

The associated IDL file must contain a function that returns a pointer to the interface class and that matches the *creator_function* name.

The *manager_class* argument to the **cxx_new** attribute specifies the class name the application uses to locally implement the interface class. The server stub requires the *manager_class,* which must be declared for it in a header file and included by using the **sstub** attribute with the **include** statement. The format in C++ of the *manager_class* declaration is as follows:

```
class manager_class : public interface_class {
        // The constructor, destructor, function declarations, and data.
        ...
}
```

The manager class may include not only a constructor to create objects of the class, but also all the nonstatic member functions declared in the interface class. A server implements the *manager_class* member functions in its manager code. Manager code handles requests from clients for all of the interface's member functions (static and nonstatic), including the *creator_function* which dynamically creates interface objects on the server for the client.

When a client calls the *creator_function*, the client stub executes a proxy function that uses RPCs to execute a manager class constructor on a server. A client can use the *manager_class* argument to specify a class name when implementing its own local version of the interface class. In this case, the client links into its application the **idl**-generated server stub along with a local implementation of the interface class. When the client uses the **new** operator to creates objects of the *manager_class* type, the object is local and no RPCs are involved.

19.3.19.2 Using cxx_static to Specify Static Interface Member Functions

Member functions can be specified as static by applying the **cxx_static** attribute to the function name. The **cxx_static** attribute is an operation attribute with a format as follows:

[cxx_static *[(local_function)]* **]** *member_function( )***;**

The *member_function* name must match a function named in the associated IDL file.

Both remote and local versions of objects are implemented in an application by linking in both client and server stubs. A client links in the server stub to implement client-local versions of interface objects. A server links in the client stub to allow access to remote (in this case, client-local) objects that are passed in as parameters to member functions. The *local_function* argument to the **cxx_static** attribute specifies the function name that the application uses to locally implement the static member function and avoid name conflicts with the remote version of the function (always defined in the client stub).

The server implements a static function named *member_function* in its manager code if no *local_function* is specified. However, if a *local_function* is specified, the server implements a static function named *local_function* in its manager code. In this case, the *manager_function* is automatically implemented in the client stub which is linked into the application (along with the server stub) to handle marshalling of parameters that are client- local objects (remote to the server). When there is a *local_function*, it must be declared for the server stub in a header file and included by using the **sstub** attribute with the **include** statement in the ACF.

When a client calls the static *member_function* , the client stub executes a proxy function that uses RPCs to execute the associated remote function on a server. A client uses the *local_function* argument to specify a function name to use when implementing its own local version of the *member_function*. In this case, in addition to linking in the client stub, the client application also links in the **idl**-generated server stub with a local implementation of the function. When you develop a client, it might be easier if you think of the server stub as a local-implementation stub, because, when the client calls the static *local_function*, the call is strictly local and no RPCs are involved. If you compile an interface such that a server stub is not generated, the *local_function* argument to **cxx_static** is ignored.

An interface can instead specify static member functions by using the **static** keyword in the interface definition, in front of a member function.

19.3.19.3 Using cxx_lookup to Declare a Server's Object Lookup Function

If a client requests the use of a known object that is not yet in the server's runtime, the server can automatically look it up and create it by using an application-specific function. The object lookup function name is specified by using the **cxx_lookup** attribute in an ACF header. The ACF format is as follows:

cxx_lookup (*object_lookup_function***)**

The *object_lookup_function* must be declared in a header file and included in the server stub by using the **sstub** attribute with the **include** statement in the ACF. The C++ function declaration must have the following format:

interface_name ******object_lookup_function***(uuid_t *);**

The lookup function has one input pointer argument of type **uuid_t** representing the UUID of the object desired. The function returns a pointer to the interface class. The returned pointer represents the newly created object. If the object cannot be found or created, the function must return a zero.

19.4 Summary of Attributes

The following table lists the attributes available for use in the ACF and where in the file the attribute can be used.

Table 19–1. Summary of the ACF Attributes

Attribute	**Where Used**
auto_handle	Interface header
binding_callout	Interface header
code	Interface header, operation

Attribute	Where Used
comm_status	Operation, parameter
cs_char	Type
cs_drtag	Parameter
cs_rtag	Parameter
cs_stag	Parameter
cs_tag_rtn	Operation, interface header
cxx_delegate	Interface header
cxx_lookup	Interface header
cxx_new	Operation
cxx_static	Operation
cstub	include statement
decode	Operation, interface header
enable_allocate	Operation
encode	Operation, interface header
explicit_handle	Interface header, operation
extern_exceptions	Interface header
fault_status	Operation, parameter
heap	Type, parameter
implicit_handle	Interface header
nocode	Interface header, operation
represent_as	Type
sstub	include statement

19.5 Attribute Configuration Language

This section summarizes the ACF syntax, in extended BNF notation.

```
<acf_interface> ::=
   <acf_interface_header> "{" <acf_interface_body> "}"


<acf_interface_header> ::=
   [ <acf_interface_attr_list> ] "interface" <idl_interface_name>


<acf_interface_attr_list> ::= "[" <acf_interface_attrs> "]"


<acf_interface_attrs> ::=
   <acf_interface_attr> [ "," <acf_interface_attr> ] ...


<acf_interface_attr> ::= <acf_code_attr>
   | <acf_nocode_attr>
   | <acf_auto_handle_attr>
   | <acf_explicit_handle_attr>
   | <acf_implicit_handle_attr>
   | <acf_cs_tag_rtn_attr>
   | <acf_extern_exceps_attr>
   | <acf_encode_attr>
   | <acf_decode_attr>
   | <acf_binding_callout_attr>
   | <acf_delegate_attr>
   | <acf_lookup_attr>


<acf_auto_handle_attr> ::= "auto_handle"


<acf_explicit_handle_attr> ::= "explicit_handle"


<acf_implicit_handle_attr> ::=
   "implicit_handle" "(" <acf_named_type> <Identifier> ")"
```

```
<acf_extern_exceps_attr> ::=
   "extern_exceptions" "(" <acf_ext_excep_list> ")"


<acf_ext_exceps_list> ::=
   "<acf_ext_excep> ["," <acf_ext_excep] ...


<acf_ext_excep> ::= <Identifier>


<acf_binding_callout_attr> ::=
   "binding_callout" "(" <acf_bind_call_rtn_name> ")"


<acf_delegate_attr> ::= "cxx_delegate" "(" acf_delegate_name ")"

<acf_delegate_name> ::= <Identifier>

<acf_lookup_attr> ::= "cxx_lookup" "(" acf_lookup_name ")"

<acf_lookup_name> ::= <Identifier>


<acf_bind_call_rtn_name> ::= <Identifier>


<acf_interface_name> ::= <Identifier>


<acf_interface_body> ::= [ <acf_body_element> ] ...


<acf_body_element> ::= <acf_include> ";"
   | <acf_type_declaration> ";"
   | <acf_operation> ";"
```

```
<acf_include> ::= [ <acf_include_attr> ] \
             "include" <acf_include_list>

<acf_include_attr> ::= "sstub" | "cstub" | "sstub" "," "cstub"

<acf_include_list> ::= <acf_include_name> \
             [ "," <acf_include_name> ] ...

<acf_include_name> ::= """ <filename> """

<acf_type_declaration> ::= typedef [ <acf_type_attr_list> ] \
                                              <acf_named_type>

<acf_named_type> ::= <Identifier>

<acf_type_attr_list> ::= "[" <acf_type_attrs> "]"

<acf_type_attrs> ::= <acf_type_attr> [ "," <acf_type_attr> ] ...

<acf_type_attr> ::= <acf_represent_attr>
   | <acf_cs_char_attr>
   | <acf_heap_attr>

<acf_represent_attr> ::= "represent_as" "(" <acf_repr_type> ")"
```

```
<acf_cs_char_attr> ::=
 "cs_char" "C" "(" <acf_cs_char_type> ")"


<acf_cs_char_type> ::= <acf_named_type>


<acf_repr_type> ::= <acf_named_type>


<acf_operation> ::= [ <acf_op_attr_list> ] <Identifier> "("
   [ <acf_parameters> ] ")"


<acf_op_attr_list> ::= "[" <acf_op_attrs> "]"


<acf_op_attrs> ::= <acf_op_attr> [ "," <acf_op_attr> ] ...


<acf_op_attr> ::= <acf_explicit_handle_attr>
   | <acf_comm_status_attr>
   | <acf_cs_tag_rtn_attr>
   | <acf_encode_attr>
   | <acf_decode_attr>
   | <acf_fault_status_attr>
   | <acf_code_attr>
   | <acf_nocode_attr>
   | <acf_enable_allocate_attr>
   | <acf_static_attr>
   | <acf_new_attr>


<acf_cs_tag_rtn_attr> ::=
 "cs_tag_rtn" "(" <acf_cs_tag_rtn_name> ")"
```

```
<acf_cs_tag_rtn_name> ::=
 <Identifier>


<acf_parameters> ::= <acf_parameter> [ "," <acf_parameter> ] ...


<acf_parameter> ::= [ <acf_param_attr_list> ] <Identifier>


<acf_param_attr_list> ::= "[" <acf_param_attrs> "]"


<acf_param_attrs> ::= <acf_param_attr> [ "," <acf_param_attr> ] ...


<acf_param_attr> ::= <acf_comm_status_attr>
   | <acf_fault_status_attr>
   | <acf_cs_stag_attr>
   | <acf_cs_drtag_attr>
   | <acf_cs_rtag_attr>
   | <acf_heap_attr>


<acf_code_attr> ::= "code"


<acf_nocode_attr> ::= "nocode"


<acf_encode_attr> ::= "encode"


<acf_decode_attr> ::= "decode"
```

```
<acf_cs_stag_attr> ::= "cs_stag"

<acf_cs_drtag_attr> ::= "cs_drtag"

<acf_cs_rtag_attr> ::= "cs_rtag"

<acf_comm_status_attr> ::= "comm_status"

<acf_fault_status_attr> ::= "fault_status"

<acf_enable_allocate_attr> ::= "enable_allocate"

<acf_static_attr> ::= "cxx_static" | "cxx_static" \
         "(" <acf_static_name> ")"

<acf_static_name> ::= <Identifier>

<acf_new_attr> ::= "cxx_new" "(" <acf_new_name> ")"

<acf_new_name> ::= <Identifier>

<acf_heap_attr> ::= "heap"
```

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