ULTRIX

digital

DECrpc Programming Guide

Order Number: AA–PBKYA–TE

ULTRIX

DECrpc Programming Guide

Order Number: AA-PBKYA-TE
June 1990

Product Version: ULTRIX Version 4.0 or higher

This manual provides information for programmers developing distributed applications based on DECrpc.

digital equipment corporation
maynard, massachusetts

digital	DECUS	ULTRIX Worksystem Software
	DECwindows	VAX
CDA	DTIF	VAXstation
DDIF	MASSBUS	VMS
DDIS	MicroVAX	VMS/ULTRIX Connection
DEC	Q-bus	VT
DECnet	ULTRIX	XUI
DECstation	ULTRIX Mail Connection	

Contents

5 Developing Distributed Applications

About This Manual

This manual provides programming information for the Digital Remote Procedure Call (DECrpc) Version 1.0. The software is based on and is compatible with Version 1.5 of Apollo's Network Computing System (NCS).

This is a new manual in the DECrpc documentation set; the manual is based on the manual *NCS Reference* by Apollo Systems Division of Hewlett Packard.

Audience

This reference manual is for programmers developing applications based on DECrpc. If you are running, rather than developing, distributed applications, you should not need this book. *Guide to the Location Broker* explains how to establish and maintain the runtime support necessary for distributed applications.

In general, the body of this book shows examples written in C for the ULTRIX operating system.

Organization

This manual contains seven chapters, a glossary, and an index.

Chapter 1 introduces DECrpc and the concept of a distributed application.

Chapter 2 surveys DECrpc software.

Chapter 3 introduces the steps in building a distributed application.

Chapter 4 describes how to define interfaces in Network Interface Definition Language (NIDL).

Chapter 5 describes how to develop distributed applications that use DECrpc.

Chapter 6 describes the C syntax of NIDL.

Chapter 7 describes special programming topics.

To submit comments on this document, please use the Reader's Response form at the back of the book.

Related Documentation

For more information on topics related to NCS, see the following documents:

Guide to the Location Broker

This book explains how to set up and administer the DECrpc runtime software, the Location Broker.

ULTRIX Reference Pages

The *ULTRIX Reference Pages* describe the commands and special files referred to in this manual, and the library routines described in the *DECrpc Programming Guide.*

Conventions

The following conventions are used in this guide:

`special`	In text, each mention of a specific command, option, partition, pathname, directory, or file is presented in this type.
`command`(x)	In text, cross-references to command documentation include the section number in the reference manual where the command is documented. For example: See the `cat`(1) command. This indicates that you can find the material on the `cat` command in Section 1 of the *ULTRIX Reference Pages.*
variable	In syntax descriptions, this type indicates terms that are variable.
`literal`	In syntax descriptions, this type indicates terms that are constant and must be typed just as they are presented.
italics	In syntax descriptions, this type indicates terms that are variable.
[ ]	In syntax descriptions, brackets indicate terms that are optional.
. . .	In syntax descriptions, a horizontal ellipsis indicates that the preceding item can be repeated one or more times.
UPPERCASE	The ULTRIX system differentiates between lowercase and uppercase characters. Enter uppercase characters only where specifically indicated by an example or a syntax line.
`example`	In examples, computer output text is printed in this type.
`example`	In examples, user input is printed in this bold type.
new term	In text, new terms are introduced in this bold type.
$	This is the default user prompt in multiuser mode.
#	This is the default superuser prompt.
• • •	In examples, a vertical ellipsis indicates that not all of the lines of the example are shown.

Concepts and Terminology 1

This chapter describes the concepts and terminology of DECrpc, the remote procedure call mechanism supported by the ULTRIX operating system. DECrpc is based on and is compatible with the RPC component of Apollo's Network Computing System (NCS) Version 1.5. NCS is a set of tools for heterogeneous distributed computing.

1.1 Distributed Applications

Using remote procedure calls, software applications can be distributed across heterogeneous collections of computers, networks, and programming environments. Distributed applications can take advantage of computing resources throughout a network or internet, with different parts of each program executing on the computers best suited for the tasks.

There are many applications that can be distributed among multiple systems. For example, one program might perform graphical input and output on a workstation while it does intense computation on a supercomputer. A program that performs many independent calculations on a large set of data could distribute these calculations among any number of available processors on the network or internet.

1.2 RPC Software

The software for writing distributed applications is written in portable C wherever possible. The components are:

- Remote Procedure Call (RPC) runtime library
- Network Interface Definition Language (NIDL) Compiler
- Location Brokers

The RPC runtime library and the Location Brokers provide runtime support for distributed applications.

The NIDL Compiler is a tool for developing distributed applications.

1.2.1 RPC Runtime Library

The DECrpc runtime library provides the routines that enable local programs to execute procedures on remote hosts. These routines transfer requests and responses between the programs calling the procedures and the programs executing the procedures.

When you develop distributed applications, you usually do not use many runtime routines directly. Instead, you write interface definitions in Network Interface Definition Language and use the NIDL Compiler to generate most of the required calls to the runtime library.

1.2.2 Location Broker

A **broker** is a server that provides information about resources. The Location Broker enables clients to locate specific **objects**, such as a database or a specialized processor, or specific **interfaces**, such as a data retrieval interface or a matrix arithmetic interface.

Location Broker software includes the Local Location Broker (LLB) that manages information about resources on the local host, the Global Location Broker (GLB) that manages information about resources available on all hosts, a **client agent** through which programs use the Location Broker facilities, and the `lb_admin` administrative tool.

The GLB stores in a database the locations of objects and interfaces in a network or internet. Clients can use the GLB to access an object or interface, without knowing its location beforehand. The LLB also implements a forwarding facility that provides access by way of a single address to all of the objects and interfaces at the host.

Guide to the Location Broker describes the administration of the Location Brokers.

1.2.3 Network Interface Definition Language Compiler

The NIDL Compiler takes as input an **interface definition** written in NIDL. From this definition, the NIDL Compiler generates client and server **stub** programs. An interface definition specifies the interface between a user of a service and the provider of the service. The definition describes how a client application *sees* a remote service and how a remote server *sees* requests for its service.

The stubs produced by the NIDL Compiler contain nearly all of the *remoteness* in a distributed application. The client stub program performs data conversions, assembles and disassembles packets, and interacts with the RPC runtime library. The server stub program provides similar support for the server. It is easier to write an interface definition in NIDL than it would be to write the stub code that the NIDL Compiler generates from your definition.

1.3 Object Orientation

Programs written with RPC routines access **objects** through interfaces and are cast in terms of the objects they manipulate rather than the machines with which they communicate. Object-oriented programs are easy to design and can readily accommodate changes to hardware and network configurations.

1.3.1 Interfaces, Objects, and Types

An **object** is an entity accessed by well-defined operations. A file, a serial line, a printer, and a processor can all be objects.

Every object has a **type**. Programs can access any object of a given type through one or more **interfaces**, with each interface a set of **operations** that can be applied to any of those objects. For example, you can classify printer queues as objects of the type `printqueue`, accessed through a `directory` interface that includes operations to add, delete, and list jobs in the queues.

As another example of how object, type, and interface apply to distributed applications, consider array processors as objects of the `arrayproc` type. Programs access these objects through either of two interfaces: a `vector` interface, with operations such as `vector$add` and `vector$multiply`, and a `misc` interface, with operations such as `misc$root_mean_square` and `misc$max_abs_val`.

1.3.2 Universal Unique Identifiers

DECrpc identifies every object, type, and interface by a **Universal Unique Identifier (UUID)**. The UUID is defined as a 16-byte quantity identifying the host on which the UUID is created and the time at which it is created. Six bytes identify the time, two are reserved, and eight identify the host.

The `uuid_gen` utility generates a UUID as a text string or as a data structure defined in C syntax. The string representation used by the Network Interface Definition Language (NIDL) Compiler consists of 28 hexadecimal characters arranged as in this example:

```
3a2f883c4000.0d.00.00.fb.40.00.00.00
```

1.3.3 Clients and Servers

A **client** is a program that makes remote procedure calls. A remote procedure call requests that a particular operation be performed on a particular object.

A **server** is a program that implements one or more interfaces and provides access to one or more objects. A server accepts requests for operations in any of its interfaces. When it receives a request from a client, it executes the procedures that perform the operation and it sends a response to the client.

All DECrpc applications involve communication between clients and servers through interfaces. However, some applications do not involve specific objects and types. If your application operates on only one object, you can specify `uuid_$nil`, the nil UUID, as the identifier for its type. If your application does not operate on any object, you can specify `uuid_$nil` for both the type and the object.

1.4 Communication Protocols

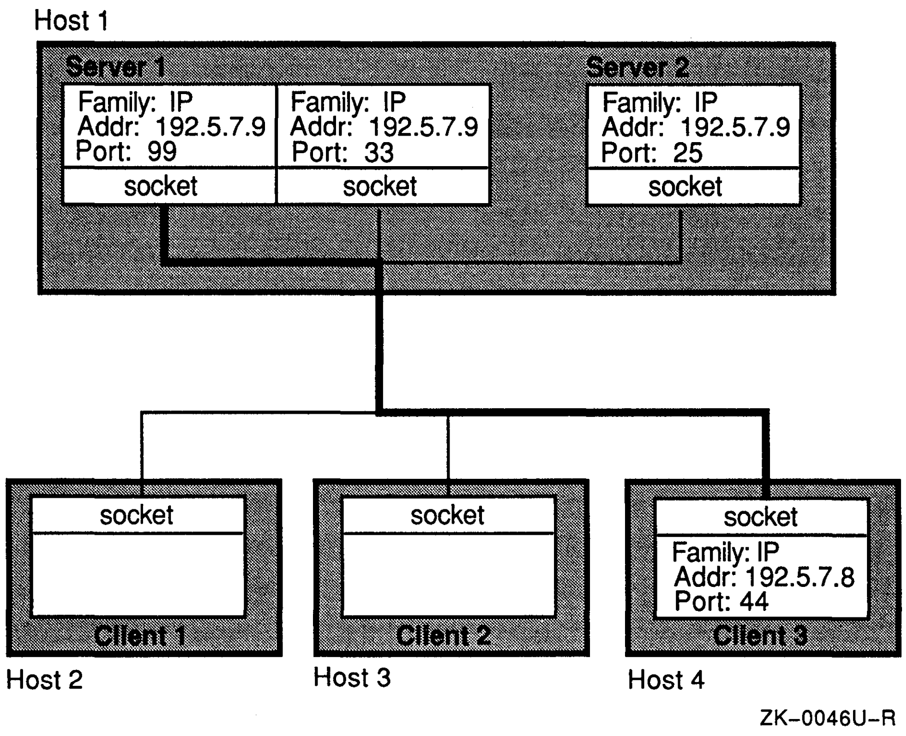
The RPC runtime library is independent of any underlying communications protocol. The DECrpc V1.0 runtime library, however, provides support for only the DARPA-defined Internet Protocols (IP).

1.4.1 Sockets and Socket Addresses

The remote procedure calls use the Berkeley UNIX **socket** abstraction for interprocess communications. A socket is an endpoint for communications, in the form of a message queue. An RPC server *listens* on one or more sockets and receives any message delivered to a socket on which it is listening.

Figure 1-1 illustrates RPC communications using sockets. It shows two servers running on one host and several clients on other hosts.

Figure 1-1: RPC Communications



Each socket is identified uniquely by a **socket address**. A socket address, sometimes named `sockaddr`, is a data structure that specifies these socket characteristics:

- Address family
- Network address
- Port number

The **address family**, also called the **protocol family**, determines the communications protocol used to deliver messages and the structure of the addresses used to represent communications endpoints.

The **network address**, given the address family, uniquely identifies a host and contains information sufficient to establish communication with the host. Hosts also have **host IDs**; a host ID uniquely identifies a host but may not be sufficient to establish communication. In the IP family, the network address and the host ID are identical.

The **port number** specifies a communications endpoint within the host. The terms *port* and *socket* are synonymous, but *port number* and *socket address* are not. A port number is one of the three parts in a socket address. For example, the character string *77* might represent a port number, while *ip:wooster[77]* might represent a socket address.

Figure 1-2 illustrates the structure of socket addresses in the IP family.

Figure 1-2: Socket Address Structures

Family	Port	Network Address
16-bit Integer	16-bit Integer	Network ID and Host ID
		32-bit Integer

ZK-0047U-R

A socket address can be represented textually by a string of the form *family:host[port], where family* is the textual name of an address family, *host* is either a textual host name or a numeric host ID preceded by a number sign (#), and *port* is a port number. Several of the routines and utilities accept textual representations of socket addresses as input or produce them as output.

Example 1-1 shows two textual representations of socket addresses for the IP address family. The first line shows a textual host name and the second shows a numeric host ID.

Example 1-1: Textual Representations of Socket Addresses

```
ip:cactus[57]
ip:#192.5.7.9[53]
```

1.4.2 Well-Known and Opaque Ports

It is possible to design an interface with a specific port number built in. Clients of the interface always send to that port and servers always listen on that port. The port used in such an interface is called a **well-known** port. Some well-known ports are assigned to particular servers by the administrators of a protocol. For example, the administrators of the Internet Protocols have assigned the port number 23 to the `telnet` remote login facility. All telnet servers listen on this well-known port, and all telnet user programs send to it.

For very widely used services such as telnet, well-known ports offer a simple way to coordinate communication between clients and servers. For most applications, however, well-known ports are impractical. Each protocol family has a limited number of ports, so, unless you obtain an assignment from a central administrator, your application's well-known port number is liable to conflict with that of another program.

The Location Broker solves this problem by enabling clients to locate servers without direct use of well-known ports. A server can use ports that the RPC runtime library assigns dynamically. The server registers its socket address, including the assigned port, with the Location Broker. A client can then use Location Broker lookup calls to obtain the socket address of the server. The dynamically assigned port is said to be **opaque**, because there is no need for either the client or the server to know the port number.

Although the RPC runtime library supports both kinds of ports, if you use opaque ports your application can always coexist with other services.

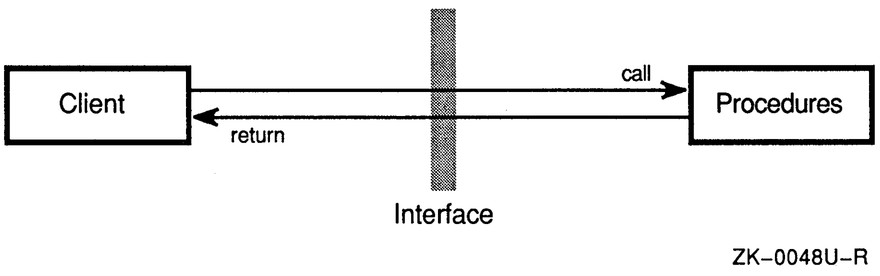
The Local Location Broker itself uses one well-known port to listen for requests. Clients and servers find Global Location Brokers by broadcasting to this port.

Section 1.7 describes the Location Broker.

1.5 The Remote Procedure Call Paradigm

Remote procedure calls extend the procedure call mechanism from a single computer to a distributed computing environment. They enable you to distribute the execution of a program among several computers in a way that is transparent to the application code. Figure 1-3 shows the flow of ordinary local procedure calls between a calling client and called procedures.

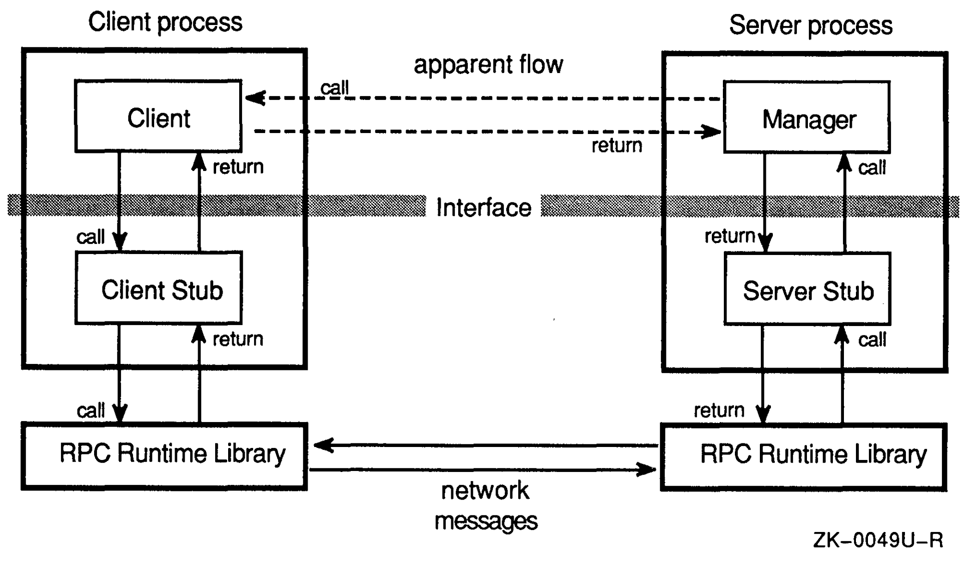
Figure 1-3: Ordinary Local Procedure Call Flow



In contrast to Figure 1-3, which shows the flow of local procedure calls, Figure 1-4 shows the flow of remote procedure calls and illustrates how the RPC paradigm hides the remote aspects of a call from the calling client. The client application uses ordinary calling conventions to request a procedure as if the procedure were a part of the local program, but the procedure is executed by a remote server. The client stub acts as the *local representative* of the procedure.

A stub is a program module generated by the NIDL Compiler from a user-written interface definition. The stub uses RPC runtime library calls to communicate with the server. Similar activities occur within the server process. Section 1.6 briefly describes interface definitions and Chapter 4 describes the procedure for writing an interface definition.

Figure 1-4: Remote Procedure Call Flow



1.5.1 Interfaces

The interface determines the calling syntax – the signature – for each of its operations. Both client and server procedures use the same syntax. The interface is independent of the mechanism that conveys the request between client and server. It is also independent of the way the operations are implemented. A server that implements the operations in an interface is said to **export** the interface. A client that requests the operations is said to **import** the interface.

For example, suppose that a remote matrix arithmetic package is running as a server on an array processor. Servers on array processor hosts export a `vector` interface containing operations such as `vector$add` and `vector$multiply`. Clients on other hosts import the `vector` interface by calling `vector$add` or `vector$multiply`. The client programs run on their local hosts, but the matrix operations run on the remote array processor.

1.5.2 Clients, Servers, and Managers

An RPC **client** is a program that makes remote procedure calls to request operations. A client does not know how an interface is implemented and might not know the location of a **server** exporting the interface.

An RPC server is a program that performs the operations in one or more interfaces. It executes these operations on objects of one or more types. A server receives requests for operations from clients and it sends responses containing the results of the operations. A server can export interfaces for one object or for several objects. In the array processor example, there is only one object, the array processor. A file server, however, might manage many file objects.

A server can also be a client. For example, a server that gets time from a time server is a client of the time server.

A **manager** is a set of procedures that **implement** the operations in one interface for objects of one type. It is possible for a server to export several interfaces or to export an interface for several types of objects; each combination of interface and type has its own manager.

Figure 1-4 showed the simplest case, a server that exports one interface for objects of one type. Figure 1-5 illustrates a server that exports two interfaces.

Figure 1-5: An RPC Server Exporting Two Interfaces

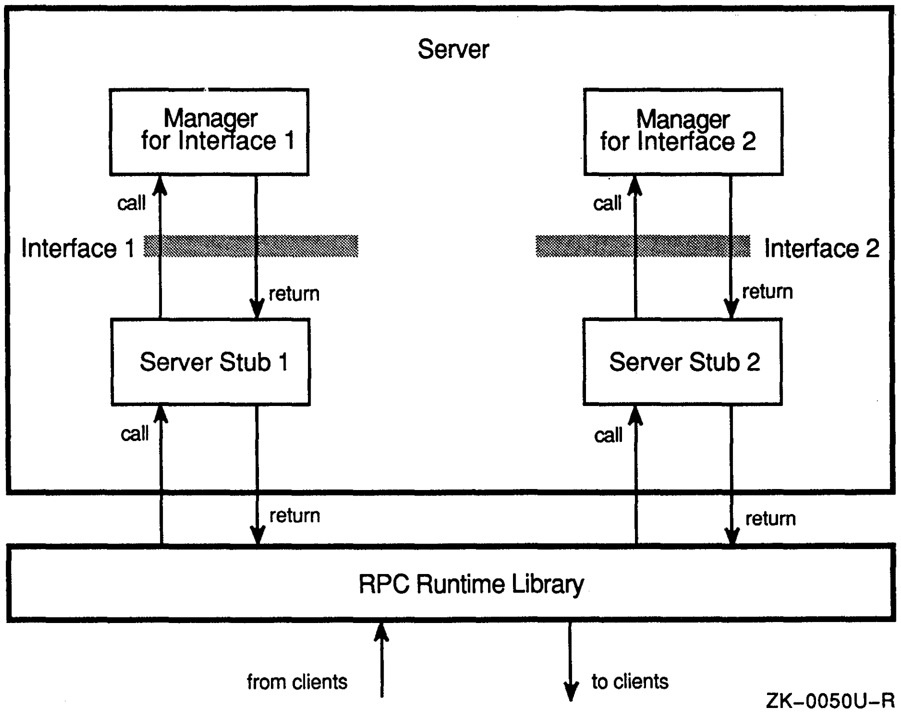
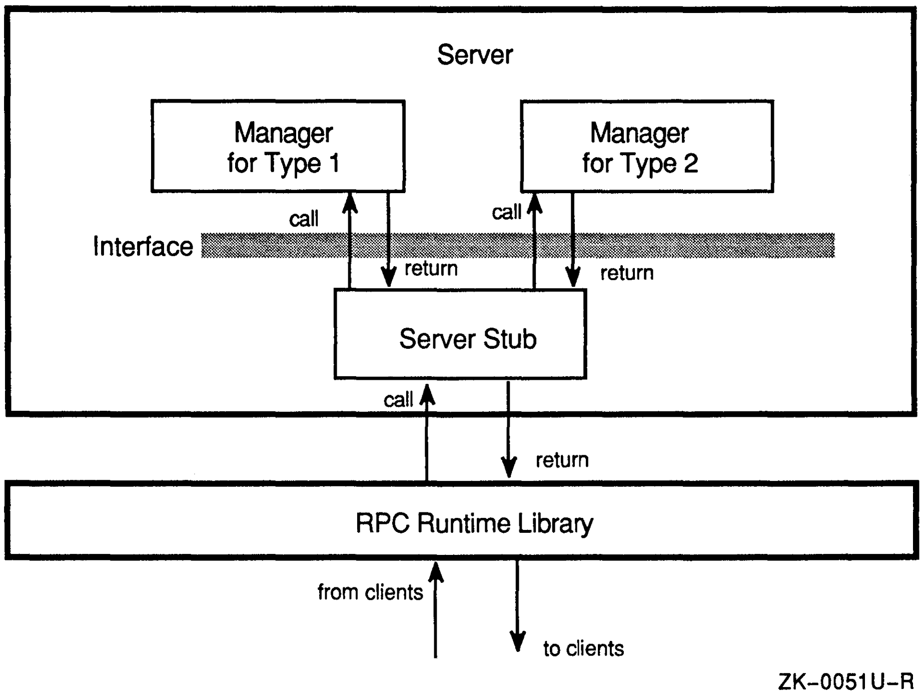


Figure 1-6 shows a server that exports one interface to objects of more than one type.

Figure 1-6: An RPC Server Exporting an Interface for Two Types



1.5.3 Handles

When a client makes a remote procedure call, requesting that a particular operation be performed on a particular object, the RPC runtime library needs the following information to transmit the call:

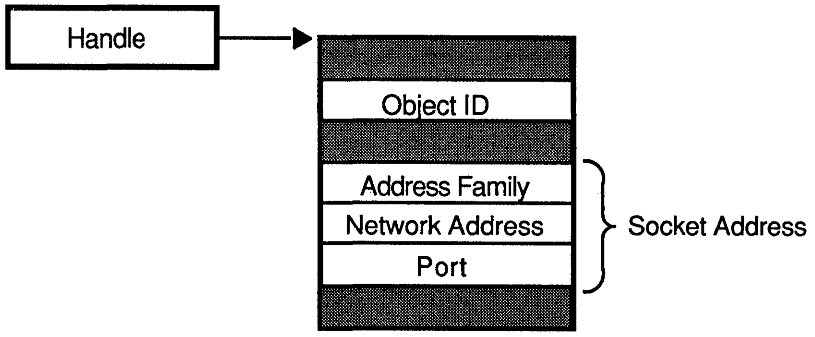
- The object on which the operation is to be performed
- The location of the server that exports the interface containing the operation

The client process represents this information about the object and the server location in a **handle**, which is a pointer to a data structure. The runtime library provides several routines to create and manage handles. Once created, a handle always represents the same object. However, it may represent different servers at different times, or it may not represent a server at all. The server location represented in a handle is called the **binding**. To **bind** a handle is to set its server location.

1.5.3.1 RPC Handles – An RPC handle is a pointer to an opaque data structure containing the information needed to access an object. The name for this pointer type is `handle_t`. In this manual, the term **RPC handle** refers to handle variables of this type and the term **generic handle** refers to handle variables of other types, such as a pathname.

Clients and servers manipulate RPC handles indirectly, through RPC runtime library routines. Figure 1-7 shows an RPC handle.

Figure 1-7: RPC Handle



ZK-0083U-R

1.5.3.2 RPC Binding States – An RPC handle can exist in three **binding states:**

unbound

An unbound handle (also called an **allocated** handle) identifies an object but does not identify a location. When a client uses an unbound handle to make a remote procedure call, the RPC runtime library broadcasts the request to all hosts on the local network. Any server that exports the requested interface and supports the requested object can respond. The client accepts the first response it receives. This mechanism is inefficient and has other disadvantages described in Chapter 5.

bound-to-host

A bound-to-host handle identifies an object and a host but does not identify the port number of the server that exports the requested interface. When a client uses a bound-to-host handle to make a remote procedure call, the RPC runtime library sends the request to the host identified in the handle. If the requested interface specifies a well-known port, the request goes to that port; otherwise, the request goes to the Local Location Broker forwarding port, and the LLB forwards the request to the server.

fully bound

A fully bound handle (also called a **bound-to-server** handle) identifies an object and the complete socket address of a server. When a client uses a fully bound handle to make a remote procedure call, the RPC runtime library sends the message directly to the socket address identified by the handle.

In all cases, when the client RPC runtime library receives a response from a server, it binds the handle to the server socket address. Therefore, RPC handles are always fully bound when a remote procedure call returns, and the client does not need to use the broadcasting or forwarding mechanism for subsequent calls to the server.

Table 1-1 shows, for each possible binding state of a handle when a remote procedure call is made, the information that the handle represents, the delivery mechanism of the remote procedure call, and the binding state when the procedure call returns.

Table 1-1: RPC Binding States

Binding State on Call	Information Represented	Delivery Mechanism	Binding State on Return
Unbound	Object	Broadcast to all hosts on the local network	Fully bound
Bound-to-host	Object Host	Sent to LLB forwarding port at host	Fully bound
Fully bound	Object Host Server	Sent to specific port at host	Fully bound

1.5.4 Handle Representations and Binding Techniques

DECrpc provides a choice of handle representations and binding techniques. It allows applications to use:

- Explicit or implicit handles
- Manual or automatic binding

The **handle representation**, explicit or implicit, determines whether the client represents handle information with a parameter in each operation or with a global variable. The **binding technique**, manual or automatic, determines whether the client uses RPC handles directly or uses generic handles that are then converted to RPC handles by automatic binding routines. Table 2-2 summarizes the effects of the handle representation and the binding technique on the handle variable.

Table 1-2: Handle Representations and Binding Techniques

Handle	Manual Binding	Automatic Binding
Explicit Handle	Data Type: `handle_t` Representation: Operation parameter	Data Type: Generic, user defined Representation: Operation parameter
Implicit Handle	Data Type: `handle_t` Representation: Client global variable	Data Type: Generic, user defined Representation: Client global variable

1.5.4.1 **Explicit and Implicit Handles –** In an application that uses **explicit handles**, each operation in the interface must have a handle variable as its first parameter. This parameter passes explicitly from the client to the server, through the client stub, the client and server RPC runtime libraries, and the server stub. (The server runtime library manipulates the location information in the handle so that, on the server side of the application only, the handle specifies the location of the client making the call. The server can thereby identify its client. Of course, the handle always represents the same object.)

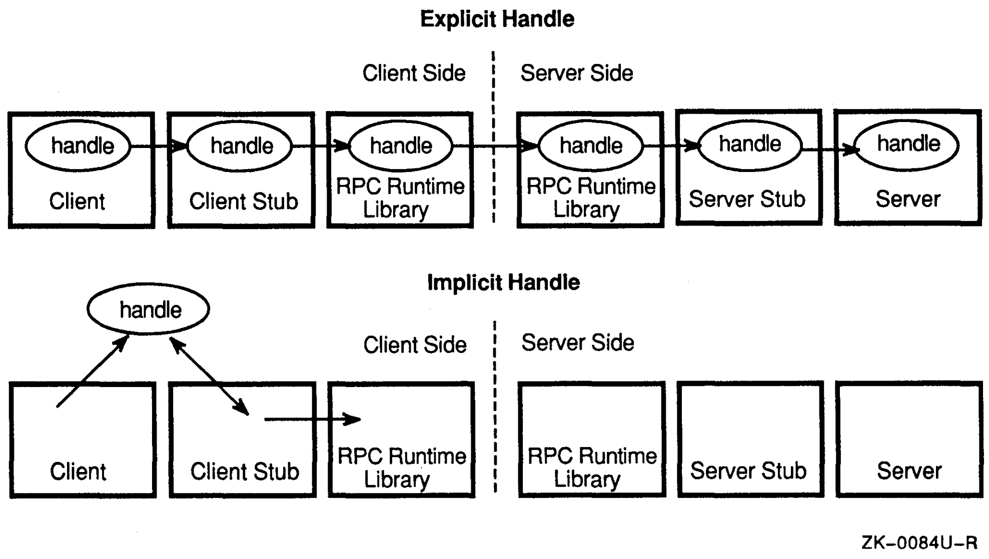
In an application that uses **implicit handles**, the handle identifier is a global variable in the client. The operations do not need to include a handle parameter, and the server does not receive a handle. When the client stub delivers a remote procedure call, it uses the implicit handle variable to supply the handle information needed by the client RPC runtime library.

An implicit handle makes remote procedure calls look more like ordinary procedure calls, because there is no need to pass *special* information in each call. However, this added simplicity comes at the expense of reduced flexibility. Applications that use implicit handles have two major limitations:

- Because the server does not receive the object identifier that a handle contains, the client can access only one object at any time, unless it explicitly passes some other form of object identifier, such as a pathname, as an operation parameter.
- Because all remote procedure calls use the same global variable, the client can access only one server at any time. For example, you cannot use implicit handles in applications that divide computation in parallel among several hosts.

Figure 1-8 illustrates the differences between explicit and implicit handles.

Figure 1-8: Explicit and Implicit Handles



1.5.4.2 Manual and Automatic Binding – In an application that uses **manual binding**, the handle variable is an RPC handle, and the client makes all the RPC runtime library calls that create and bind the handle.

In an application that uses **automatic binding**, the handle variable is generic, and the application developer must supply **autobinding** and **autounbinding** routines that convert generic handles (used by the client) to RPC handles (used by the RPC runtime library). The client stub invokes the autobinding routine each time the client makes a remote procedure call; it invokes the autounbinding routine after the remote call returns. The generic handle variable must contain information sufficient for the autobinding routine to generate an RPC handle.

Automatic binding offers convenience at the expense of performance. Each time the client stub processes a remote procedure call, it must call routines to convert between generic handles and RPC handles. Thus, an interface that uses automatic binding can require more processing than one in which the client performs the binding once and passes an RPC handle to the stub. The difference in performance is smallest in interfaces such as the remote file system example, where each call is likely to require rebinding of the handle.

Table 1-3 shows the differences between manual and automatic binding when a client makes a remote procedure call.

Table 1-3: Comparison of Steps in Manual and Automatic Binding

Manual Binding	Automatic Binding
1. *Client:* Generates RPC handle Binds handle, as necessary Makes procedure call to stub 2. *Client stub:* Sends request to server Receives response from server Returns to client 3. *Client:* Receives call return from stub Manages RPC handle, as necessary, including unbinding the handle	1. *Client:* Using generic handle, makes procedure call to stub 2. *Client stub:* Calls autobinding routine 3. *Autobinding routine:* Generates RPC handle from generic handle Binds RPC handle as necessary Returns RPC handle to stub 4. *Client stub:* Sends request to server Receives response from server Calls autounbinding routine 5. *Autounbinding routine:* Frees handles as necessary Returns to stub 6. *Client stub:* Returns to client 7. *Client:* Receives call return from stub

Chapter 7 includes an example of an automatic binding routine.

1.5.5 Stubs

Both clients and servers are linked (in the sense of combining object modules to form executable files) with stubs, which are generated by the NIDL Compiler from a user-written interface definition. The client stub takes the place of the remote procedures in the client process and the server stub takes the place of the client in the server process. Stubs make remote procedure calls resemble local calls, which enables clients and servers to use the RPC facilities almost transparently.

The client stub **marshalls** data (copies data into an RPC packet) and **unmarshalls** data (copies data from an RPC packet) and transmits and receives the packet from the server stub.

When a client calls an interface operation, it invokes a routine in the client stub. The client stub then performs these actions:

1. Marshalls the input parameter values
2. Calls `rpc_$sar`, an RPC runtime library routine called only by stubs, to send the packet to the server stub and await a reply
3. Receives the reply packet
4. Unmarshalls the output parameters from the reply packet into the data types expected by the client (that is, the data types specified in the interface definition)
5. Converts the output data to the client's native representation, if the client's native representation is different (for example, converts characters from EBCDIC to ASCII)
6. Returns to the client

Similarly, the RPC runtime library at a server host calls a server stub routine when the server receives a request from the client. The server stub then performs these actions:

1. Unmarshalls the input parameters from the request packet into the data types expected by the server (that is, the data types specified in the interface definition)
2. Converts the input data into the representation native to the server, if the client uses a different representation (for example, converts characters from ASCII to EBCDIC)
3. Calls the manager procedure that implements the operation
4. Marshalls the output parameter values into an RPC packet
5. Returns the packet to the RPC runtime library for transmission to the client stub

As the preceding summary shows, stub procedures in both the client and the server check the data representation format in incoming packets. Each side uses its native format when it marshalls parameters. A label in the header of each transmitted packet indicates the sender's data representation format for integers, characters, and floating-point numbers. If the sender's representation of a data type is different from the receiver's representation, the receiving stub converts that data type when it unmarshalls values.

There is no conversion of data if the sending and receiving hosts have identical representations. This technique allows heterogeneity at minimum cost.

The NIDL Compiler automatically generates source code for the client and server stubs from a definition of the interface written in Network Interface Definition Language. Section 1-6 provides more information about the NIDL Compiler and the stubs that it generates. Chapter 6 describes NIDL syntax in detail.

1.6 Interface Definitions and the NIDL Compiler

An interface definition written in NIDL defines the signatures for each operation in an interface. The NIDL compiler takes this definition as input and generates C source code files that you can use in building an application.

1.6.1 Interface Definitions

An interface definition describes the constants, types, and operations associated with an interface. NIDL contains constructs for specifying all of this information, but it contains no executable constructs; NIDL is strictly a declarative language. You can write NIDL in either of two syntaxes, one that resembles C or one that resembles Pascal.

DECrpc supports only the C syntax of NIDL and all of the examples in this book are in the C syntax.

Chapter 3 introduces NIDL interface definitions with a simple example and describes the input and output files in the NIDL compilation. Chapter 4 describes how to write an interface definition and Chapter 6 completely describes the C syntax of NIDL.

1.6.2 Files Generated by the NIDL Compiler

The NIDL compiler translates a NIDL interface definition into stub modules that you then link with clients and servers. As Section 1.5.5 described, these modules facilitate remote procedure calls by copying arguments to and from RPC packets, converting data representations as necessary, and calling the RPC runtime library.

In addition to stub files, the NIDL compiler generates C language header files.

1.7 The Location Broker

The Location Broker provides clients with information about the locations of objects and interfaces. Servers register with the Location Broker their socket addresses and the objects and interfaces to which they provide access. Clients issue requests to the Location Broker for the locations of objects and interfaces they wish to access; the broker returns database entries that match an object, type, interface, or combination of these, as specified in the request.

The Location Broker also implements the RPC message-forwarding mechanism. If a client sends a request for an interface to the Location Broker forwarding port on a host, the broker automatically forwards the request to the appropriate server on the host.

This chapter describes the structure and function of the Location Broker software and databases. *Guide to the Location Broker* explains how to configure and administer the Location Brokers.

1.7.1 Location Broker Software

The Location Broker consists of the following interrelated components:

Local Location Broker (LLB)
The Local Location Broker is a server that maintains a database of information about objects and interfaces located on the local host. The LLB runs as the daemon `llbd`(8ncs). The LLB provides access to its database for application programs and also provides the Location Broker forwarding service. An LLB must run on any host that runs DECrpc servers.

Global Location Broker (GLB)
The Global Location Broker is a server that maintains information about objects and interfaces throughout the network or internet. The GLB daemon is named `nrglbd`(8ncs).

Location Broker Client Agent
The Location Broker Client Agent is a set of library routines that application programs call indirectly to access LLB and GLB databases. When a program issues any Location Broker call, the call goes to the Client Agent at the local host. The Client Agent then performs the actual lookup or update of information in the appropriate Location Broker database.

1.7.2 Location Broker Data

Each entry in a Location Broker database contains information about an object, an interface, and the location of a server that exports the interface to the object. Table 1-4 lists the fields in a database entry.

Table 1-4: Location Broker Database Entry

Field	Description
Object UUID	The unique identifier of the object
Type UUID	The unique identifier that specifies the type of the object
Interface UUID	The unique identifier of the interface to the object
Flag	A flag that indicates whether the object is global (and therefore should be registered in the GLB database)
Annotation	64 characters of user-defined information
Socket address length	The length of the socket address field
Socket address	The location of the server that exports the interface to the object

Because each database entry contains one object UUID, one interface UUID, one type UUID, and one socket address, a Location Broker database must have an entry for each possible combination of object, interface, and socket address. Thus, the database must have 10 entries for a server that:

- Listens on two sockets, `socket_a` and `socket_b`
- Exports `interface_1` for `object_x`, `object_y`, and `object_z`

- Exports `interface_2` for `object_p` and `object_q`
- Has only one `type` UUID

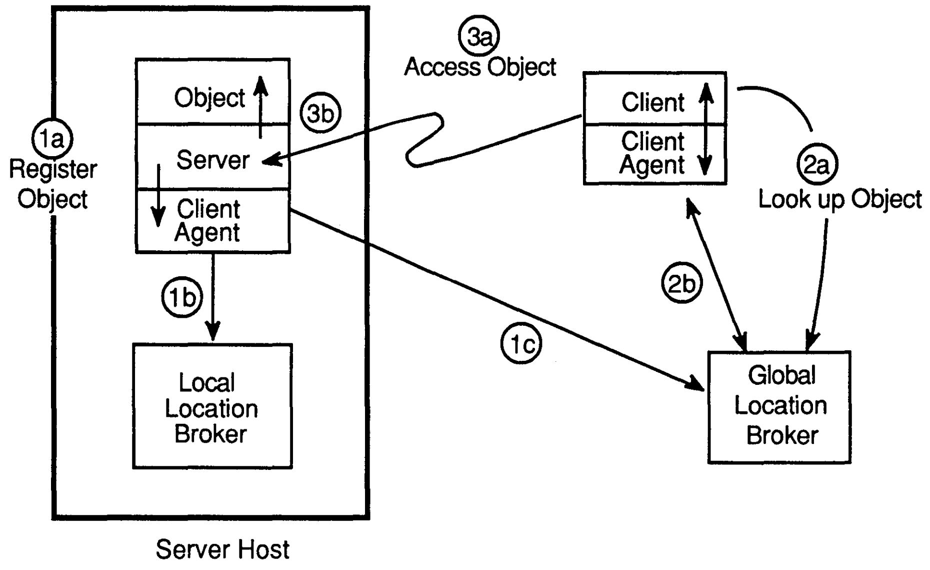
When you look up Location Broker information, you specify any combination of the object UUID, type UUID, and interface UUID as keys, and you request the information from the GLB database or from a particular LLB database. Thus, for example, you can obtain information about all objects of a specific type, all hosts with a specific interface to an object, or all objects and interfaces at a specific host.

1.7.3 Location Broker Registrations and Lookups

This section describes how servers register their locations with the Location Broker and how clients use Location Broker lookups to locate servers.

Figure 1-9 illustrates a typical case in which a client requires a particular interface to a particular object but does not know the location of a server exporting the interface to the object. In this figure, a server registers itself with the Location Broker by calling the Client Agent in its host (1a). The Client Agent registers the server with the LLB at the server host (1b) and with the GLB (1c). To locate the server, the client issues a Location Broker lookup call (2a). The Client Agent on the client host sends the lookup request to the GLB, which returns it through the Client Agent to the client (2b). The client can then use RPC calls to communicate directly with the located server (3a, 3b).

Figure 1-9: Client Agents and Location Brokers



ZK-0086U-R

1.7.4 The Local Location Broker

The LLB manages information about servers running on the local host. It also acts as a forwarding agent for remote procedure calls.

The forwarding facility of the LLB eliminates the need for a client to know the specific port that a server uses and thereby helps to conserve well-known ports. The

LLB listens on one well-known port per address family. It forwards any messages that it receives to the local server that exports the requested object. Forwarding is particularly useful when the requestor of a service already knows the host where the server is running. The server can use a dynamically assigned opaque port and register only with the LLB at its local host, not with GLB. To access the server, a client needs to specify the object, the interface, and the host, but not a specific port.

Although it is recommended that you run an `llbd` on every host, the daemon is absolutely required only on hosts that run RPC servers. *Guide to the Location Broker* describes Location Broker configuration and the utility.

1.7.5 The Global Location Broker

The GLB manages information about servers running anywhere in the network or internet. Clients typically issue lookup calls to the GLB when they do not know at what host a server is running.

Guide to the Location Broker describes how to configure the Global Location Broker.

1.7.6 Designing an Application to Use Global Name Services

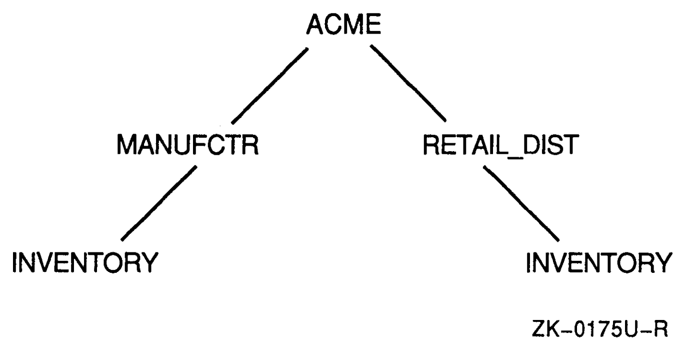
Currently, DECrpc uses the Location Broker as its sole name service. However, when designing an application that may eventually migrate to other environments, you should accommodate the naming requirements of global name services such as Digital Distributed Name Service (DECdns), X.500, and Hesiod/bind. Such services use global names to provide a means of advertising and locating computing resources in any size network.

Global names reflect a naming scheme that is distinct from the UUID-based naming scheme of the Location Broker. A global name, like a UUID, is a unique identifier with universal scope. Unlike a UUID, a **global name** is an easy-to-read, structured text string that is meaningful to users in a particular computing environment. For example, a DECdns global name comprises a series of text strings, read from left to right, that begin with a dot (such as .ACME_CORP.MANUFCTR.INVENTORY). Establishing naming conventions for a given computing environment helps users to specify unique global names.

Being structured enables global names to represent one thing in terms of its relationship to other things. For instance, in a full DECdns global name, each successive string is subordinate to the preceding string. The right-most string is a **simple name** that identifies a specific resource. For example, the full global name .ACME_CORP.MANUFCTR.INVENTORY reflects the organization of a hypothetical company, Acme Corporation; the first string represents the company as a whole, the middle string represents Acme's manufacturing division, and the final string is a simple name representing a specific account named INVENTORY on a system in the manufacturing division.

All name services maintain a database whose individual entries correspond to a specific resource. Database organization, however, differs between the Location Broker and global name services. In a Location Broker database, each entry has only unstructured identifiers (an object UUID, interface UUID, and/or object type). These unstructured identifiers limit the Location Broker to a flat database, whose entries reside side-by-side, much like the files of a single-level directory. In contrast, in a global name-service database, each entry has a global name whose textual and structural information dictates the relative placement of the entry in the database.

When entries have full global names, the entries reside in subgroups, much like files in subdirectories within a multiple-level directory. This allows resources belonging to different groups to have the same simple name. For example, the DECdns entries .ACME_CORP.MANUFCTR.INVENTORY and .ACME_CORP.RETAIL_DIST.INVENTORY would reside in a directory tree with the following organization:



The differences in the naming schemes of the Location Broker and global name services can obstruct the eventual migration of a DECrpc application from the Location Broker to a global name service. Though global name services can interpret UUIDs, the exclusive use of UUIDs to identify objects is incompatible with the structural aspects of global naming schemes. Moreover, the Location Broker can look up an entry by its object type, but some global name services cannot. Therefore, when designing a DECrpc application that might eventually use a global name service, you should constrain the use of Location Broker as follows:

- Avoid proliferating UUIDs as object IDs. You can isolate UUIDs, for example, by restricting them to the `lb_$register` and `lb_$lookup_object` routines or by creating a table to map UUIDs to object names.
- Avoid defining object types.

DECrpc Software 2

DECrpc software includes daemons and utilities, library routines, interface definition files, and header files. This chapter provides a survey of the software to give you general background for the programming information in Chapter 4, Writing Interface Definitions; Chapter 5, Developing Distributed Applications; and Chapter 7, Special Topics. Table 2-1 lists the DECrpc software.

The *ULTRIX Reference Pages* include a reference page for each utility, library routine, or daemon.

Table 2-1: DECrpc Software

Software	Description
`nidl`	Network Interface Definition Language compiler
`uuid_gen`	UUID generating program
`stcode`	Status code translator
`llbd`	Local Location Broker Daemon
`nrglbd`	Global Location Broker Daemon (non-replicatable)
`lb_admin`	Location Broker administrative tool
`.idl` files	Interface definitions
`.h` files	C header files
Library routines	`rpc_$`, `rrpc_$`, `socket_$`, `lb_$`, `uuid_$`, `error_$`, `pfm_$`, and `pgm_$` routines

Note

Although the names for the RPC library routines include a dollar sign ($), you must omit the dollar sign from the name when using the `man`(1) utility to read a reference page.

2.1 Daemons and Utilities

The programs described in this section run as shell commands. The utilities `nidl`(1ncs), `uuid_gen`(1ncs) and `stcode`(1ncs) help you to develop distributed applications. The Location Broker daemons, `nrglbd`(8ncs) and `llbd`(8ncs), enable client applications to locate servers on remote hosts. The administrative tool, `lb_admin`(1ncs), helps you to maintain Location Broker databases.

2.1.1 The uuid_gen(1ncs) Utility

The `uuid_gen` utility generates a UUID. Depending on the options you specify, `uuid_gen` produces as output a character string representing a UUID, a C initialization for the UUID, or a skeletal interface definition file in the C syntax of NIDL.

2.1.2 The NIDL Compiler

The NIDL Compiler, `nidl`, compiles interface definitions. It takes as input an interface definition written in NIDL. It produces as output a server stub, a client stub, and a client switch (all in the C language), together with header files.

2.1.3 Location Broker Daemons

DECrpc includes daemons that manage the Local Location Broker (LLB) database and the Global Location Broker (GLB) database.

Any host that runs an RPC server must also run the LLB daemon, `llbd`. Any network that supports RPC activity must have at least one host running a GLB daemon. In an internet, at least one GLB daemon must run in each network.

The Location Broker daemons typically run as background processes. On most ULTRIX systems, they start at boot time from the file `/etc/rc.local`.

See *Guide to the Location Broker* for more information on Location Broker configuration.

2.1.4 Location Broker Administrative Tool

The `lb_admin` utility allows you to inspect or modify the contents of a Location Broker database. It provides lookup, register, unregister, and cleanup operations. It can perform these operations on any LLB or GLB database.

2.1.5 Status Code Translator

The `stcode` utility translates hexadecimal status code values produced by programs to textual messages.

2.2 The rpc_$ Client and Server Library Routines

The `rpc_$` library routines constitute the interface to the RPC runtime library. Some of these routines are used only by clients, some only by servers, and some by either clients or servers.

The next subsections describe each set of routines.

2.2.1 Client Routines

Most of the `rpc_$` client routines either create a handle or manage its binding state.

`rpc_$alloc_handle`

Allocates an RPC handle that identifies a specific object but not a specific server.

`rpc_$set_binding`

Sets the binding in an allocated handle so that it specifies a socket address.

`rpc_$bind`

Allocates an RPC handle and sets its binding. This call has the same effect as an `rpc_$alloc_handle` call followed by an `rpc_$set_binding` call.

`rpc_$clear_server_binding`

Removes the association of an RPC handle with a server, but retains the association with a host. If a client uses this handle to make a remote procedure call, the call is sent either to a well-known port or to the Local Location Broker forwarding port on the remote host.

`rpc_$clear_binding`

Removes the association of an RPC handle with a server and a host. This call saves the handle for reuse in accessing the same object, possibly via a different server. If a client uses this handle to make a remote procedure call, the call is broadcast.

`rpc_$dup_handle`

Returns a copy of an existing RPC handle. A handle is not freed until `rpc_$free_handle` is called on all copies of the handle.

`rpc_$free_handle`

Frees an RPC handle. This call removes any association of the handle with an object and an address and releases the handle.

`rpc_$set_async_ack`

Sets or clears asynchronous-acknowledgement mode in a client. Asynchronous-acknowledgement mode allows a client to acknowledge its receipt of replies from servers asynchronously, for greater efficiency.

`rpc_$set_short_timeout`

Sets or clears short-timeout mode on a handle. If a client uses a handle in short-timeout mode to make a remote procedure call, but the server shows no signs of life, the call fails quickly.

`rpc_$sar`

Sends a remote procedure call request and awaits a reply from the server. This call is for use only by client stubs that the NIDL Compiler generates, so there is no reference description for it.

2.2.2 Server Routines

This section describes the `rpc_$` server routines, most of which initialize the server so that it has a socket on which to listen and is registered with the RPC runtime library on its host.

`rpc_$use_family`

Creates a socket that the server will use to communicate with clients. You specify the address family. The runtime library assigns an available port number for the socket.

`rpc_$use_family_wk`

Creates a socket that uses a well-known port. You specify both the address family and the port number.

`rpc_$register`

Registers an interface with the RPC runtime library. This call is superseded by `rpc_$register_mgr` and `rpc_$register_object`. Any server that contains more than one implementation of a type interface or more than one version of a manager must use `rpc_$register_mgr` rather than `rpc_$register`.

`rpc_$register_mgr`

Registers a generic interface with the RPC runtime library. You specify an interface, a type for which the server exports the interface and the set of manager procedures that implement the interface for that type. Any server that contains more than one implementation or more than one version of a manager must use this call rather than `rpc_$register`.

`rpc_$register_object`

Registers an object with the RPC runtime library. You declare an object for which the server exports interfaces and declare the type of the object.

`rpc_$unregister`

Unregisters an interface that was previously registered with the server by the `rpc_$register_mgr` or `rpc_$register` routines. The server will not respond to requests for the unregistered interface.

`rpc_$listen`

Listens for remote procedure call requests from clients. When a request is received, call the requested manager procedure for the requested operation and send the result in a reply to the client.

`rpc_$inq_object`

Returns the UUID of the object represented by an RPC handle. This call enables manager procedures to determine the specific object that they must access.

`rpc_$shutdown`

Shuts down. The server stops processing incoming requests and `rpc_$listen` returns.

`rpc_$allow_remote_shutdown`

Allows or disallows remote shutdown initiated by `rpc_$shutdown`.

`rpc_$set_fault_mode`

Controls handling of faults that occur in server routines. By default, the server reflects faults back to the client and continues processing. You can use this routine to set the fault-handling mode so that the server sends a ''communications failure'' fault to the client and exits.

2.2.3 Routines for Clients or Servers

The `rpc_$` routines listed in this section can be used by either clients or servers.

`rpc_$inq_binding`

Returns the socket address identified by an RPC handle. Typically, a client uses this call to identify the specific server that responded to a remote procedure call.

`rpc_$inq_object`

Returns the UUID of the object represented by an RPC handle.

`rpc_$name_to_sockaddr`

Given a host name and port number, returns the equivalent socket address. This call is superseded by `socket_$from_name`.

`rpc_$sockaddr_to_name`

Given a socket address, returns the equivalent host name and port number. This call is superseded by `socket_$to_name`.

2.3 The rrpc_$ Client Library Routines

This section describes the `rrpc_$` routines. These routines enable a client to request information about a server or to shut down a server.

`rrpc_$inq_stats`

Obtains statistics about a server.

`rrpc_$inq_interfaces`

Obtains a list of the interfaces that a server exports.

`rrpc_$shutdown`

Shuts down a server, if the server allows it. See `rpc_$allow_remote_shutdown`.

2.4 The socket_$ Library Routines

This section describes the `socket_$` routines. These routines manipulate socket addresses. Unlike the calls that operating systems typically provide, the `socket_$` routines operate on addresses of any protocol family.

`socket_$equal`

Compares two socket addresses.

`socket_$to_name`

Converts a socket address to a textual host name and port number.

`socket_$to_numeric_name`

Converts a socket address to a numeric host name and port number.

`socket_$from_name`

Converts a textual host name and port number to a socket address.

`socket_$family_to_name`

Converts the integer value of a protocol family to its textual name.

`socket_$family_from_name`

Converts the textual name of a protocol family to its integer value.

`socket_$valid_family`

Checks whether an address family is usable.

`socket_$valid_families`

Lists the address families that are usable.

2.5 The lb_$ Library Routines

This section describes the `lb_$` routines. These routines constitute the interface to the Location Broker Client Agent. The routines direct the Client Agent to look up, register, or unregister entries in a Location Broker database.

`lb_$lookup_object`

Finds entries in the GLB database that match the specified object identifier.

`lb_$lookup_type`

Finds entries in the GLB database that match the specified type identifier.

`lb_$lookup_interface`

Finds entries in the GLB database that match the specified interface identifier.

`lb_$lookup_object_local`

Finds entries in the specified LLB database that match the specified object identifier.

`lb_$lookup_range`

Finds entries in the specified database (LLB or GLB) that match the specified combination of object, type, and interface UUIDs.

`lb_$register`

Registers a specific object and interface, that is, creates an entry in the Location Broker database. You can specify an entry as local or global. If it is local, it will be registered only in the LLB. If it is global, it will also be registered in the GLB.

`lb_$unregister`

Unregisters a specific object and interface, that is, removes an entry from the Location Broker database.

2.6 The uuid_$ Library Routines

This section describes the `uuid_$` routines. These routines generate and manipulate Universal Unique Identifiers.

`uuid_$gen`

Generates a new UUID.

`uuid_$decode`

Converts a character-string representation of a UUID (as generated by the `uuid_gen` utility) into a `uuid_$t` value that is usable by a program.

`uuid_$encode`

Converts a UUID into its character-string representation.

`uuid_$equal`

Compares two UUIDs.

2.7 The error_$ Library Routines

Most of the runtime library routines indicate their completion status with status codes. The `error_$` routines, which are listed in this section, convert these status codes into textual error messages.

`error_$c_get_text`

Returns system, module, and error texts for a status code.

`error_$c_text`

Returns an error message for a status code.

2.8 The pfm_$ Library Routines

The `pfm` fault management routines, which are described in this section, allow programs to manage signals, faults, and exceptions by establishing cleanup handlers.

`pfm_$cleanup`

Establishes a cleanup handler.

`pfm_$enable`

Enables asynchronous faults after they have been inhibited by a call to `pfm_$inhibit`.

`pfm_$enable_faults`

Enables asynchronous faults after they have been inhibited by a call to `pfm_$inhibit_faults`.

`pfm_$inhibit`

Inhibits asynchronous faults.

`pfm_$inhibit_faults`

Inhibits asynchronous faults but allows task switching.

`pfm_$init`

Initializes the PFM package.

`pfm_$reset_cleanup`

Resets a cleanup handler.

`pfm_$rls_cleanup`

Releases cleanup handlers.

`pfm_$signal`

Signals the calling process.

2.9 The pgm_$ Library Routine

The `pgm_$exit` program management routine listed in this section is often used at the end of a cleanup handler to terminate a program.

`pgm_$exit`

Exits from the calling program.

2.10 The System idl Directory

The system `idl` directory, `/usr/include/idl`, contains several interface definition files distributed with DECrpc.

2.10.1 Interface Definition Files for Types and Constants

The following files in the system `idl` directory define only data types and constants, not operations:

`base.idl`

Defines some basic types and constants.

`nbase.idl`

Defines types and constants used in network interfaces.

`ncastat.idl`

Defines the completion status codes specified by the RPC runtime library.

Several of the interface definitions described in the following sections import one or more of these files.

2.10.2 Interface Definition Files for Local Interfaces

The following files in the system `idl` directory define local interfaces:

`lb.idl`

Defines the interface to the Location Broker Client Agent.

`rpc.idl`

Defines the interface to the RPC runtime library. The NIDL Compiler automatically imports `rpc.idl` when it compiles the definition for any remote interface.

`socket.idl`

Defines types, constants, and operations pertaining to socket addresses and protocol families.

`uuid.idl`

Defines types, constants, and operations pertaining to UUIDs

The operations in these interfaces cannot be called remotely. The NIDL defines the interfaces so that header files can be generated from a common source. The NIDL files, rather than the generated header files, serve as readable descriptions of the interfaces.

2.10.3 Interface Definition Files for Remote Interfaces

The following files in the system `idl` directory define remote interfaces:

`conv.idl`

Defines operations that manage client-server conversations.

`glb.idl`

Defines the interface to the Global Location Broker.

llb.idl

Defines the interface to the Local Location Broker.

rrpc.idl

Defines operations that a client can use to request information about a server or to shut down a server.

You should not ordinarily need to call any of the operations in the conv_, glb_, and llb_ interfaces, because you can access most of their functionality through the lb_ and rpc_ interfaces.

The rrpc_ interface is automatically exported by every RPC server. Its operations are implemented by the runtime support for the server and are not part of the server proper.

2.11 Header Files and Insert Files

For each of the interface definition files described in the previous section, DECrpc provides corresponding header files in C. DECrpc also provides two header files that are hand coded, not generated from an interface definition.

The C header files reside in the c subdirectory of the system idl directory, /usr/include/idl. Many C compilers support options that allow you to specify this directory as a place where the compiler should look for header files.

idl_base.h

This file defines primitives that are present in NIDL but lacking in C, such as the boolean type. The idl_base.h file also contains declarations or definitions for data types, external functions, and macros used by stubs.

pfm.h

This file defines a portable interface to the Process Fault Manager subsystem.

Steps in Building a Distributed Application 3

To build a distributed application, you combine code that the NIDL Compiler generates with code that you write. This chapter describes the binop application to introduce the steps in building a distributed application. Section 3.1 uses binop to illustrate NIDL interface definitions, and Section 3.2 describes the user-written files for the application. Many details, however, are unexplained in this section. Chapters 4, 5, 6, and 7 describe interface definition and application development more thoroughly.

See also Section 3.3, which describes binop_lu, an application that uses the Location Broker.

3.1 A Distributed Application: the binop Interface Definition

This section describes binop, an application that performs integer additions on a remote server. The /usr/examples/ncs/binop directory contains the source code files for binop.

The binop application uses explicit handles and manual binding. The binop.idl file, shown in Example 3-1, defines the binop interface. Section 3.2 describes the binop client and server programs.

Chapter 4 describes how to generate the UUID and the skeletel interface definition file with uuid_gen.

Example 3-1: The binop.idl Interface Definition

```
%c   1
[uuid(41979f30a000.0d.00.00.fb.40.00.00.00),   2
     port( ip:[6677]),version(1)]
interface binop
{

[idempotent]   3
void binop$add( 4
     handle_t [in] h,
     long [in] a,
     long [in] b,
     long [out] *c
     );
}
```

$\boxed{1}$ The first line of the interface definition states that the definition uses the C syntax of NIDL.

$\boxed{2}$ The next three lines specify the UUID, well-known ports, version, and name of the interface.

3 This operation has the **idempotent** attribute, which specifies that the operation can safely be executed more than once and allows the RPC runtime library to employ more efficient calling semantics.

4 The remainder of the definition defines the signature of `binop$add`, the one operation in the interface. The first parameter is an RPC handle. The next two are inputs. The last parameter is an output.

Since the `binop` example imports no other interface definitions, defines no constants, and uses only predefined data types, it does not illustrate the NIDL import, constant, and type declarations. Examples in Chapter 5 and 6 illustrate these constructs.

To keep the client and server for `binop` very simple, the interface definition specifies well-known ports. However, as Chapter 1 recommends, you should avoid well-known ports in real applications and use opaque ports instead. Section 3.3 describes the `binop_lu` example, which uses opaque ports by means of Location Broker lookups. Chapters 4 and 5 develop the `binop_fw` example, which uses opaque ports by means of Location Broker forwarding.

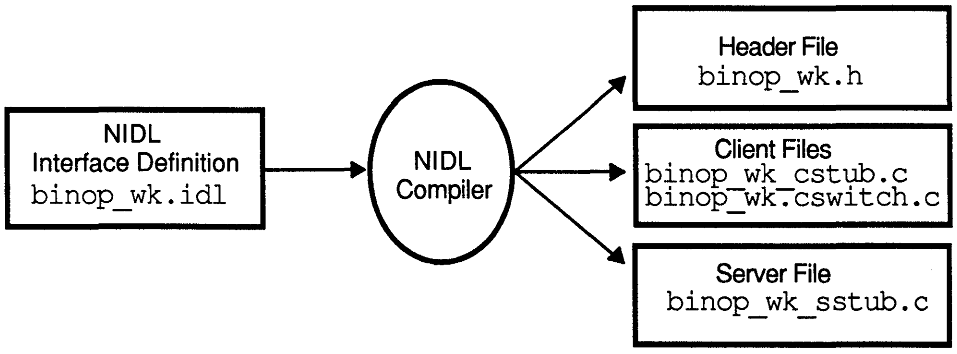
To compile an interface definition, run the NIDL Compiler in the examples directory as shown for `binop` in this example:

```
$ nidl binop.idl -m
```

The `-m` option allows a server to export more than one version of an interface and to implement an interface for more than one type. The compiler appends the version number to the interface name when it generates identifiers in the stub and header files. For example, the interface specifier for version 2 of the `binop` interface would be `binop_v3$if_spec`.

Figure 3-1 shows the input and output files involved in the compilation of `binop.idl`. If you build the `binop` programs in the example directories, as described in the next section, you can examine the stub, switch, and header files that the NIDL Compiler produces. (The switch file (`binop_cswtch.c`) is generated but is not used.)

Figure 3-1: Input and Output Files in the binop.idl Compilation



ZK-0085U-R

The header file `binop.h` declares the `binop$add` procedure, initializes the `binop_v1$if_spec` interface specifier, and defines the `binop_v1$epv_t` data type. It also contains directives to include the standard DECrpc header files that define basic data types and declare RPC runtime library routines.

An `if_spec` is a data structure that clients and servers pass to the RPC runtime library when they bind or register an interface. An `epv_t` is the data type for an **entry point vector** (EPV), a record of pointers to the operations in an interface. If you run the NIDL Compiler with the `-m` option, which allows multiple versions of an interface, the NIDL Compiler appends the version number, for example, `_v1`, to the interface name when it generates EPV identifiers.

The `binop_cstub.c` and `binop_cswtch.c` modules together implement the client stub. They contain a procedure named `binop$add`. This procedure marshalls its two input arguments, *a* and *b*, into an RPC packet and calls `rpc_$sar` to send a remote procedure call. When `rpc_$sar` returns, the result is unmarshalled from the returned packet into the output argument, *c*.

The module `binop_sstub.c` is the server stub. It unmarshalls *a* and *b* from the packets sent by clients, then passes those values to the manager procedure `binop$add`. It marshalls the result, *c,* into an RPC packet and returns control to the RPC runtime library, which sends the packet back to the waiting client.

As Figure 3-1 shows, the NIDL Compiler generates two client files for an interface: a stub file, *interface*`_cstub.c`, and a switch file, *interface*`_cswtch.c`. The client switch contains ''public'' procedures (such as `binop$add`), while the client stub contains only ''private'' procedures whose names are not visible outside of the `_cstub.c` file. The client stub defines an EPV containing function pointers to the private procedures, and the client switch invokes these procedures through the EPV (for example, by calling `binop_v1$client_epv.binop$add`).

To build a client, you link both the client switch and the client stub with the client. The client calls the procedures by their ordinary public names, as specified in the NIDL definition. These procedures are contained in the client switch, which then calls the client stub procedures through the client EPV.

3.2 A Distributed Application: the binop User-Written Files

Section 3.1 described the compiler-generated files for the `binop` example. This section describes the user-written files:

`client.c`	The main client module
`server.c`	The main server module
`binop.c`	The manager

The `client.c` and `server.c` examples shown in this chapter omit some conditional and diagnostic code, the utility module `util.c`, and the compiler-generated header, stub, and switch files. The `binop` example directory contains complete source code for `binop`.

3.2.1 The Client

The `binop` application uses well-known ports, explicit handles, and manual binding. The client code generates and binds an RPC handle that it passes as the first argument in its remote procedure calls.

Example 3-2 shows the client module, `client.c`.

Example 3-2: The client.c Module for binop

```
#include <sys/time.h>
#include <stdio.h>
#include "binop.h"
#include "socket.h"
#define CALLS_PER_PASS 100

globalref uuid_$t uuid_$nil;

main(argc, argv)
int argc;
char *argv[];
{
    handle_t h;
    status_$t st;
    socket_$addr_t loc;
    unsigned long llen;
    long i, n;
    int k, passes;
    int start_time, stop_time;

    if (argc != 3) {
        fprintf(stderr, "usage: client hostname passes\n"); $\boxed{1}$
        exit(1);
    }

    passes = atoi(argv[2]);

    socket_$from_name(socket_$unspec, (ndr_$char *) argv[1], $\boxed{2}$
        (long) strlen(argv[1]), (long) rpc_$unbound_port,
        &loc, &llen, &st);

    h = rpc_$bind(&uuid_$nil, &loc, llen, &st);         $\boxed{3}$

    for (k = 1; k <= passes; k++) {
        start_time = time(NULL);
        for (i = 1; i <= CALLS_PER_PASS; i++) {
            binop$add(h, i, i, &n); $\boxed{4}$
            if (n != i+i)
                printf("Two times %ld is NOT %ld\n", i, n);
        }
        stop_time = time(NULL);
        printf("pass %3d; real/call: %2d ms\n",
            k, ((stop_time - start_time) * 1000) / CALLS_PER_PASS);
    }
}
```

$\boxed{1}$ This example program takes two arguments: the network address of a host where a server is running and the number of passes to execute.

$\boxed{2}$ To convert the network address of the server host to a socket address, the client calls `socket_$from_name`, part of the socket address manipulation interface in the RPC runtime library. Because the port parameter for `socket_$from_name` is the predefined constant `rpc_$unbound_port`, the resulting socket address specifies a host, but not a particular port at that host.

$\boxed{3}$ The client then supplies this socket address to the `rpc_$bind` library call, which creates an RPC handle and binds this handle to the socket address. Because the socket address does not specify a port, the `rpc_$bind` call generates a bound-to-host handle. The first argument to `rpc_$bind`, the object identifier, is `uuid_$nil`, because `binop` does not operate on any particular object.

4 When the client issues its first call to binop$add, the RPC runtime library at the client host extracts the well-known port number for the server from the binop_v1$if_spec interface specifier, so that the handle is fully bound when the runtime library sends the request. The handle remains fully bound for all subsequent calls.

3.2.2 The Server

Example 3-3 shows the server module, server.c.

Example 3-3: The server.c Module for binop

```
#include <stdio.h>
#include "binop.h"
#include "socket.h"

globalref uuid_$t uuid_$nil;
globalref binop_v1$epv_t binop_v1$manager_epv;

main(argc, argv)
int argc;
char *argv[];
{
    status_$t st;
    socket_$addr_t loc;
    unsigned long llen;
    unsigned long family;
    socket_$string_t name;
    unsigned long namelen = sizeof(name);
    unsigned long port;

    if (argc != 2) {
        fprintf(stderr, "usage: server family\n"); 1
        exit(1);
    }

    family = socket_$family_from_name((ndr_$char *) argv[1], 2
        (long) strlen(argv[1]), &st);
    rpc_$use_family_wk(family, &binop_v1$if_spec,  3
        &loc, &llen, &st);

    rpc_$register_mgr(  4
        &uuid_$nil,  5
        &binop_v1$if_spec,
        binop_v1$server_epv,
        (rpc_$mgr_epv_t) &binop_v1$manager_epv,
        &st);

    socket_$to_name(&loc, llen, name, &namelen, &port, &st);  6
    name[namelen] = 0;
    printf("Registered: name='%s', port=%ld\n", name, port);

    rpc_$listen((long) 1, &st);  7
}
```

1 This program takes one argument, the name of an address family.

2 The call to socket_$family_from_name converts the address family name into the integer representation of the family, returned as family.

3 The server then supplies `family` and the `binop` interface specifier to `rpc_$use_family_wk`, which creates a socket for the server at its well-known port. The `loc` variable stores this socket address.

4 In order to communicate with clients, a server registers itself with the RPC runtime library at its host. The `binop` server calls `rpc_$register_mgr` to tell the runtime library that it exports the `binop_v1` interface.

5 The first argument to `rpc_$register_mgr`, the type identifier, is `uuid_$nil`, because `binop` does not operate on an object. If a server operates on objects of several types, as in Figure 1-7, it registers its managers by calling `rpc_$register_mgr` once for each type, and it must register its objects by calling `rpc_$register_object` once for each object.

6 After registering with the RPC runtime library, the `binop` server calls `socket_$to_name` to extract a textual network address and a port number from its socket address, and it uses this information to print an announcement of its registration.

7 Finally, it invokes `rpc_$listen` to begin handling remote procedure calls. The first argument to `rpc_$listen` must be 1.

3.2.3 The Manager

The manager module `binop.c` is shown in Example 3-4. This code is linked with the server module.

Example 3-4: The binop.c Manager Module

```
#include "binop.h"

globaldef binop_v1$epv_t binop_v1$manager_epv   {  1
    binop$add
};

void binop$add(h, a, b, c) 2
handle_t h;
long a, b, *c;
{
    *c = a + b;
}
```

1 The module first defines the manager EPV `binop_v1$manager_epv`.

2 The next lines contain the actual implementation of the `binop$add` procedure.

3.2.4 Building and Running the binop Programs

The `binop` client program is the result of compiling these programs:

- `client.c`
- `util.c`
- `binop_cstub.c`
- `binop_cswtch.c`

The server program is the result of compiling these programs:

- `server.c`
- `util.c`
- `binop.c`
- `binop_sstub.c`

All of these modules contain a `#include` directive to incorporate the definitions in `binop.h`.

To create the `binop` programs on your system, execute the `Makefile` file in the example directory. The file runs the NIDL Compiler to generate stub, switch, and header files, and then runs a C Compiler to build the client and server programs.

To run `binop`, first start the server, specifying the `ip` address family:

```
$ server ip
Registered: name'ip:elektra', port=6677
```

After the server has registered itself, run the client, specifying the network address of the server host (in this example, elektra) and the number of passes to execute:

```
$ client ip:elektra 4
pass   1; real/call: 20 ms
pass   2; real/call: 20 ms
pass   3; real/call: 10 ms
pass   4; real/call: 10 ms
```

3.3 Using Location Broker Lookups: the binop_lu Example

Sections 3.1 and 3.2 described `binop`, an application that uses well-known ports to coordinate communication between client and server. The examples in this section show a modified version of `binop` that uses opaque ports by means of Location Broker lookups. The modified example is called `binop_lu`. As in the `binop` example, the code shown omits some conditional and diagnostic code.

See also Chapter 1, which describes issues to consider if you are designing an application that in the future may use a name service other than the Location Broker.

3.3.1 The Interface Definition

The interface definition for `binop_lu` (Example 3-5) differs from the definition for `binop` (Example 3-1) in the interface UUID, the interface and operation names, and the absence of well-known ports.

Example 3-5: The binop_lu.idl Interface Definition

```
%c
[uuid(41979f38d000.0d.00.00.fb.40.00.00.00), version(1)]
interface binop_lu
{

[idempotent]
void binop_lu$add(
    handle_t [in] h,
    long [in] a,
```

Example 3-5: (continued)

```
    long [in] b,
    long [out] *c
    );
}
```

3.3.2 The Client

Example 3-6 contains the code for the `binop_lu` client.

Example 3-6: The client.c Module for binop_lu

```
#include <sys/time.h>
#include <stdio.h>
#include "binop_lu.h"
#include "lb.h"
#include "socket.h"
#define CALLS_PER_PASS 100

globalref uuid_$t uuid_$nil;

main(argc, argv)
int argc;
char *argv[];
{
    handle_t h;
    status_$t st;
    lb_$entry_t entry;
    lb_$lookup_handle_t ehandle = lb_$default_lookup_handle;
    unsigned long nresults;
    socket_$addr_t loc;
    unsigned long llen;
    long i, n;
    int k, passes
    int start_time, stop_time;
    if (argc != 2) {
        fprintf(stderr, "usage: client passes\n");  [1]
        exit(1);
    }
    passes = atoi(argv[1]);

    lb_$lookup_interface(&binop_lu_v1$if_spec.id, &ehandle, 1, [2]
        &nresults, &entry, &st);

    h = rpc_$bind(&uuid_$nil, &entry.saddr, entry.saddr_len, &st); [3]

    for (k = 1; k <= passes; k++) {
        start_time = time(NULL);
        for (i = 1; i <= CALLS_PER_PASS; i++) {
            binop_lu$add(h, i, i, &n);
            if (n != i+i)
                printf("Two times %ld is NOT %ld\n", i, n);
        }
        stop_time = time(NULL);
        printf("pass %3d; real/call: %2d ms\n",
            k, ((stop_time - start_time) * 1000) / CALLS_PER_PASS);
    }
}
```

[1] The `binop_lu` client program takes only one argument, the number of passes to execute. Unlike the `binop` client, which converts a host name to a socket

address, the `binop_lu` client looks up a server address in the Location Broker database. There is no need for the user to specify a host name.

2 The `lb_$lookup_interface` call takes the place of the `socket_$from_name` call in the `binop` client (Example 3-2). This lookup call returns a Global Location Broker database entry that matches the `binop_lu` interface UUID. The returned entry contains, in its `saddr` field, the socket address of the server.

3 Addresses in Location Broker entries always specify a port number, so the handle returned by `rpc_$bind` in this example is fully bound.

3.3.3 The Server

The `binop_lu` server (Example 3-7) differs from the `binop` server (Example 3-3) in two important ways:

- The `binop_lu` server calls `rpc_$use_family` rather than `rpc_$use_family_wk` to obtain the socket on which it listens. This call requests the RPC runtime library to dynamically assign an available port.
- The server calls `lb_$register` to register its interface and its socket address with the Global Location Broker.

Example 3-7: The server.c Module for binop_lu

```
#include <stdio.h>
#include "binop_lu.h"
#include "lb.h"
#include "socket.h"

globalref uuid_$t uuid_$nil;
globalref binop_lu_v1$epv_t binop_lu_v1$manager_epv;

main(argc, argv)
int argc;
char *argv[];
{
    status_$t st;
    socket_$addr_t loc;
    unsigned long llen;
    unsigned long family;
    socket_$string_t name;
    unsigned long namelen = sizeof(name);
    unsigned long port;
    lb_$entry_t entry;

    if (argc != 2) {
        fprintf(stderr, "usage: server family\n");
        exit(1);
    }

    family = socket_$family_from_name((ndr_$char *) argv[1],
        (long) strlen(argv[1]), &st);
    rpc_$use_family(family, &loc, &llen, &st); 1

    rpc_$register_mgr(
        &uuid_$nil,
        &binop_lu_v1$if_spec,
        binop_lu_v1$server_epv,
```

Example 3-7: (continued)

```
             (rpc_$mgr_epv_t) &binop_lu_v1$manager_epv,
             &st);

        lb_$register(&uuid_$nil, &uuid_$nil, &binop_lu_v1$if_spec.id, 0, 2
             (ndr_$char *) "binop_lu example", &loc, llen, &entry, &st);

        socket_$to_name(&loc, llen, name, &namelen, &port, &st);
        name[namelen] = 0;
        printf("Registered: name'%s', port=%ld\n", name, port);

        rpc_$listen((long) 1, &st);
}
```

1 The call to `rpc_$use_family` requests the RPC runtime library to dynamically assign an available port.

2 The call to `lb_$register` registers the interface and its socket address with the Global Location Broker. The first two arguments to `lb_$register`, the object and type identifiers, are both `uuid_$nil`, because `binop` does not operate on an object. The server supplies the text string ''binop_lu example'' as an annotation for its Location Broker database entry.

3.3.4 The Manager

Except for name changes, the `binop_lu` manager (Example 3-8) is the same as its counterpart in `binop` (Example 3-4).

Example 3-8: The binop_lu.c Manager Module

```
#include "binop_lu.h"

globaldef binop_lu_v1$epv_t binop_lu_v1$manager_epv  {
    binop_lu$add
};

void binop_lu$add(h, a, b, c)
handle_t h;
long a, b, *c;
{
    *c = a + b;
}
```

3.3.5 Building and Running the binop_lu Programs

You must set up Location Broker services on your network or internet before you can run the `binop_lu` client and server. A Global Location Broker should be running on at least one host in the network or internet where you intend to run a client or server. A Local Location Broker should be running on each host where you intend to run a server. *Guide to the Location Broker* contains guidelines for configuring the Location Broker and procedures for starting Location Broker daemons.

After you set up the Location Broker services and build the `binop_lu` application, start the `binop_lu` server, specifying the address family as `ip` as shown in this example:

```
$ server ip
Registered: name'ip:elektra', port=1330
```

Your port number may differ from this one, because `binop_lu` uses dynamically assigned opaque ports.

After the server has registered itself, run the client, specifying the number of passes to execute as shown in this example:

```
$ client 4
pass    1; real/call: 20 ms
pass    2; real/call: 20 ms
pass    3; real/call: 10 ms
pass    4; real/call: 10 ms
```

Writing Interface Definitions 4

The first step in developing a distributed application is to define its interface or interfaces in Network Interface Definition Language (NIDL). A NIDL interface definition contains:

- A heading
- Import declarations
- Constant declarations
- Type declarations
- Operation declarations

The NIDL Compiler uses the information in an interface definition to generate header files and client and server stubs.

This chapter explains how to:

- Generate an interface Universal Unique Identifier (UUID) and a skeleton interface file
- Write an interface definition in NIDL
- Run the NIDL Compiler to produce the server and client stub files

This chapter shows the development of an interface definition for `binop_fw`, an application that uses the Location Broker forwarding facility to perform integer additions on a remote server. Chapter 5 describes how to develop and build the `binop_fw` client and server programs.

This chapter introduces NIDL through examples rather than syntax descriptions. For details of NIDL syntax, see Chapter 6.

4.1 Generating Interface UUIDs

Each object, type, and interface must have a UUID. You must generate a new UUID each time you create an object, type, or interface. You can create a UUID with the `uuid_gen` utility or in your application program with the `uuid_$gen` routine.

To generate a skeletal interface definition file in the C syntax, run `uuid_gen` with the `-c` option as shown in this example. The command generates the interface definition file and places the output in the file `binop_fw.idl`.:

```
$ /etc/ncs/uuid_gen -c > binop_fw.idl
```

Example 4-1 shows the interface file generated by `uuid_gen`.

Example 4-1: Interface File Generated by uuid_gen

```
%c [1]
[
uuid(41979f400000.0d.00.00.fb.40.00.00.00), [2]
version(1)
]
interface INTERFACENAME { [3]
}
```

[1] The first line of the skeletal definition is the **syntax** identifier, which is `%c` in this example, for the C language.

[2] The next part of the definition is the heading, which specifies a name, a UUID, and a version number for the interface.

[3] The last part of the definition is an empty pair of braces between which go import, constant, type, and operation declarations. This chapter describes the syntax for the declarations.

By convention, the names of interface definition files end with the suffix `.idl`. To generate names for header, stub, and switch files, the NIDL Compiler replaces the suffix with `.h`, `_cstub.c`, `_cswtch.c`, and `_sstub.c`.

4.2 The Heading

The heading of an interface definition specifies the name and attributes of the interface.

4.2.1 Interface Names

After you have used `uuid_gen` to generate a skeletal interface definition, replace the dummy string ''INTERFACENAME'' with the name of your interface.

One naming convention uses interface names that end with an underscore, such as `rpc_` and `socket_`. Operation names begin with a dollar sign ($), so that operations in interfaces have names such as `rpc_$listen` and `socket_$equal`. Applications have interface names such as `bank` and `binop` and operation names such as `bank$deposit` and `binop$add`.

4.2.2 Interface Attributes

There are five interface attributes. Any interface that contains operations must specifiy at least the `uuid` attribute or the `local` attribute.

`uuid`	The Universal Unique Identifier assigned to the interface by `uuid_gen`. No other object, type, or interface can be assigned this UUID.
`version`	The version number of the interface. If you want several versions of an interface to coexist, you can distinguish them with version numbers.
`port`	The well-known port or ports on which servers exporting this interface will listen. In most cases, you should not use the `port` attribute; instead, you should allow the RPC runtime library to assign ports dynamically. See Chapter 1 for a discussion of well-known ports.

`implicit_handle`
: The global variable containing handle information. If you do not specify this attribute, the handle must be passed as an explicit parameter to each operation.

`local`
: A flag indicating that the NIDL Compiler should generate only header files (`.h`), not stubs. The interface definition should contain declarations only for constants and types, not for operations. If you specify the `local` attribute, the NIDL Compiler ignores any other interface attributes.

4.2.3 Examples of Interface Headings

The heading for the `binop_fw` interface definition specifies only an interface UUID, a version number, and the interface name:

```
[uuid(41979f400000.0d.00.00.fb.40.00.00.00), version(1)]
interface binop_fw
```

The heading for the `binop` application (see Chapter 3) specifies well-known ports for the IP address family:

```
[uuid(41979f30a000.0d.00.00.fb.40.00.00.00),
    port(ip:[6677]), version(1)]
interface binop
```

4.3 Import Declarations

The NIDL `import` declaration is similar to the C `#include` directive. An `import` declaration specifies another interface definition whose types and constants are used by the importing interface.

The `import` declaration allows you to collect the 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 `lookup` and `update`, and these interfaces have many constants in common, you can declare those constants in a `db.idl` file and import this file in the `lookup.idl` and `update.idl` interface definitions:

```
[
uuid(41979f400000.0d.00.00.fb.40.00.00.00),
version(1)
]
interface lookup {

import 'db.idl';
}
```

Interface definitions can also use the `import` declaration to import one or more of the files supplied in the system `idl` directory, `/usr/include/idl`. (You should never need to explicitly import `rpc.idl`, the interface definition for the RPC runtime library, since the NIDL Compiler automatically imports `rpc.idl` when it compiles any interface without the `local` interface attribute.)

The `-idir` option of the NIDL Compiler allows you to specify a directory from which the Compiler will resolve the pathnames of imported files. You can thereby avoid putting absolute pathnames in your interface definitions.

Chapter 2 describes files in `/usr/include/idl`.

4.4 Constant Declarations

The NIDL `const` declaration allows you to declare integer, character, or character string constants, as in the following examples:

```
[
uuid(41979f400000.0d.00.00.fb.40.00.00.00),
version(1)
]
interface music {

import 'music.idl';
const int array_size  100;
const char jsb  "Johann Sebastian Bach";
}
```

4.5 Type Declarations

NIDL provides a variety of data types, including simple types (such as integers, floating-point numbers, characters, and enumerations), constructed types (such as sets, strings, structures, unions, arrays, and pointers), and the `handle_t` type. The NIDL type declaration lets you give a name to any of these types.

The general form of a type declaration is

```
typedef [ type_attribute_list ] type_specifier type_declarator_list;
```

The *type_declarator_list* is optional.

This type declaration defines `integer32` as a name for a 32-bit integer type:

```
typedef   long integer32;
```

4.5.1 The Type Attributes handle and transmit_as

The type attributes `handle` and `transmit_as` specify characteristics of a named type.

The `handle` attribute specifies that a type can serve as a generic handle. You supply an autobinding routine to convert the generic handle type to the RPC handle type.

The `transmit_as` attribute associates a **transmitted type** that stubs pass over the network with a **presented type** that clients and servers manipulate. You supply routines that perform conversions between the presented and transmitted types.

One use of the `transmit_as` attribute is to help applications pass complex data types such as trees, linked lists, and records that contain pointers. The NIDL Compiler cannot generate code to marshall and unmarshall (copy data into and out of RPC packets) these data types, but the `transmit_as` attribute allows you to supply routines that convert the complex types into simpler types that can be marshalled and unmarshalled.

You can also use this feature to pass data more efficiently. For example, you might write routines that convert between sparse arrays and packed arrays; stubs transmit packed arrays over the network, and they present sparse arrays to the client and server programs. Chapter 7 illustrates this technique.

4.5.2 The Field Attributes last_is and max_is

The field attributes `last_is` and `max_is` can apply either to members of structures or to parameters of operations. These attributes let you pass **open arrays** between clients and servers. An open array is an array whose length is determined at runtime, when an operation that uses it is called. The `last_is` and `max_is` attributes control the amount of data transmitted between the client and server and the amount of storage allocated at the server.

The type declaration for a structure containing an open array must specify `last_is` and can also specify `max_is`. Chapter 7 includes a description of the `last_is` and `max_is` attributes and presents an example.

4.5.3 Examples of Type Declarations

The following example declares the type `sockhandle_t` as the textual representation of a socket address and specifies that this type is to be used as a generic handle:

```
typedef [handle] socket_$string_t sockhandle_t;
```

The interface definition for an example called `sparse` declares the type `compress_t` as a structure containing an open array, then declares two array types, `compress_array` and `no_compress_array`:

```
/* a run-length-encoded representation of an array */
typedef struct {
    int last;
    int [last_is(last)] data[CARRAY_SIZE];
} compress_t;

/* this type will be transmitted as a more compact type */
typedef [transmit_as(compress_t)] int compress_array[ARRAY_SIZE];

/* this type will be transmitted as is */
typedef int nocompress_array[ARRAY_SIZE];
```

For more examples of type declarations, you can look at the files in `/usr/include/idl`, which contains interface definitions of structures used at run time, and in its `c` subdirectory, for C compiler include file formats. You can find representations of structures in these files so you will know the form if you want to extract information from a structure.

4.6 Operation Declarations

Operation declarations specify the signature of each operation in the interface, including the operation name, the type of data returned (if any), and the types of all parameters passed in the call. They also specify various field, parameter, and operation attributes.

The general form of an operation declaration is:

[*operation_attribute_list*] *type_specifier operation_declarator* (*parameter_list*) ;

The operation_attribute_list is optional. Each entry in the *parameter_list* specifies the type, attributes, and the name of a parameter.

This interface for a `sparse` operation contains the following declaration for the operation `sparse$compress_sum`:

```
[idempotent]
int sparse$compress_sum(
    handle_t [in] h,
    compress_array [in] array
    );
```

4.6.1 Operation Attributes

The operation attributes describe characteristics of an operation that affect communication between server and client. You can specify any of the following operation attributes:

- idempotent
- broadcast
- maybe
- comm_status

The `idempotent` attribute specifies that an operation can be executed any number of times, not just once. This attribute allows the RPC runtime library to forego enforcement of the default "at most once" semantics. You should specify `idempotent` for any operation that can safely be executed more than once. The `binopfw$add` operation is idempotent.

The `broadcast` attribute specifies that an operation should always be broadcast to all hosts on the local network, rather than delivered to a specific host. The RPC runtime library automatically applies idempotent semantics to any operation with the `broadcast` attribute. We discourage use of this attribute; see the discussion in Chapter 5.

The `maybe` attribute specifies that there is no need for confirmation that an operation has been executed. You can apply this attribute only if an operation has no output parameters and returns no value.

The `comm_status` attribute specifies that an operation returns a completion status. If a communications error occurs while the operation is executing, a cleanup handler in the client stub will catch the error and return the error code to the client.

4.6.2 Parameters

If an interface uses explicit handles, you must supply a handle as the *first* parameter in each operation declaration, as in the following example:

```
void exp$op(
    handle_t [in] h,
    int [in] a,
    int [in] b,
    int [out] c
    );
```

If an interface uses an implicit handle, you must specify the handle variable in an `implicit_handle` attribute of the interface, and the operations in the interface do not require handle parameters:

```
[uuid(338b5f985000.0d.00.00.37.27.00.00.00),
                implicit_handle(handle_t array_handle)]

void imp$op(
    int [in] a,
    int [in] b,
    int [out] c
    );
```

The in and out keywords in the preceding examples are parameter attributes. Section 4.2.2 describes the attributes you can apply to parameters.

4.6.3 Pointers as Parameters

NIDL pointers are really references: they must point to something and cannot be null.

In the C syntax of NIDL, specify a pointer by preceding the parameter name with an asterisk (*). This construct is used primarily for output parameters, which, as in C, must be passed by reference. You can also use pointers to denote input parameters passed by reference.

The NIDL Compiler generates code that can marshall and unmarshall pointers only at top level and not within any constructed types. Chapter 7 describes the data type conversion mechanism that allows you to overcome this restriction.

4.6.4 Arrays as Parameters

In the C syntax of NIDL, specify an array by placing the array length in brackets after the parameter name. Array subscripts start at 0. Arrays are always passed by reference, so an output array does not require a preceding asterisk. The following example specifies an array of 13 integers, indexed from 0 to 12, named `outputs`:

```
long [out] outputs[13]
```

NIDL also supports multidimensional arrays and open arrays. Chapter 6 explains array syntax in more detail.

4.6.5 Parameter Attributes

Characteristics of an operation parameter are specified by `parameter` attributes.

`in` The parameter is an input. It passes from client to server.

`out` The parameter is an output. It passes from server to client. In the C syntax of NIDL, an output parameter must be a pointer marked by the * operator.

`comm_status`
An operation returns a completion status. If a communications error occurs while the operation is executing, a cleanup handler in the client stub will catch the error and return the error code to the client.

4.6.6 The Field Attributes last_is and max_is

If you pass an open array (an array of variable length) as an operation parameter, you should use the `last_is` and `max_is` attributes to control how many elements are transmitted between the client and server and how much storage is allocated at the server. In operation declarations, field attributes appear together with parameter attributes, preceding the parameter.

Chapter 6 includes descriptions of these attributes. Chapter 7 discusses the attributes in more detail and provides an example.

4.6.7 Examples of Operation Declarations

The binop_fw interface definition declares one operation, binop_fw$add:

```
[idempotent]
void binop_fw$add(
    handle_t [in] h,
    long [in] a,
    long [in] b,
    long [out] *c
    );
```

The next example shows one operation from among several in the bank interface definition. This operation declares the UUID as the RPC handle.

```
[ uuid(35c2c6a25000.0d.00.00.c3.66.00.00.00), version(1) ]
interface bank{

import 'nbase.idl';

type int bank$acct_t [32]
  .
  .
  .
void bank$inq_acct(
    uuid_$t      [in]  h,
    bank$acct_t  [in]  acct,
    int          [out] balance,
    int          [out] trans_time,
    int          [out] create_time,
    );
  .
  .
  .
}
```

The interface definition for a primes procedure, declares a primes$gen operation:

```
[idempotent]
void primes$gen(
    handle_t     [in] h,
    int          [in, out] *last,
    int          [in] max,
    status_$t    [comm_status, out] *st,
    int          [in, out, last_is(last), max_is(max)]
values[]
    );
```

4.7 The binop_fw Interface Definition

Example 4-2 shows the complete definition for the binop_fw interface.

Example 4-2: The binop_fw Interface Definition

```
%c
[uuid(4448ee491000.0d.00.00.fe.da.00.00.00), version(1)]

interface binopfw
{
[idempotent]
void binopfw$add(
    handle_t [in] h,
```

Example 4-2: (continued)

```
    long [in] a,
    long [in] b,
    long [out] *c
    );
}
```

4.8 Running the NIDL Compiler

After you have written the interface definition, run the NIDL Compiler to generate stub and header files. The syntax for the command is shown in this example:

nidl *filename* [-m | -s] [*other options*]

The *filename* argument is the pathname of the interface definition file.

You should specify either the -m option or the -s option. These options determine how stubs generated by the Compiler will dispatch remote procedure calls. If you specify -m, the stubs will support multiple versions, multiple interfaces, or both within a single server, enabling you to build a server that exports more than one version of an interface. If you specify -s, the stubs will support only one version of an interface.

This command for the binop_fw application uses the -m option, which allows you to write multiple versions of the interface:

```
$ nidl binop_fw.idl -m
```

The examples directory contains a Makefile file that invokes the NIDL Compiler as follows:

```
nidl binop.idl -s -idir idl.d -no_cpp -idir /usr/include/idl
```

The -idir option specifies a directory from which the compiler should resolve pathnames of imported files. The -no_cpp option specifies that the interface definition should not be run through a C preprocessor before it is compiled.

On ULTRIX systems, the compilation of binop_fw.idl generates files named binop_fw.h, binop_fw_cstub.c, binop_fw_cswtch.c, and binop_fw_sstub.c. These files are used to build the binop_fw client and server programs.

Developing Distributed Applications 5

After you have written interface definitions for a distributed application, you write a client program, write a server program, and build the application. This chapter follows the `binop_fw` application, whose interface definition was presented in Chapter 4.

5.1 The binop_fw Application

Table 5-1 compares the `binop_fw` example with the `binop` and `binop_lu` examples. In `binop_fw`, the user of the client program specifies a server host on the command line, and the server listens on an opaque port dynamically allocated by the RPC runtime library. The server registers with the Local Location Broker on its host so that the LLB can forward calls to the server port. All three `binop` examples use explicit handles and manual binding in which the client code generates and binds an RPC handle that it passes as the first argument in its remote procedure calls.

Table 5-1: Comparison of the binop, binop_lu, and binop_fw Examples

Example	Server Host	Server Port	LB Registration	Call Delivery
`binop`	Specified on command line	Well-known	None	Direct to server port
`binop_lu`	Obtained from LB lookup	Opaque	Global and local	Direct to server port
`binop_fw`	Specified on command line	Opaque	Local only	From server host forwarding port

For applications in which the client knows where a server is running, you should use LLB forwarding, as illustrated in `binop_fw`. The server listens on an opaque port and does not require the server to register with the GLB. When the client makes its first remote procedure call, the server host LLB forwards the call to the server port. On return, the handle is fully bound, so that any subsequent calls go directly to the server port.

For applications in which the client does not know where a server is running, you should use Location Broker registration and lookup, as illustrated in `binop_lu`. The server listens on an opaque port and registers its objects, interfaces, and socket address with the GLB. The client uses a Location Broker lookup call to obtain the server socket address and fully binds the handle to this address.

Your applications should use opaque ports with one of these two techniques rather than well-known ports. (See the discussion of well-known ports in Chapter 1.)

Complete source code for the `binop` example is in the examples directory. Chapter 3 includes descriptions of `binop` and `binop_lu`.

5.2 Data Types and Portability

When you develop distributed applications, the client and manager code that you write must conform to the interfaces that you define. The C data types used by your code must therefore be equivalent to the NIDL data types specified in your interface definitions.

Many systems (including most systems with Motorola MC680x0, Intel 80x86, Digital VAX, or IBM System/370 processors) support C scalar types that correspond straightforwardly and exactly to the NIDL scalar types. On other systems, however, C types that match the NIDL types may not exist. A NIDL type may also be matched by different C types on different systems.

The NIDL Compiler generates C code that uses data types defined by the Network Data Representation (NDR) protocol. Every NIDL scalar type maps to one NDR scalar type; this mapping is the same for all systems. The header file `idl_base.h` contains C definitions of the NDR types for particular systems. To ensure portability, you can use NDR data types to declare variables that correspond to scalars specified in your interface definitions. The examples in this manual often use the NDR types `ndr_$char`, `ndr_$short_int`, and `ndr_$long_int`.

5.3 Writing the Client

This section explains how to write a client program. Section 5-4 presents the `binop_fw` client code.

5.3.1 Client Structure

The source code for a client program consists of these elements:

- The header file generated from your interface definition by the NIDL Compiler
- The client application itself, that is, the user-written code that implements the client program and calls the remote procedures
- The client switch generated from the interface definition by the NIDL Compiler
- The client stub generated from the interface definition by the NIDL Compiler
- Any user-written code that performs autobinding or data type conversion (see Chapter 7)

If a client imports several interfaces, the client source code must include the header file, client switch, client stub, any autobinding routines, and any type conversion routines for *each* interface.

Table 5-2 lists the source files that make up the client in the `binop_fw` example. There are two application code modules: `client.c`, which contains the main program, and `util.c`, which contains utility routines that are used by both the client and the server.

Table 5-2: Client Source Code Files for the binop_fw Example

Source Code File	Module
`binop_fw.h`	Header file generated by the NIDL Compiler
`client.c`	Main program
`util.c`	Utility routines used by client and server
`binop_fw_cswtch.c`	Client switch generated by the NIDL Compiler
`binop_fw_sstub.c`	Client stub generated by the NIDL Compiler

5.3.2 Managing RPC Handles

When a client makes a remote procedure call, it must specify to the RPC runtime library the object that it is trying to access. The client uses an RPC handle to represent the object and the location of a server that can execute the call.

5.3.2.1 Binding Techniques – There are two binding techniques:

Manual binding	The client creates and manages RPC handles directly.
Automatic binding	The client uses generic handles instead of RPC handles. Whenever the client makes a remote procedure call, the stub calls a user-written **autobinding routine** that converts the generic handle into an RPC handle.

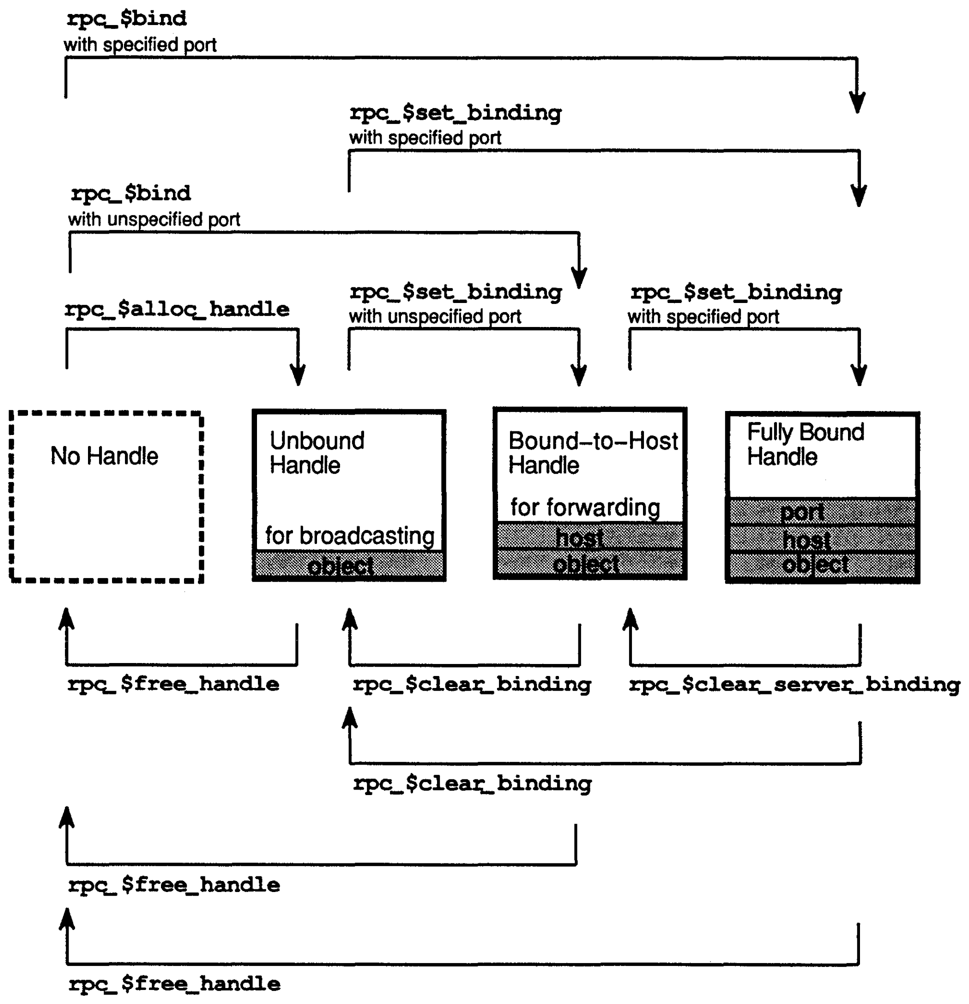
Chapter 1 discusses the differences between manual and automatic binding and compares the advantages and disadvantages of these techniques.

The binding technique determines where RPC handle management occurs, in client code or in autobinding code, but it does not affect how RPC handle management is implemented. You use the same library routines in both cases.

Like most of the examples in this book and in the online examples directory, `binop_fw` uses manual binding.

5.3.2.2 Overview of RPC Handle Management Routines – The RPC runtime library contains several routines that client applications can use to create handles, free handles, or change their binding states. Figure 5-1 illustrates the effects of these routines and shows the information represented in each possible binding state of an RPC handle. (See Section 5.3.4 for more information about RPC binding states.)

Figure 5-1: Calls That Manage RPC Handles and Their Binding States



ZK-0091U-R

5.3.2.3 Creating Handles – As Figure 5-1 illustrates, the `rpc_$bind` and `rpc_$alloc_handle` routines enable you to create an RPC handle in any binding state: fully bound, bound-to-host, or unbound.

The `rpc_$bind` routine takes as input an object UUID and a socket address. It creates a handle to represent the object and binds the handle to the socket address. You can create a fully bound handle by calling `rpc_$bind` with a fully specified socket address. You can create a bound-to-host handle by calling `rpc_$bind` with a socket address whose port number is `socket_$unspec_port`.

The `rpc_$alloc_handle` routine takes as input an object UUID. It creates an unbound handle to represent the object. You can use this handle to broadcast a remote procedure call, or you can invoke `rpc_$set_binding` to set its binding.

5.3.2.4 Changing Binding States

Changing Binding States – The `rpc_$set_binding` routine sets or resets the binding state in a handle. This routine enables a client to change the binding state without freeing and recreating the handle. For example, if an application sequentially accesses several locations of an object, the client can:

1. Use `rpc_$alloc_handle` to create a handle.
2. Use `rpc_$set_binding` to bind to a server.
3. Make the remote procedure call to access the object.

Repeat steps 2 and 3, binding to servers on each host in sequence, to access all of the other objects.

The client does not need to call `rpc_$clear_binding` before it rebinds the handle to the next server, because `rpc_$set_binding` replaces any existing binding.

As with `rpc_$bind`, you can use `rpc_$set_binding` to obtain a bound-to-host handle, if you supply as input a socket address with a port number of `socket_$unspec_port`. You can use `rpc_$clear_binding` or `rpc_$clear_server_binding` to remove parts of the binding information in a handle.

5.3.3 Obtaining Socket Addresses

To obtain the socket address that `rpc_$bind` and `rpc_$set_binding` require as input, you can use a Location Broker lookup routine or the `socket_$from_name` routine.

5.3.3.1 Using Location Broker Lookup Calls

Using Location Broker Lookup Calls – The Location Broker Client Agent offers routines that perform Location Broker lookups by object, type, interface, or any combination of these identifiers. Each lookup routine returns as output an array of database entries that match the specified criteria. This chapter illustrates the use of `lb_$lookup_interface`, which looks up servers by interface. The syntax and arguments for this routine are:

```
lb_$lookup_interface (&interface, &lookup_handle,
                      max_results, &num_results, results, &status);
```

The arguments are described here:

interface	an interface UUID
lookup_handle	a position in a Location Broker database
max_results	the maximum number of database entries that can be returned
num_results	the number actually returned
results	an array of the returned entries
status	the completion status

A client usually specifies `lb_$default_lookup_handle` as the value for `lookup_handle` in its first Location Broker lookup call; this value indicates that the lookup should start at the beginning of the database.

Chapter 3 described the `binop_lu` example, in which the client uses the Location Broker to find a server for the `binop_lu` interface. The client calls `lb_$lookup_interface` as follows:

```
status_$t st;
lb_$entry_t entry;
lb_$lookup_handle_t lookup_handle = lb_$default_lookup_handle;
unsigned long nresults;
. . .
do {
     lb_$lookup_interface(&binop_lu_v1$if_spec.id, &lookup_handle, 1L,
          &nresults, entry, &st);
     if (nresults < 1) {
          fprintf(stderr,
               "interface on valid family not found on lb_admin lookup\n");
          exit(1);
   }
} while (!socket_valid_family((long)entry.saddr.family, &st));
```

The `binop_lu` client initializes `lookup_handle` to the constant `lb_$default_lookup_handle`, which on input indicates that the lookup should begin at the start of the GLB database. The value 1L for `max_results` indicates that the routine can return at most one result; `nresults` is the number of entries that are actually returned.

If the lookup call returns an entry, the `binop_lu` client uses the routine `socket_$valid_family` to check that the address family for that entry is valid for the client host.

The `max_results` parameter specifies the maximum number of entries that a lookup routine can return (in the preceding example, one) and should not exceed the length of the `results` array.

If a lookup operation finds `max_results` entries before it has searched the entire database, it returns a value for `lookup_handle` that represents the start of the unsearched part of the database.

If a lookup operation reaches the end of the database before it finds `max_results` entries, it returns `lb_$default_lookup_handle` as the value of `lookup_handle`. Thus, a client can obtain all entries that match the lookup criteria by repeating the lookup call, using at each iteration the `lookup_handle` returned by the previous call, until the call returns `lb_$default_lookup_handle`.

Under normal conditions, repeated lookup calls obtain all matching entries in a database. However, some conditions can cause entries to be skipped or duplicated, for instance, if the database is modified between lookup calls. The client should be prepared to deal with missing or duplicated entries in the `results` array by retrying and verifying the answer or by using `lb_$` routines or `lb_admin`(1ncs) to alter the database.

The routine may return an entry whose address families cannot be used by the host doing the lookup. The client program can protect against this by doing a global `lb_$lookup_interface` to get a list of all interfaces and verify that address families are valid. The client can also use the `socket_$valid_families` routine, which returns a list of the valid address families on the calling host.

Once the client has obtained the Location Broker entry for a server with a valid address family, it can use the socket address information in the entry to bind its handle. The `binop_lu` client calls `rpc_$bind` as follows:

```
h = rpc_$bind(&uuid_$nil, &entry.saddr, entry.saddr_len, &st);
if (st.all != status_$ok) {
    fprintf(stderr, "Can't bind - %s\n", error_text(st));
    exit(1);
}
```

The code uses the `error_text` routine, which is defined in `util.c`, to print any error message.

5.3.3.2 Converting Names to Addresses

5.3.3.2 Converting Names to Addresses – If a client knows the name and the address family of the host it wishes to access, it can call `socket_$from_name` to obtain a socket address without using the Location Broker.

The `socket_$from_name` call requires a port number as one of its parameter. Unless the client knows the port number for a server, specify `socket_$unspec_port`. The runtime library will determine the port number at runtime. The RPC runtime library extracts a port number, if one was specified in the NIDL definition of the interface, from the *interface*`$if_spec` variable. Otherwise, the port remains unknown, and the call is sent to the forwarding port at the host.

The `binop_fw` client, which knows the name of a host where a server is running but not a port number, uses `socket_$from_name` to convert the name into a socket address, then calls `rpc_$bind`:

```
socket_$from_name((long)socket_$unspec, (ndr_$char *) argv[1],
    (long) strlen(argv[1]), (long) socket_$unspec_port,
    &loc, &llen, &st);
h = rpc_$bind(&uuid_$nil, &loc, llen, &st);
```

5.3.4 Using RPC Binding States

The RPC runtime library has a different delivery mechanism for each of the three RPC binding states. This section describes how and why an RPC client might use fully bound, bound-to-host, and unbound handles.

5.3.4.1 Fully Bound Handles – When a client uses a fully bound handle to make a remote procedure call, the RPC runtime library sends the call directly to the host and port identified in the handle.

To obtain a fully bound handle, supply a fully specified socket address to either `rpc_$bind` or `rpc_$set_binding`. Any socket address obtained from a Location Broker will be fully specified. A socket address converted from a host name will not be.

Fully bound handles are always a direct and efficient means of communicating with a server.

5.3.4.2 Bound-to-Host Handles – When a program uses a bound-to-host handle to make a remote procedure call, the RPC runtime library sends the call to the host identified in the handle.

If a well-known port was specified in the definition of the requested interface, the call is delivered to that port. Otherwise the call is delivered to the LLB forwarding port. The LLB–provided a server for the requested object and interface has registered with it–forwards the call to the port on which the server is listening. When the call returns, the RPC runtime library at the client host then binds the handle to that port, and any subsequent calls are sent directly to the server.

You can obtain a bound-to-host handle in two ways:

- By calling `rpc_$bind` or `rpc_$set_binding` with an unspecified port in the socket address input parameter
- By calling `rpc_$clear_server_binding` on a fully bound handle

A client typically uses the first method, invoking `rpc_$bind` or `rpc_$set_binding` after it uses `socket_$from_name` to generate a socket address. For example, the following code sends a matrix multiplication call to a server located at the host identified by `hostname`:

```
socket_$from_name (socket_$internet, hostname, hlen,
                   socket_$unspec_port, &saddr, slen, &st);
h = rpc_$bind (&matrix_id, &saddr, slen, &st);
matrix$multiply (h, a, b, result, &st);
```

A client typically uses the second method, invoking `rpc_$clear_server_binding` after it has received an `rpc_$wrong_boot_time` error in `st.all`. If a client is fully bound to a server that exits and then restarts, listening on a new port, the client can reset the binding to the new port by calling `rpc_$clear_server_binding` on the existing handle; the handle will be rebound when the server responds to the next call.

Bound-to-host handles are most efficient when a client already knows the name or address of a host that is running the server it needs. For example, the client might be seeking a service that is provided by all hosts in the network, or the client might have been given the name of a particular host to access. The client does not need to do a Location Broker lookup. The server needs to register with the LLB on its host, but not with the GLB.

5.3.4.3 Unbound Handles – When a program uses an unbound handle to make a remote procedure call, the RPC runtime library broadcasts the call to all hosts on the local network. If a well-known port was specified in the definition of the requested interface, the call is broadcast to that port. Otherwise, the call is broadcast to the LLB forwarding port.

You can obtain an unbound handle in two ways:

- By calling `rpc_$alloc_handle` to generate a new unbound handle
- By calling `rpc_$clear_binding` on an existing handle to clear the binding

You can also cause an operation to be broadcast by specifying the `broadcast` attribute in its NIDL declaration. If you make a remote procedure call to request an operation that has the `broadcast` attribute, the call is always broadcast, because the RPC runtime library automatically clears any binding of the handle before it issues the call. The client does not need to clear the binding before broadcasting again.

Instead of using unbound handles or specifying the `broadcast` attribute, it is preferable, whenever possible, to determine the address of a server host from a Location Broker lookup or the `socket_$from_name` routine. The broadcast delivery mechanism has several disadvantages:

- Not all systems and networks support broadcasting.
- 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.

All of these disadvantages pertain both to `broadcast` operations and to any operations that are called with unbound handles.

The RPC runtime library raises an error (`rpc_$comm_failure`, described in Section 5.3.8) if you attempt to make a call with an unbound handle, unless you have declared the operation to be idempotent.

The NIDL Compiler issues a warning if you specify the `broadcast` operation attribute without also specifying the `idempotent` attribute.

5.3.5 Identifying Servers

If a client application uses an unbound or bound-to-host handle to make a call, it may wish to identify the particular server that responded, for use in diagnostic or logging output. Because the handle is automatically bound to the responding server when the call returns, you can derive the location of the server from information in the returned handle.

The `rpc_$inq_binding` routine extracts a socket address from a handle. The `socket_$to_name` routine converts a socket address to a textual hostname. For example, a client might issue the following calls to report the location to which its handle is bound:

```
rpc_$inq_binding (h, &saddr, &slen, &st);
socket_$to_name (&saddr, slen, name, &namelen, &port, &st);
name[namelen] = 0;
printf ("bound to server on port %ld at host %s\n", port, name);
```

This technique works even for operations with the `broadcast` attribute. After a client receives a reply to a broadcast, the handle is fully bound, and the RPC runtime library does not clear the binding until the client uses that handle to issue another call.

5.3.6 Handling Errors

Distributed applications handle some errors in much the same way as local applications. For example, if a client issues a remote procedure call to request an operation, and the manager routine for the operation encounters a divide-by-zero error, that error is reflected to the client as if the server had been locally linked with the client.

However, a distributed application can also encounter errors that a purely local application would not. The next sections discuss the causes of three kinds of errors that are specific to remote procedure calls: communications errors, server failures, and interface mismatches.

5.3.6.1 Communications Errors – Communications errors occur in the underlying communications mechanisms, resulting in the failure of a client's request to reach the server or the failure of a server's response to reach the client. Communications errors are usually indicated by the `rpc_$comm_failure` status. The `intro`(3ncs) reference page lists other RPC runtime library statuses. To recover, a client can retry the failed call or try to find another server.

You can use a status parameter, identified by the `comm_status` parameter attribute to check for communications errors. Chapter 4 describes status parameters.

5.3.6.2 Server Crashes – If a server crashes while handling a remote procedure call, an `rpc_$comm_failure` status is signaled to the client. To the client, the server failure is a form of communications error.

If the server fails and restarts between remote calls, the failure is usually indicated by an `rpc_$wrong_boot_time` status. A client can also receive an `rpc_$wrong_boot_time` status if one server fails and a different server starts, using the same port number as the failed server.

Recovery techniques depend on whether the client and the server maintain any state information between procedure calls:

- In a ''connectionless'' application, one that maintains no state between calls, the client needs only to rebind the handle. The client can call `rpc_$clear_server_binding`; then it can check whether the server has restarted. If the server did not restart, the client should unbind completely by calling `rpc_$clear_binding`, locate a new server, and rebind to the new server.
- In an application that does maintain some state between calls, the client must first clear the state (for example, by unwinding to the point at which it bound to the server), then rebind as in the connectionless case.

5.3.6.3 Interface Mismatches – An interface mismatch occurs when the interface definition used to build a server differs from the interface definition used to build a client. If you increment the version number in the version interface attribute every time you change the interface definition, mismatches are easily detected and are indicated by an `rpc_$unk_if` status. If you do not increment the version number, the resulting errors may be difficult to diagnose.

In most cases, programs cannot recover from interface mismatch errors. To eliminate the errors, you should rebuild the out-of-date client or server.

If you want some clients to import an old version of an interface and some clients to import a new version, you can build one server that exports both versions of the interface. Chapter 7 describes how to build such a server.

You can add operations to an interface and maintain some backward compatibility without changing the version number, provided you do not change the signature or implementation of any existing operation. When you modify the interface definition, place declarations for new operations after all declarations for existing operations; that is, add new operations at the end of the interface, not in the middle.

Clients built with the old definition and servers built with the new definition will interoperate correctly. However, if a ''new'' client requests a new operation from an ''old'' server, the RPC runtime library will signal an `rpc_$op_rng_error` status. Example 5-1 shows how you can use a cleanup handler to check for an `rpc_$op_rng_error` status.

5.3.7 Using Cleanup Handlers

The RPC runtime library always signals a fault if an error occurs while it is handling a remote procedure call. Therefore, you should set cleanup handlers around remote procedure calls to catch and handle any such faults.

5.3.7.1 Initializing the Fault Management Routines

Initializing the Fault Management Routines – Before invoking any other DECrpc routines, a client or server should always invoke `pfm_$init` to initialize the fault management routines. This call causes C signals to be translated into signals that can be handled by the fault management routines. Attempts to use C signal handlers in the same program as fault management cleanup handlers can therefore result in unexpected behavior.

5.3.7.2 Setting and Releasing Cleanup Handlers

Setting and Releasing Cleanup Handlers – The `pfm_$cleanup` call sets a cleanup handler. The initial call to `pfm_$cleanup` returns as its value `pfm_$cleanup_set`, a status indicating that the cleanup handler is set; this call also returns as its output a cleanup record, a record of the context when the cleanup handler was set.

If a fault is signaled while a cleanup handler is set, these actions occur:

1. The process stack is unwound to the most recent `pfm_$cleanup` call.
2. The cleanup handler is released.
3. The `pfm_$cleanup` call returns the status value for the error that caused the fault.
4. Execution proceeds with the code that immediately follows the `pfm_$cleanup` call.

After you call `pfm_$cleanup`, you should test its return value, so that fault handling code executes only if the value is an error status (indicating that an error has occurred), not if the value is `pfm_$cleanup_set` (indicating that the cleanup handler has just been set).

A cleanup handler typically ends either with code to continue back into the program or with a call to `pfm_$signal` or `pgm_$exit`. If the program will continue, it should call either `pfm_$reset_cleanup` or `pfm_$enable`.

The `pfm_$rls_cleanup` call releases a cleanup handler. You should release a cleanup handler as soon as it is no longer necessary, so that fault handling code is not executed inappropriately. For example, suppose a cleanup handler is set before a remote procedure call, and the cleanup handler contains code that prepares to retry the call. If you do not release the cleanup handler immediately after the call, a fault that occurs later in the program could cause the call to be executed again, unnecessarily.

In RPC applications, a cleanup handler is typically set just before a remote procedure call and released just after the call.

In Section 5.3.6.3 we explained how to add new operations to an interface and maintain compatibility between ''old'' clients (which call only the old operations) and ''new'' servers (which export both old and new operations). Of course, an ''old'' server cannot execute new operations for a ''new'' client; when such a client calls a new operation, it should be prepared to receive an `rpc_$op_rng_error` status.

Example 5-1 shows how a client might use a cleanup handler to check for `rpc_$op_rng_error` errors.

Example 5-1: Setting Up a Cleanup Handler

```
pfm_$cleanup_rec clrec;                 /* set the cleanup handler */
st = pfm_$cleanup(&clrec);              /* test the return value */
/*
 * if an error occurred, clean up
 */
if (st.all != pfm_$cleanup_set) {
        if (st.all == rpc_$op_rng_error) {
        found an out-of-date server; find another one and rebind
        pfm_$reset_cleanup(&clrec, &st);
    }
    else {
         some other error occurred; report the error and exit
         pfm_$signal(st);
    }
}
/*
 * otherwise, proceed normally
 */
if$newop(h, input, &output);            /* call the operation */
pfm_$rls_cleanup(&clrec, &st);          /* release the cleanup handler */
```

5.3.7.3 **Setting Multiple Cleanup Handlers –** More than one cleanup handler can be in effect at once. If a program has set several cleanup handlers and a fault occurs, the most recently established cleanup handler is entered first, followed by the next most recently established cleanup handler, and so on to the first established cleanup handler if necessary.

5.3.7.4 **Portability Considerations –** The PFM package uses the C routines `setjmp` and `longjmp` to implement cleanup handlers. If you use local variables in fault handling code, the unusual flow of control introduced by `setjmp` and `longjmp` can lead some optimizing C compilers to generate errant object code. Here, we explain how to circumvent this problem in a portable way.

If a local variable is modified after a cleanup handler is set but before the cleanup handler is invoked, the variable has an indeterminate value when referenced in the ''fault handling code path.'' To ensure that modifications made to the variable in the ''normal code path'' are visible to the fault handling code, the variable should be declared with the ANSI C `volatile` qualifier.

Because `volatile` is not yet supported by all C compilers, the PFM header file defines a portable `Volatile` macro. This macro translates to `volatile` on systems whose compilers support the qualifier; on other systems it is null. Any program that uses local variables in cleanup handlers should declare those variables `Volatile`. The code in Example 5-2 shows how to use a local variable portably in fault handling code.

Example 5-2: Using Local Variables Portably in Fault Handling Code

```
Volatile boolean flag;
flag = false;
st = pfm_$cleanup(&crec);
if (st.all != pfm_$cleanup_set) {
    if (flag)
        release_pkt(pkt);
    pfm_$signal(st);
}
pkt = allocate_pkt();
flag = true;
```

more code
if a fault occurs here, the value of flag is indeterminate
more code

```
pfm_$rls_cleanup(&crec, &st);
```

Without the `Volatile` qualifier, the code in the example would not be portable. If a fault occurred at the point indicated, thereby invoking the cleanup handler, the value of `flag` would be indeterminate, and the cleanup handler would execute incorrectly.

5.3.8 Using the comm_status Parameter Attribute

The `comm_status` parameter attribute identifies a parameter as a `status parameter`. A status parameter provides a convenient way to check for communications errors in the execution of a remote procedure call. If you specify `comm_status` for an operation parameter, the NIDL Compiler puts a cleanup handler in the client stub routine for the operation. The cleanup handler catches any error with the `rpc_$mod` module code and passes the error to the client in the status parameter.

All `rpc_$` statuses have the `rpc_$mod` module code. The `intro`(3ncs) reference page describes the `rpc_$` statuses.

5.3.8.1 Declaring Status Parameters in Interface Definitions – A status parameter must have the `comm_status` and `out` attributes and must be of type `status_$t`. The declaration of `primes$gen`, the operation in a `primes` application shown in Example 5-3, identifies a status parameter.

Example 5-3: Identifying a Status Parameter

```
[idempotent]
void primes$gen(
    handle_t [in] h,
    int [in, out] *last,
    int [in] max,
    status_$t [comm_status, out] *st,
    int [in, out, last_is(last), max_is(max)] values[]
    );
```

5.3.8.2 Checking Status Parameters in Client Programs – A client checks status parameters in the same way that it checks statuses returned by `rpc_$` calls or other RPC calls. The client in the `primes` example checks a status parameter after `primes$gen` returns as shown in Example 5-4.

Example 5-4: Checking Status Parameters in Client Programs

```
primes$gen(h, &last, MAXVALS-1, &st, values);
/* check comm_status value */
if (st.all != status_$ok) {
    fprintf(stderr, "Error in rpc - %s\n", error_text(st));
    exit(1);
}
```

The primes client simply prints an error message and exits if the status parameter indicates an error. In other applications, the client might retry the call that failed or try to find another server, depending on the particular status that is returned.

5.3.8.3 Initializing Status Parameters in Manager Routines – If a remote procedure call executes without error, the value of its status parameter is not set. The manager routine should therefore set the status parameter to `status_$ok` before it returns. Example 5-5 includes code from the `primes$gen` manager routine.

Example 5-5: Initializing Status Parameters in Manager Routines

```
void primes$gen(h, last, max, status, values)
handle_t h;
status_$t *status;
ndr_$long_int *last, max, values[];
{
    ndr_$long_int n, highest = values[0], index = 0;

    for (n = 2; n <= highest; n++)
        if (is_prime(n)) {
            values[index++] = n;
            if (index > max) break;
        }
    *last = index-1;
    status->all = status_$ok;
    return;
}
```

5.3.9 Using the comm_status Operation Attribute

NIDL also supports a `comm_status` operation attribute, which specifies that an operation returns a completion status. The client stub routine for such an operation contains a cleanup handler that catches any error with the `rpc_$mod` module code and returns the error code as its return value.

The manager routine for an operation with `comm_status` should be coded to return `status_$ok` if successful.

5.3.10 The binop_fw Client

The `binop_fw` client is the result of compiling four source code modules:

- `client.c`
- `util.c`
- `binop_fw_cstub.c`

- `binop_fw_swtch.c`

The switch and stub modules, of course, are generated by the NIDL Compiler from the interface definition The `util.c` module contains a routine to print error messages; both the client and the server use this routine. The `main` routine is in the `client.c` module

5.3.10.1 The client.c Module – The client module contains directives to include three header files:

`binopfw.h`	The header file generated from the `binop_fw` interface definition
`socket.h`	The header file for the `socket_` interface
`pfm.h`	The header file for the portable PFM interface

Example 5-7 shows the client module, `client.c`.

Example 5-7: The client.c Client Module for binop_fw

```
#include <stdio.h>
#include "binop_fw.h" [1]
#include "socket.h"
#include <pfm.h>

#define CALLS_PER_PASS 100

globalref uuid_$t uuid_$nil;  [2]
extern long time();
extern char *error_text();

main(argc, argv)
int argc;
char *argv[];
{
    handle_t h;
    status_$t st;
    socket_$addr_t loc;
    unsigned long llen;
    socket_$string_t name;
    unsigned long namelen = sizeof(name);
    unsigned long port;
    ndr_$long_int i, n;
    int k, passes;
    int start_time, stop_time;

    if (argc != 3) {
        fprintf(stderr, "usage: client hostname passes\n"); [3]
        exit(1);
    }

    passes = atoi(argv[2]);

    pfm_$init((long) pfm_$init_signal_handlers);[4]

    socket_$from_name((long)socket_$unspec, (ndr_$char *) argv[1], [5]
         (long) strlen(argv[1]), (long) socket_$unspec_port,
         &loc, &llen, &st);
    if (st.all != status_$ok) {                                 [6]
        fprintf(stderr, "Can't convert name to sockaddr - %s\n",
            error_text(st));
        exit(1);
    }

   h = rpc_$bind(&uuid_$nil, &loc, llen, &st);  [7]
    if (st.all != status_$ok) {
```

Example 5-7: (continued)

```
        fprintf(stderr, "Can't bind - %s\n", error_text(st));
        exit(1);
    }
    rpc_$inq_binding(h, &loc, &llen, &st); 8
    if (st.all != status_$ok) {
        fprintf(stderr, "Can't inq binding - %s\n", error_text(st));
        exit(1);
    }
    socket_$to_name(&loc, llen, name, &namelen, &port, &st); 8
    if (st.all != status_$ok) {
        fprintf(stderr, "Can't convert sockaddr to name - %s\n",
            error_text(st));
        exit(1);
    }
    name[namelen] = 0;
    printf("Bound to port %ld at host %s\n", port, name);
    for (k = 1; k <= passes; k++) {
        start_time = time(NULL);
        for (i = 1; i <= CALLS_PER_PASS; i++) {
            binop_fw$add(h, i, i, &n); 9
            if (n != i+i)
                printf("Two times %ld is NOT %ld\n", i, n);
        }
        stop_time = time(NULL);
        printf("pass %3d; real/call: %2ld ms\n", 10
            k, ((stop_time - start_time) * 1000) / CALLS_PER_PASS);
    }
}
```

1 The client module contains directives to include `binop_fw.h`, the header file generated from the `binop_fw` interface definition, and `socket.h`, the header file for the `socket_` interface. The handler file `binop_fw.h` contains an `include` directive for `rpc.h`, the header file for the `rpc_` interface. The NIDL Compiler automatically puts such a directive in the header file it generates for any remote interface (that is, any interface without the `local` attribute).

2 The module declares `uuid_$nil`, the nil UUID, as an external variable. The client uses `uuid_$nil` as the object UUID in its handle. The `globalref` declaration provides portability to VAX C. For other compilers, the `idl_base.h` header file, which is included by `rpc.h`, defines `globalref` as a synonym for `extern`.

3 The client program takes two arguments: the network address of a host where a server is running and the number of passes to execute.

4 After it has processed its arguments, the client calls `pfm_$init` to initialize the PFM package. This call should be made before calls to any other RPC routines.

5 To convert the network address of the server host into a socket address, the client calls `socket_$from_name`, part of the socket address manipulation interface in the RPC runtime library. Because the port parameter for `socket_$from_name` is the predefined constant

socket_$unspec_port, the resulting socket address specifies a host, but not a particular port at that host.

6 After socket_$from_name returns, the client checks the completion status of the call, and if the status is not status_$ok, it prints an error message. Both the client and the server check the completion status of any call that returns a status. They use the error_text routine, which is defined in util.c, to print error messages.

7 The client supplies the address returned by socket_$from_name to rpc_$bind, which creates an RPC handle and binds this handle to the socket address. Because the address does not specify a port, rpc_$bind generates a bound-to-host handle. The object UUID in the rpc_$bind call is uuid_$nil, since binop_fw does not operate on any particular object.

8 For diagnostic and teaching purposes, the client in this example calls rpc_$inq_binding and socket_$to_name, so that it can print the host and port to which it is bound. Most real applications omit this step.

9 The first time the client calls binop_fw$add, the call is sent to the LLB forwarding port at the server host, and the LLB forwards the call to the server. On return, the handle is fully bound, so that all subsequent calls are sent directly to the server port.

10 After each pass, the client prints the real elapsed time per call.

After the last pass, the client exits.

5.3.10.2 The util.c Module – The util.c module in Example 5-8 contains only one routine, error_text. Both the client and the server use this routine to generate error messages.

Example 5-8: The util.c Module for binop_fw

```
#include "binop_fw.h"

char *error_text(st)
status_$t st;
{
    static char buff[200];
    extern char *error_$c_text();

    return (error_$c_text(st, buff, (sizeof) buff));
}
```

5.4 Writing the Server

This section explains how to write a server program.

5.4.1 Server Structure

The source code for a server program consists of the following elements:

- The header file generated from your interface definition by the NIDL Compiler
- The server initialization code, which registers the interface with the RPC runtime library and the Location Broker

- The manager code, which implements the operations in the interface
- The server stub generated from the interface definition by the NIDL Compiler
- Any user-written code that performs data type conversion

If a server exports several interfaces, the server source code must include the header file, manager code, server stub, and any type conversion routines for each interface.

Table 5-3 lists the source files that make up the server in the `binop_fw` example.

Table 5-3: Server Source Code Files for the binop_fw Example

Source Code File	Element
`binop_fw.h`	Header File generated from `binopfw.idl` by the NIDL Compiler
`server.c`	Main program, which contains server initialization code
`binop_fw.c`	Manager module
`binop_fw_sstub.c`	Server stub generated from `binopfw.idl` by the NIDL Compiler
`util.c`	Module containing utility routines used by both the client and the server

Manager procedures are independent of RPC routines and are exactly as they would be in a local implementation. The following subsections discuss server initialization code.

5.4.2 Writing Server Initialization Code

The server initialization code usually appears in the server main procedure (`main` in C). This code typically:

- Processes any arguments supplied on the command line
- Creates the sockets on which it will listen
- Registers the server's objects and managers with the RPC runtime library
- Registers the server's objects and interfaces with the Location Broker
- Establishes termination and fault handling conditions
- Begins listening for requests

The next sections describe each of these activities, using as an example the `binop_fw` server program, `server.c`.

5.4.2.1 Processing Arguments – The `binop_fw` server program performs several initialization tasks. It checks that there are the right number of input arguments; it checks that the specified address family is valid; and, just before it begins listening for requests, it prints a notification of its host and port.

The server takes as an argument the textual name of the address family `ip`. It calls `socket_$family_from_name` to convert this name into the integer representation that the `rpc_$` calls use, as shown in this example:

```
family = socket_$family_from_name((ndr_$char *) argv[1],
    (long) strlen(argv[1]), &st);
```

The server calls `socket_$valid_family` to check whether the specified address family is valid for the host on which it is running:

```
validfamily = socket_$valid_family (family, &st);
if (!validfamily) {
    printf ("Family %s is not valid\n", argv[1]);
    exit (1);
}
```

5.4.2.2 Creating Sockets – A single server can listen on several sockets at a time. However, a server that exports several interfaces can listen on one socket for requests for operations in any of those interfaces. Hence, most servers use only one socket per address family.

To obtain sockets on which to listen, a server calls `rpc_$use_family` or `rpc_$use_family_wk` once for each socket. The routine `rpc_$use_family` dynamically assigns an available opaque port, while `rpc_$use_family_wk` assigns the well-known port that you specified in the interface definition. We recommend that you avoid using well-known ports as discussed in Chapters 1 and 3.

The `binop_fw` server listens on one opaque port. It calls `rpc_$use_family` to obtain its socket:

```
rpc_$use_family (family, &loc, &llen, &st);
```

In this call, `family` is the integer representation of the address family specified on the command line, `loc` is the socket address for the port assigned by the RPC runtime library, and `llen` is the length of `loc`.

5.4.2.3 Registering with the RPC Runtime Library – As described in Chapter 3, a server can export several interfaces and can offer access through these interfaces to several types of objects. Each combination of interface and type requires a separate manager.

When the server RPC runtime library receives a remote procedure call from a client, it determines the correct manager to execute the call, based on the object and the operation requested, and dispatches the call to that manager. Every server must therefore inform the RPC runtime library about its managers and objects. A server calls `rpc_$register_mgr` once for each manager that it implements and calls `rpc_$register_object` once for each object that it supports.

The `binop_fw` server program makes the following call to register its manager with the RPC runtime library:

```
rpc_$register_mgr(
    &uuid_$nil,
    &binop_fw_v1$if_spec,
    binop_fw_v1$server_epv,
    (rpc_$mgr_epv_t) &binop_fw_v1$manager_epv, &st);
```

To register a manager, a server must supply a type identifier, an interface specifier, a server EPV, and a manager EPV. Because `binop_fw` does not involve any particular type, the `binop_fw` server specifies `uuid_$nil` as the type identifier. The interface specifier is defined in the header file, and the server EPV is defined in the server stub; both of these files, of course, are generated by the NIDL Compiler from your interface definition. You must define the manager EPV; typically this definition appears in the manager module.

Because `binop_fw` does not involve any particular object, the `binop_fw` server does not need to call `rpc_$register_object`.

5.4.2.4 Registering with the Location Broker

Registering with the Location Broker – Most servers register their objects and interfaces with the Location Broker; clients can then use `lb_$` lookup calls to locate objects. A server must make a separate `lb_$register` call to register each possible combination of object, interface, and socket address. For example, the server should make six registration calls if it:

- Listens on one IP socket
- Exports two interfaces
- Manages three objects

Because the `binop_fw` application does not involve an object, its server specifies `uuid_$nil` as the object UUID for its Location Broker registration. Clients locate this server with Location Broker forwarding, so the server should register only with the Local Location Broker and not with the Global Location Broker.

The `binop_fw` server uses the following call to register with the Location Broker:

```
lb_$register (&uuid_$nil, &uuid_$nil, &binop_fw_v1$if_spec.id,
    (long)lb_$server_flag_local, (ndr_$char *) "binop_fw example",
    &loc, llen, &entry, &st);
```

This call specifies `uuid_$nil` for the object and type identifiers. The interface identifier is the `id` member of the `if_spec` for `binop_fw`, defined in the header file. To register only with the Local Location Broker, the server specifies `lb_$server_flag_local`. It supplies the text string ''binop_fw example'' as an annotation for the database entry. The `loc` specified in this call is the socket address that the server obtained from a call to `rpc_$use_family`.

5.4.2.5 Unregistering and Fault Handling –

When a server starts, it should register itself with the RPC runtime library and with the Location Broker, so that clients can locate the server and communicate with it. When a server exits, it should unregister itself, so that clients do not continue trying to use it.

To unregister from the RPC runtime library, a server calls `rpc_$unregister`. In servers that export several interfaces or manage several objects, unregistrations should balance registrations: there should be an `rpc_$unregister` for every `rpc_$register_mgr` and an `lb_$unregister` for every `lb_$register`.

The code to unregister a server typically appears in a cleanup handler. The server sets the cleanup handler before it begins listening for requests. If the server receives a signal, it removes its registrations with the RPC runtime library and the Location Broker before exiting.

Following is the cleanup handler in the `binop_fw` server:

```
st = pfm_$cleanup(&crec);
if (st.all ! pfm_$clean_set) {
    status_$t stat;
    fprintf(stderr, "Server received signal - %s\n",
        error_text(st));
    lb_$unregister(&lb_entry, &stat);
    rpc_$unregister(&binopfw_v1$if_spec, &stat);
    pfm_$signal(st);
```

The code uses the `error_text` routine, which is defined in `util.c`, to print any error message.

5.4.2.6 Listening for Requests

Listening for Requests – To begin listening for requests, the server calls `rpc_$listen`. The first argument specifies the maximum number of requests that the server can process concurrently, in the DECrpc implementation, one (1).

The server uses this call to begin accepting requests from clients:

```
rpc_$listen ((long) 1, &st);
```

On normal completion, `rpc_$listen` does not return. However, the call will return on a catastrophic event or if an application issues a call to `rpc_$shutdown`. The shutdown call returns with `status_$ok`.

After a server creates sockets, registers objects and interfaces, and begins listening, it need not make any more calls. However, servers can register or unregister objects and interfaces while running, and they can also shut themselves down. A server can take these actions on its own or as part of its execution of client requests (in a manager routine).

5.4.3 Writing Manager Code

A manager implements the operations in one interface for objects of one type. In addition to defining a routine for each operation, the manager module defines the EPV through which these routines are called. Manager modules sometimes also require code to identify objects, to identify clients, or to register objects with the Location Broker.

5.4.3.1 Defining Manager EPVs – A manager EPV names the routines that implement the operations in an interface. The names of manager EPVs and manager routines are arbitrary, since these names appear only in code that you write, not in code that the NIDL Compiler generates. By convention, we choose EPV names similar to those of the client and server EPVs and routine names similar to the operation names in the interface definition.

The `binop_fw` manager defines its EPV as follows:

```
globaldef binop_fw_v1$epv_t binopfw_v1$manager_epv {binop_fw$add};
```

Chapter 7 describes examples in which a server contains more than one manager or more than one version of a manager. In these examples, the manager EPVs help to distinguish different implementations of an interface.

5.4.3.2 Identifying Objects – In some applications, one manager supports several objects, and the manager must be able to identify the particular object on which the client wishes to operate. Clients in such applications typically use explicit handles, so that a handle passes from client to server with each call.

If the interface is manually bound, the manager can call `rpc_$inq_object` to extract the object UUID from the RPC handle. If, however, the interface is automatically bound, the handle must be either the object UUID itself or some other data type from which the manager can determine the UUID.

Example 5-9 shows a routine that checks to see if the object referred to by the RPC handle is the object expected. In the example, the `bankd` program passes the CheckObject routine a UUID, `h`. The routine compares the UUID to the known bank UUID.

Example 5-9: Checking the UUID in an Automatically Bound Interface

```
static boolean CheckObject(h, st)
uuid_$t *h;
status_$t *st;
{
    if (bcmp(h, &BankUUID, sizeof(BankUUID))) {
        fprintf(stderr, "(bankd) Request for wrong bank!\n");
        st->all = -1;        /* "object not found" */
        return(false);
    }

    st->all = status_$ok;
    return(true);
}
```

5.4.3.3 Identifying Clients – A server may wish to identify clients from which it receives requests, for use in diagnostic or logging output. The RPC runtime library at a server host manipulates the location information in an RPC handle so that on the server side of an application, the handle specifies the location of the client making the call. Thus, just as a client can identify its server by extracting location information from a handle, a server can identify its client.

A manager routine might issue the following calls to report the location from which a server received a request:

```
rpc_$inq_binding(h, &loc, &llen, &st);
socket_$to_name(&loc, llen, name, &namelen, &port, &st);
name[namelen] = 0;
printf("Request from port %ld at host %s\n", port, name);
```

5.4.3.4 Registering Objects – In most applications, server initialization code registers the objects with the RPC runtime library and the Location Broker. However, if the server manages transient objects that it creates and deletes, the manager routine that creates the objects should register them, and the manager routine that deletes objects should unregister them.

5.4.3.5 Initializing Status Parameters – If an operation has a status parameter (a parameter with the `comm_status` attribute), the manager routine that implements the operation should set the status parameter to `status_$ok` before it returns.

5.4.4 The binop_fw Server

The `binop_fw` server is the result of compiling four source code modules: `server.c`, `binop_fw.c`, `util.c`, and `binop_fw_sstub.c`. The stub module is generated by the NIDL Compiler from the interface definition. We saw `util.c`, which contains a routine to print error messages, in Example 5-8. The manager module, `binop_fw.c`, contains the `binop_fw$add` routine that executes the actual addition operations. The `server.c` module performs all of the server initialization tasks.

5.4.4.1 The server.c Initialization Module – Example 5-10 contains the code for `server.c`.

Example 5-10: The server.c Module for binop_fw

```
#include <stdio.h>

#include "binop_fw.h"
#include "lb.h"              [1]
#include "socket.h"
#include <pfm.h>

globalref uuid_$t uuid_$nil;
globalref binop_fw_v1$epv_t binop_fw_v1$manager_epv;  [2]
extern char *error_text();

main(argc, argv)
int argc;
char *argv[];
{
    status_$t st;
    socket_$addr_t loc;
    unsigned long llen;
    unsigned long family;
    boolean validfamily;
    socket_$string_t name;
    unsigned long namelen = sizeof(name);
    unsigned long port;
    lb_$entry_t entry;
    pfm_$cleanup_rec crec;

    if (argc != 2) {
        fprintf(stderr, "usage: serverfamily\n");
        exit(1);
    }
    pfm_$init((long)pfm_$init_signal_handlers); [3]

    family = socket_$family_from_name((ndr_$char *) argv[1], [4]
        (long) strlen(argv[1]), &st);
    if (st.all != status_$ok) {
        fprintf(stderr, "Can't get family from name - %s\n",
            error_text(st));
        exit(1);
    }

    validfamily = socket_$valid_family(family, &st); [5]
    if (st.all != status_$ok) {
        fprintf(stderr, "Can't check family - %s\n", error_text(st));
        exit(1);
    }
    if (!validfamily) {
        printf("Family %s is not valid\n", argv[1]);
        exit(1);
    }

    rpc_$use_family(family,&loc, &llen, &st); [6]
    if (st.all != status_$ok {
        fprintf(stderr, "Can't use family - %s\n", error_text(st));
        exit(1);
    }

    rpc_$register_mgr(    [7]
        &uuid_$nil,
        &binop_fw_v1$if_spec,
        binop_fw_v1$server_epv,
        (rpc_$mgr_epv_t) &binop_fw_v1$manager_epv,
        &st);
```

Example 5-10: (continued)

```
    if (st.all != 0) {
        printf("Can't register manager - %s\n", error_text(st));
        exit(1);
    }
    lb_$register ( [8]
        &uuid_$nil,
        &uuid_$nil,
        &binop_fw_v1$if_spec.id,
        (long)lb_$server_flag_local,
        (ndr_$char *) "binop_fw example",
        &loc,
        llen,
        &lb_entry,
        &st);
    if (st.all != 0) {
        printf("Can't register - %s\n", error_text(st));
        exit(1);
        }
    socket_$to_name(&loc, llen, name, &namelen, &port, &st); [9]
    if (st.all != status_$ok) {
        fprintf(stderr, "Can't convert sockaddr to name - %s\n",
            error_text(st));
        exit(1);
    }
    name[namelen] = 0;
    printf("Registered: name'%s', port=%ld\n", name, port);
    st = pfm_$cleanup(&crec); [10]
    if (st.all != pfm_$cleanup_set) {
        status_$t stat;
        fprintf(stderr, "Server received signal - %s\n",
            error_text(st));
        lb_$unregister(&lb_entry, &stat);
        rpc_$unregister(&binopfw_v1$if_spec, &stat);
        pfm_$signal(st);
    }
    rpc_$listen((long) 1, &st); [11]
}
```

[1] The `binopfw` server module, like the client module, includes the `binopfw.h`, `socket.h`, and `pfm.h` header files. In addition, since the server makes Location Broker calls, the server module includes `lb.h`, the header file for the Location Broker Client Agent interface.

[2] The server declares as an external variable the manager EPV `binopfw_v1$manager_epv`. The manager module defines this EPV. The server specifies the EPV when it registers its manager with the RPC runtime library.

[3] Like the client, the server calls `pfm_$init` to initialize the PFM package before it makes any RPC calls.

[4] The server program takes as an argument the textual name of an address family. It calls `socket_$family_from_name` to convert the textual name into the corresponding integer representation.

5 The call to socket_$valid_family checks whether the family is valid.

6 To obtain a socket on which to listen, the server supplies the address family, in its integer representation, to rpc_$use_family. The RPC runtime library assigns an available opaque port to the server; the runtime library returns the socket address for this port in the loc parameter.

7 To register its manager with the RPC runtime library, the server supplies the manager EPV to rpc_$register_mgr. The first parameter, the type UUID, is uuid_$nil, because the binopfw application does not involve any particular type.

8 To register with the Location Broker, the server calls lb_$register. It supplies the following information for its entry in the Location Broker database:

- An object UUID, in this case nil
- A type UUID, also nil
- An interface UUID, taken from the if_spec
- A flag indicating that the entry should appear only in the Local Location Broker database
- An annotation
- A socket address

9 The server uses socket_$to_name to extract the host name and the port number from its socket address. It prints this information in a message.

10 Before it begins listening for requests, the server sets a cleanup handler. If the server receives a signal, it removes its registrations with the RPC runtime library and the Location Broker before exiting.

11 To begin listening for requests, the server calls rpc_$listen.

5.4.4.2 The binop_fw.c Manager Module – Example 5-11 contains code for the manager module.

The manager makes no RPC calls, so it includes only binop_fw.h, which defines binop_fw_v1$epv_t and declares the binop_fw$add operation.

Example 5-11: The binop_fw.c Manager Module for binop_fw

```
#include "binop_fw.h"
globaldef binop_fw_v1$epv_t binop_fw_v1$manager_epv = { binop_fw$add }; 1
void binop_fw$add(h, a, b, c) 2
handle_t h;
long a, b, *c;
{
    *c = a + b;
}
```

1 The manager module defines binopfw_v1$manager_epv, the manager EPV. The globaldef provides portability to VAX C; for other C compilers, the idl_base.h header file in the c subdirectory of the system directory /usr/include/idl defines globaldef as a macro with no replacement text.

2 The manager module contains the implementation of the `binop_fw$add` procedure. The definition is just as it would be in a local application.

5.5 Steps in Building an Application

This section lists the usual steps in building a distributed application:

1. For each interface, run the NIDL Compiler to generate header files and to generate the source code for the server stub, the client stub, and the client switch.
2. For each interface, use the C compiler to generate object modules for the server stub, the client stub, and the client switch.
3. For each interface, compile any routines that perform automatic binding or data type conversion.
4. Compile the client application source to create the client object modules.
5. Compile the server initialization code and the managers to create the server object modules.
6. Link the client application object modules, the client switches, the client stubs, any automatic binding routines, and any type conversion routines to make the executable client.
7. Link the server and manager object modules, the server stubs, and any type conversion routines to make the executable server.

Remember that the client and the server must include the header files for any `lb_$`, `rpc_$`, `socket_$`, or `uuid_$` library routines or types they use; similarly, any interface definition that uses predeclared system types should import the corresponding NIDL file.

The NIDL files are located in the the `/usr/include/idl` directory; the C header files are located in the `c` subdirectory.

The `/usr/examples/ncs/binop` directory includes a README file, a `Makefile` file, and the source files for the `binop` client and server programs.

NIDL C Syntax 6

This chapter describes the C syntax of the Network Interface Definition Language (NIDL). This syntax of NIDL is a set of ANSI C, with a few constructs added to express remote procedure call semantics.

Section 6.1 describes the overall structure of a NIDL interface definition. Sections 6.2 through 6.7 describe each of the elements in that structure. Section 6.8 is a detailed discussion of NIDL data types.

6.1 Interface Definition Structure

A NIDL interface definition file has the following structure:

```
%c
[ interface_attribute_list ] interface identifier
{
import_declarations
constant_declarations
type_declarations
operation_declarations
}
```

6.1.1 Syntax Identifier

The first line of an interface definition file identifies the syntax of NIDL in which the interface definitions are written. For the C syntax of NIDL, this identifier is `%c`.

6.1.2 Heading

The interface definition heading consists of three elements: an interface attribute list, enclosed in brackets; the keyword `interface`; and the interface identifier. Section 6.2 describes interface attributes in detail.

6.1.3 Body

The *interface definition body* follows the heading and consists of one or more of these declarations:

import_declaration	Described in Section 6.3
constant_declaration	Described in Section 6.4
type_declaration	Described in Section 6.5
operation_declaration	Described in Section 6.6

There must be at least one constant, type, or operation declaration; a body containing only import declarations is not sufficient.

A semicolon terminates each declaration. Braces enclose the entire body.

6.1.4 Comments

As in C, `/*` and `*/` delimit comments as illustrated in this example:

```
/* all natural */
import 'cereal.idl';  /* no preservatives */
```

6.2 Interface Attributes

An interface definition heading specifies the name and attributes of the interface, as follows:

[*interface_attribute_list*] `interface` *identifier*

An *interface_attribute_list* is enclosed in brackets and includes one or more of the following elements, separated by commas:

`uuid` (*uuid_string*)
`version` (*version_number*)
`port` (*port_identifier_list*)
`implicit_handle` (*type_specifier identifier*)
`local`

If an interface definition contains any operation declarations, its heading must specify at least the `local` attribute or the `uuid` attribute.

6.2.1 UUID Attribute

The `uuid` attribute assigns a Universal Unique Identifier (UUID) to the interface. No other object, interface, or type can be assigned this UUID.

The `uuid` attribute has the following syntax, where *uuid_string* is the character-string representation of a UUID:

`uuid` (*uuid_string*)

6.2.2 Version Attribute

The `version` attribute helps you to manage multiple versions of an interface. It has the following syntax, where *version_number* is an integer:

`version` (*version_number*)

For example, if you were changing the parameters to a procedure in the `array` interface, the interface definition heading might look like this:

```
%c
[uuid(338b5f985000.0d.00.00.37.27.00.00.00), version (2)]
interface array
```

6.2.3 Port Attribute

The `port` attribute specifies the well-known port or ports on which servers that export the interface will listen. In most cases, you should not use this attribute; instead, you should allow the RPC runtime library to assign opaque ports dynamically. See Chapter 1 for a discussion of well-known and opaque ports.

The `port` attribute has the following syntax:

```
port ( port_identifier_list )
```

Entries in a *port_identifier_list* are separated by commas. Each entry has this form, where *family* is the address family and *port_number* is the well-known port:

```
family: [port_number]
```

Specify at most one port per family. Table 6-1 lists the *family* values supported by NIDL.

Table 6-1: Family Values Supported by NIDL

Value	Address Family
`unspec`	Unspecified protocol
`unix`	Local to host (UNIX pipes, portals)
`ip`	Internetwork protocols (TCP, UDP)
`implink`	ARPANET Interface Message Processor (IMP) addresses
`pup`	XEROX PARC Universal Packet (PUP) protocols
`chaos`	MIT CHAOS protocols
`ns`	XEROX Network Systems (XNS) protocols
`nbs`	National Bureau of Standards (NBS) protocols
`ecma`	European Computer Manufacturers Association (ECMA)
`datakit`	Datakit protocols
`ccitt`	International Telegraph and Telephone Consultative Committee (CCITT) protocols (X.25, for example)
`sna`	IBM Systems Network Architecture (SNA) protocols
`unspec2`	Unspecified protocol

Although NIDL supports the families in the preceding list, the DECrpc runtime software supports only the IP address family. For example, the interface definition `binop.idl`, described in Chapter 3, specifies a well-known port for the IP address family:

```
port(ip:[6677])
```

6.2.4 Implicit Handle Attribute

The `implicit_handle` attribute indicates that an interface uses implicit global variables rather than explicit operation parameters to represent objects.

The `implicit_handle` attribute has the following syntax:

```
implicit_handle ( type_specifier identifier )
```

The *type_specifier* and *identifier* are the type and name of the global variable to be used as an implicit handle. The *type_specifier* must be either the RPC handle type `handle_t` or a generic handle type for which you have specified the `handle` type attribute.

If you specify an implicit handle for an interface, the client stub uses this handle to represent objects in all remote procedure calls and it passes no handle information to the server. Operations in the interface should not include handle parameters in their signatures.

If you do not specify an `implicit_handle` in the interface definition heading, the interface uses explicit handles, and each operation must include a handle as the first parameter in its signature.

The interface definition heading for an interface that uses an implicit handle might look like this:

```
%c
[uuid(338b5f985000.0d.00.00.37.27.00.00.00),
                implicit_handle(handle_t array_handle)]
interface array
```

Chapter 1 discusses handles and binding in detail.

6.2.5 Local Attribute

The `local` attribute indicates that the interface definition does not declare any remote operations; therefore, the NIDL Compiler should generate only header files (`.h` files), not stubs.

If you specify the `local` attribute, the NIDL Compiler ignores any other interface attributes.

6.3 Import Declarations

The NIDL *import_declaration* is analogous to the C `#include` directive. It specifies an interface definition file that declares constants and types that the importing interface uses. It takes this form, where *file* is the pathname, enclosed in double quotation marks, of the file that you are importing:

`import` *file* `;`

For example, the following declaration imports the definition for the `potato_` interface:

```
import "potato.idl";
```

The NIDL Compiler translates `import` declarations into C `#include` directives to include header files that correspond to the imported interfaces. However, if the imported interface contains operation declarations, the NIDL Compiler does not generate stub procedures for these operations. For example, if the interface definition `foo.idl` contains an import declaration for the `potato_` interface, then the NIDL Compiler will generate a C header file named `foo.h` that contains the following `#include` directive:

```
#include "potato.h";
```

The stub files that the Compiler generates, however, will not contain any procedures for the `potato_` operations.

You can import interfaces defined in either of the NIDL syntaxes. Importing an interface many times has the same effect as importing it once.

6.4 Constant Declarations

The NIDL *constant_declaration* takes the form

const *type_specifier identifier integer* | *string* | *value_identifier* ;

The *type_specifier* is the data type of the constant you are declaring, *identifier* is the name of the constant, and *integer*, *string*, or *value_identifier* is the value you are assigning to the constant. A *value_identifier* can be any previously defined constant.

The C syntax of NIDL provides only `int` and `char` constants. NIDL does not support constant expressions. Following are examples of constant declarations:

```
const int MAX = 100;
const CHAR DSCH = "Dmitri Shostakovich";
```

6.5 Type Declarations

The NIDL *type_declaration* lets you give a name to a data type. It takes the following form:

typedef [*type_attribute_list*] *type_specifier type_declarator_list* ;

The *type_attribute_list* is optional.

Some of the constructs that appear in type declarations can also appear in the parameter lists of operation declarations. Section Section 6.6 describes the use of these constructs in operation declarations. Section 6.7 describes NIDL data types in detail.

6.5.1 Type Attributes

The optional *type_attribute_list* includes one or both of the following elements, separated by commas:

handle
transmit_as (*xmit_type*)

These attributes can appear only in `typedef` declarations.

6.5.1.1 The handle Attribute – The `handle` attribute specifies that a type can serve as a generic handle. You must supply automatic binding routines to convert this type to `handle_t`, the RPC handle type.

The following example declares a generic handle type, `filehandle_t`, which is a structure containing the textual representations of a host and a pathname:

```
typedef [handle] struct {
    socket_$string_t host;
    char path[1024];
    } filehandle_t;
```

Chapter 7 discusses automatic binding and autobinding and autounbinding routines, and describes an application that uses UUIDs as generic handles.

6.5.1.2 The transmit_as Attribute – The `transmit_as` attribute associates a **transmitted type** that stubs pass over the network with a **presented type** that clients and servers manipulate. You must supply routines that perform conversions between the presented and transmitted types.

There are two primary uses for this attribute:

- To pass complex data types for which the NIDL Compiler cannot generate marshalling and unmarshalling code. Such types include trees, linked lists and structures that contain pointers.
- 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).

The *xmit_type* in a `transmit_as` attribute must be a named type defined previously in another type declaration; it indicates the transmitted type that the stubs will pass between client and server.

The following `typedef` statements declare presented and transmitted types for a linked list:

```
typedef struct {
    int last;
    int [last_is(last)] values[MAXELEMENTS];
    } trans_t;
typedef [transmit_as(trans_t)] struct {
    int value;
    list_t *next;
    } list_t;
```

Because `list_t` contains a pointer to a `list_t`, the NIDL Compiler cannot generate code to marshall this data type. Instead, it generates code that calls user-written routines to convert between `list_t` and `trans_t`, and the stubs transmit the linked lists as `trans_t` structures.

Chapter 7 discusses type conversion, specifies the signatures for conversion routines, and describes two applications that use type conversion.

6.5.2 Type Specifiers

The *type_specifier* portion of a *type_declaration* can specify any of the following:

Simple types

`int`	`unsigned`	`float`	`byte`
`long`	`unsigned long`	`double`	`void`
`short`	`unsigned short`	`char`	`enum`
`small`	`unsigned small`	`boolean`	`short enum`

Constructed types

`bitset`	`union`
`string0`	arrays
`struct`	pointers

The RPC handle type `handle_t`

Named types defined with `typedef` declarations

Section 6.7 describes these types in detail.

6.5.3 Field Attributes

NIDL provides two field attributes that apply only to arrays: `last_is` and `max_is`. These attributes identify *last* and *max* fields that at runtime will supply the stubs with information about the length of an array; `last_is` and `max_is` are typically used for an open array, an array whose declaration does not specify an explicit fixed length.

An array with `last_is` or `max_is` must be either a member of a structure or a parameter of an operation. These attributes therefore can appear either in type declarations or in operation declarations. The attributes precede the array name in a *field_attribute_list*:

type_specifier [*field_attribute_list*] *array_declarator* [*array_length*]

The *field_attribute_list* comprises one or both of the following elements, separated by commas:

```
last_is ( last )
max_is ( max )
```

The `last_is` attribute identifies another field, *last*, that at runtime will be the index of the last array element to be passed. Client and server programs use this field to dynamically indicate the size of an array.

The `max_is` attribute identifies another field, *max*, that at runtime will be the maximum possible index of the array. Client programs use this field to dynamically indicate the maximum size of an array.

The following type declaration defines a structure that contains an open array, its *max*, and its *last*:

```
typedef struct {
    int pmax;
    int plast;
    int [max is(pmax), last_is(plast)] parray[];
    } pixels;
```

See Chapter 7 for a detailed discussion of `last_is` and `max_is`.

6.5.4 Type Declarators

The *type_declarator_list* specifies names for a particular type. To include more than one name in a list, separate the names with commas. For example:

```
typedef long integer32, int32;
```

6.5.4.1 Pointers

Pointers – To specify a pointer type, precede the name with an asterisk. For example:

```
typedef int *pointer_to_int;
```

6.5.4.2 Arrays

Arrays – To specify an array type, put brackets after the name. Inside the brackets you can supply the array size, an asterisk, or nothing. If you supply an asterisk or you supply nothing, you are declaring an open array (one whose length will not be known until runtime), and you must apply the `last_is` field attribute to the array. Array subscripts start at 0. The following example of a `struct` includes two arrays:

```
typedef struct {
    char    fixed[32];
    int     last;
    char    [last_is (last)] open[];
    } arrays;
```

In a `struct` that contains an open array, the array must be the last member. A `union` cannot contain an open array. See Chapter 7 for more information about open arrays.

Use consecutive pairs of brackets to declare multidimensional arrays, as in C:

```
typedef int two_by_four [2][4];
```

Only the first dimension of a multidimensional array can be unspecified:

```
typedef int n_by_four [][4];    /* this is valid */
typedef int two_by_n [2][];    /* this is NOT valid */
```

6.6 Operation Declarations

The NIDL *operation_declaration* is analogous to a C function heading. An operation declaration has the following form:

[*operation_attribute_list*] *o_type_specifier operation_declarator* (*parameter_list*) ;

Entries in a *parameter_list* are separated by commas. Each entry has the following form:

p_type_specifier [*field_attribute_list parameter _attribute_list*] *parameter_declarator*

The following subsections discuss the parts of an operation declaration.

6.6.1 Operation Attributes

The optional *operation_attribute_list* includes one or more of the following keywords, separated by commas:

```
idempotent
broadcast
maybe
comm_status
```

6.6.1.1 The idempotent Attribute – By default, the RPC runtime library provides ''at most once'' call semantics. These semantics ensure that an operation, when called once, is executed not more than once. They require the server to save the results of an operation until the client acknowledges its receipt of those results.

The `idempotent` attribute specifies that an operation can be executed any number of times. If an operation is idempotent, the server does not need to save results and the client does not need to issue acknowledgements, so performance is improved. Use the `idempotent` attribute for any operation that can safely be executed more than once; for instance, an operation that simply reads a value is idempotent, while one that increments a value is not.

6.6.1.2 The broadcast Attribute – The `broadcast` attribute specifies that the RPC runtime software should always broadcast an operation to all hosts on the local network. The broadcast is to a well-known port if one has been specified, to the Local Location Broker forwarding port if not. When a client calls an operation with the `broadcast` attribute, the runtime software automatically clears any binding from the handle before issuing the remote procedure call.

The RPC runtime library applies idempotent call semantics for all broadcast operations, so it executes any operation with the `broadcast` attribute as though the operation also had the `idempotent` attribute. For clarity, we recommend that you explicitly specify `idempotent` whenever you specify `broadcast`; if you do not, the NIDL Compiler issues a warning.

You should avoid using the `broadcast` attribute. See the discussion of unbound handles and broadcasting in Chapter 5.

6.6.1.3 The maybe Attribute – The `maybe` attribute specifies that the caller of an operation does not expect any response and that the RPC runtime software need not guarantee delivery of the call. Operations with this attribute cannot have any output parameters and cannot return anything. You might use `maybe` for an operation that posts a notification whose receipt is not crucial.

6.6.1.4 The comm_status Attribute – The `comm_status` attribute specifies that an operation returns a completion status, a status code of type `status_$t`. If a communications error occurs while the operation is executing, a cleanup handler in the client stub will handle the error and return the error code as the return value of the operation. The manager routine for an operation with the `comm_status` attribute should be coded to return `status_$ok` if successful.

NIDL also supports a `comm_status` parameter attribute; this attribute identifies an output parameter that will reflect status and hence provides functionality similar to that of the `comm_status` operation attribute. Chapter 5 describes the use of status parameters.

6.6.2 Operation Type Specifiers

The *o_type_specifier* is the data type that the operation returns. It can be any scalar type or previously named type, but it cannot be a pointer. For example, if the operation returns a short integer, specify `short` as the *o_type_specifier*. Specify `status_$t` if the operation has the `comm_status` operation attribute. Specify `void` if the operation does not return. If you omit the *o_type_specifier*, the operation must return an `int`.

6.6.3 Operation Declarators

The *operation_declarator* is the name of the operation.

6.6.4 Parameter Lists

The parameters of an operation appear in a *parameter_list*. The entry for each parameter takes the following form:

p_type_specifier [*field_attribute_list parameter_attribute_list*] *parameter_declarator*

Use commas to separate the entries in a *parameter_list.*

If an interface uses explicit handles, the first parameter in the *parameter_list* for each operation must be the explicit handle. If an operation uses manual binding, the handle must have the type `handle_t`.

6.6.4.1 Parameter Type Specifiers – The *p_type_specifier* specifies the data type of the parameter.

6.6.4.2 Field Attributes and Parameter Attributes – The *field_attribute_list* can include `last_is` and `max_is` and can apply only to array parameters. The associated *last* and *max* must also be parameters in the *parameter_list.* Subsection 6.5.3 describes field attributes; Chapter 7 discusses them in further detail and presents an example. The *parameter_attribute_list* can include the following attributes:

`in`	The parameter is an input. It passes from client to server, that is, from the calling routine (the caller) to the called routine (the callee).
`out`	The parameter is an output. It passes from server to client, that is, from the callee to the caller. Output parameters are passed by reference and must be either pointers or arrays.
`comm_status`	The parameter is a status parameter. If a communications error occurs, a cleanup handler in the client stub will handle the error and pass the error code to the client in this parameter.

Every parameter must have at least one of the directional attributes `in` and `out`. A list including both `in` and `out` indicates that the parameter passes in both directions.

A parameter with the `comm_status` attribute must be of type `status_$t` and must also have at least the `out` attribute. Chapter 5 describes the use of status parameters.

Field attributes and parameter attributes can appear in any order. If a parameter has more than one attribute, separate the attributes with commas.

6.6.4.3 Parameter Declarators – The *parameter_declarator* specifies the name of each parameter. By default, `in` parameters are passed by value. To denote an `in` parameter that is passed by reference, precede the *parameter_declarator* with an asterisk (`*`). This construct is typically used when the application software is implemented in Pascal.

All `out` parameters are passed by reference. Unless the parameter is an array, you must precede the *parameter_declarator* with an asterisk (`*`).

Use brackets to specify arrays. The syntax for array parameters is the same as for array types, described in Subsection 6.5.4.

6.6.5 Examples

The following declares an operation named `simple$op` that takes no parameters, returns no value, and need not be executed:

```
[maybe] void simple$op();
```

The interface definition for an xmitas application declares the xmitas$sum operation. This idempotent operation returns an integer. Its input parameters are an explicit RPC handle and a list structure of the named type list_t:

```
[idempotent]
int xmitas$sum(
    handle_t     [in] h,
    list_t       [in] list
    );
```

The interface definition for a primes application declares the primes$gen operation. This operation does not return a value. Its parameters include two pointers and an open array. Its declaration illustrates the use of operation attributes, field attributes, and parameter attributes:

```
[idempotent]
void primes$gen(
    handle_t     [in] h,
    int          [in, out] *last,
    int          [in] max,
    status_$t    [comm_status, out] *st,
    int          [in, out, last_is(last), max_is(max)] values[]
    );
```

6.7 Data Types

This section describes in detail the *type_specifier* expressions that you can use in type declarations and in the parameter lists of operation declarations. These expressions can specify simple types, constructed types, named types, or the RPC handle type handle_t.

6.7.1 Simple Types

NIDL supports a variety of simple data types including integers, floating-point numbers, characters, boolean, byte, void, and enumerations:

Integer Types

Type	**Size**
int	32 bits
long	32 bits
short	16 bits
small	8 bits
unsigned	32 bits
unsigned long	32 bits
unsigned short	16 bits
unsigned small	8 bits

You can include the keyword int after any of the other integer type names. For example, long and long int are synonymous.

Floating-Point types

Type	Size
`float`	32 bits
`double`	64 bits

The `byte` Type

The integer types listed in the previous table are subject to data conversion when the native data representation formats of client and server hosts differ. The `byte` type is an 8-bit integer whose representation format is guaranteed not to be converted. You can protect data of any type from data conversion by transmitting that type as an array of `byte`; Chapter 7 discusses the use of transmitted types.

The Character Type

A `char` is unsigned. NIDL does not support a signed character.

The `boolean` Type

Following C convention, a value of 0 means "false," and any nonzero value means "true."

The `void` Type

This type is used for an operation that does not return a value.

Enumerations

```
enum { identifier_list }
short enum { identifier_list }
```

The enumerated types provide names for integers. An `enum` is a 32-bit integer; a `short enum` is a 16-bit integer. You can declare these types only in `typedef` statements. The NIDL Compiler assigns integer values, beginning at 0, to `enum` identifiers based on their order in *identifier_list*. For example:

```
typedef enum {John, Paul, George, Ringo} beatles;
```

In this declaration, `John` gets the value 0, `Paul` gets 1, `George` gets 2, and `Ringo` gets 3.

6.7.2 Constructed Types

NIDL also supports constructed data types, including sets, strings, structures, discriminated unions, pointers, and arrays:

Sets

```
bitset enum { identifier_list }
short bitset enum { identifier_list }
```

A `bitset` is similar to an enumeration, but instead of defining names for integers, it defines names for bits in a single 32-bit integer, starting with the least significant bit. A `short bitset` defines names for bits in a 16-bit integer. For example:

```
typedef bitset enum {Steinhardt, Dalley, Tree, Soyer} guarneri;
```

In this declaration, `Steinhardt` represents the value of bit 0 in an integer, `Dalley` represents bit 1, `Tree` represents bit 2, and `Soyer` represents bit 3.

Strings

`string0 [` *length* `]`

A `string0` is a C-style null-terminated string, that is, a character array whose last element is the null character `\0`. The *length* indicates the maximum length of the string, including the terminating zero byte. For example:

```
string0[7]
```

The specified string is long enough to hold ''Ligeti''.

Structures

```
struct tag {
      type_specifier [ field_attribute_list ] declarator ;
      ...
      }
```

A NIDL `struct` cannot contain pointers unless you apply the `transmit_as` type attribute and supply routines to convert the structure to a transmissible type. The *tag* is optional.

The *field_attribute_list* can apply only to arrays. Subsection 6.5.3 describes field attributes.

An open array can appear in a structure only as the last member. A structure containing an open array must be passed by reference.

Unions

```
union switch ( d_type_specifier discriminator ) tag {
      case constant : type_specifier declarator ;
      ...
      default : type_specifier declarator ;
      }
```

A NIDL `union` must be discriminated and hence differs considerably from its C counterpart. In the union header, you specify a discriminator and its type; the discriminator selects a member at the time the union is used. The NIDL `union` is a combination of C `union` and `switch` syntax.

The *d_type_specifier* and the *discriminator* are the type and the name of the discriminator. The *d_type_specifier* must be one of the simple types described in Subsection 6.7.1. The NIDL Compiler uses the optional *tag* to generate identifiers in source code representations of the union; see Subsection 6.7.5.

A default member, identified by the label `default`, can optionally appear anywhere in the list of cases. At the time the union is used, if the value of *discriminator* does not match any *constant* in the list of cases, the default member applies. In the absence of a default member, failure to match a *discriminator* raises an error.

The NIDL Compiler can generate C source code, but not Pascal source code, to represent a union with a `default` case.

To indicate that several cases take the same declarator, omit the *type_specifier*, the *declarator*, and the semicolon in all but the last `case`. To indicate an empty member, omit the *type_specifier* and the *declarator*. For example:

```
typedef union switch ( int pick ) {
            case 1 :
            case 2 : int fraise;
            case 3 : float framboise;
            case 4 :
            case 5 : ;
            } berries;
```

A `union`, like a `struct`, cannot contain pointers unless you apply the `transmit_as` type attribute and supply routines to convert the union to a transmissible type.

Subsection 6.7.5 discusses how the NIDL Compiler represents discriminated unions in the C and Pascal source code it generates.

Pointers

*type_specifier *identifier*

To specify a pointer, precede the identifier with an asterisk. For example:

```
int *pointer_to_int
```

A NIDL pointer cannot be null.

The NIDL Compiler generates code that can marshall and unmarshall pointers only ''at top level'' and not within any constructed types. You can overcome this restriction by applying the `transmit_as` type attribute and supplying routines to convert the constructed type to a transmissible one.

Arrays

type_specifier identifier [*length*]

To specify an array, follow the name with brackets enclosing the number of elements in the array. If *length* is an asterisk or is omitted, the array is open. Consecutive pairs of brackets specify a multidimensional array. Subsection 6.5.4 describes array syntax in more detail.

6.7.3 The RPC Handle Type

The `handle_t` type denotes an opaque handle type meaningful to the RPC runtime library. If you specify this type for the explicit handles or the implicit handle in an interface, the interface uses manual binding.

6.7.4 Named Types

Named types are types defined by type declarations. For example, the following `typedef` statement defines `long_int` to be a synonym for `int`:

```
typedef int long_int;
```

Section 6.5 describes type declarations in detail.

6.7.5 Representation of Unions

NIDL unions are discriminated, unlike C unions. When the NIDL Compiler generates C code to represent a NIDL union, it embeds the union and the discriminator in a C structure. The name of the NIDL union becomes the name of the C structure. If you assign a tag to the NIDL union in your type declaration, the compiler uses the tag to name the embedded C union; otherwise, the compiler uses a generic name.

In the following declaration, we assign `utag` as the tag for a union named `union_with_tag`:

```
typedef union switch (short i) utag {
    case 1:
    case 2:
        struct { short a, b; } struct1;
    case 3:
    case 4:
        struct { float x, y; } struct2;
    case 5:
        char p;
    case 6:
        char q;
    } union_with_tag;
```

In the C definition that the NIDL Compiler generates, the union name `union_with_tag` becomes the name of the embedding structure, and the tag `utag` becomes the name of the embedded union:

This example of NIDL Compiler output shows code reformatted for readability and with comments added.

```
typedef struct union_with_tag union_with_tag;
struct union_with_tag {
    ndr_$short_int i;           /* the discriminator */
    union {                     /* the union */
        /* case(s): 1, 2 */
        struct {
            ndr_$short_int a;
            ndr_$short_int b;
            } struct1;
        /* case(s): 3, 4 */
        struct {
            ndr_$short_float x;
            ndr_$short_float y;
            } struct2;
        /* case(s): 5 */
        ndr_$char p;
        /* case(s): 6 */
        ndr_$char q;
        } utag;
    };
```

Special Topics 7

This chapter covers the following special topics:

- Open arrays
- Data type conversion
- Automatic binding
- Servers that export multiple interface versions
- Servers that contain multiple managers

The examples in this chapter omit most error-handling code and use ellipsis points (. . .) to indicate substantial omissions.

7.1 Open Arrays

DECrpc supports both fixed arrays, which have an explicitly declared length, and open arrays, which have no explicitly declared length. Since the length of an open array is not known until runtime, special treatment is required to dynamically inform stubs about the array length.

This section describes the NIDL constructs associated with open arrays and discusses the interface definition, client module, and manager module for a simple `primes` application that generates prime numbers and passes an open array as input and output.

7.1.1 NIDL Attributes for Arrays

NIDL provides two field attributes that apply only to arrays: `last_is` and `max_is`. These attributes identify *last* and *max* fields that, at runtime, will contain information about the length of an array. The client stub and server stub use the *last* and *max* information to marshall, unmarshall, and store the array.

An array with `last_is` or `max_is` must be either a member of a structure or a parameter of an operation. The attributes precede the array name in a *field_attribute_list*:

type_specifier [*field_attribute_list*] *array_declarator* [*array_length*]

The *array_length* is optional. To specify an open array, supply an asterisk (`*`) as the *array_length* or omit the *array_length* altogether. The *field_attribute_list* comprises one or both of the following elements, separated by commas:

`last_is` (*last*)
`max_is` (*max*)

7.1.1.1 The last_is Attribute – The `last_is` attribute enables client and server programs to indicate dynamically the size of an array. This attribute informs the NIDL Compiler that, at runtime, *last* will be the index of the last array element to be passed. When an array passes from client to server, the client program assigns a value for *last*, and the client stub uses this value to marshall the array. Likewise, when an array passes from server to client, the server manager code assigns a value for *last*, and the server stub uses this value to marshall the array.

Note that *last* is an index, not a count.

The `last_is` attribute is required for open arrays. For a fixed array, `last_is` is not required, but you can use it to increase efficiency when you intend to pass only part of the array; the stubs will not marshall any element with an index greater than *last*. Examples 7-4 and 7-6 apply `last_is` to fixed arrays.

An array with `last_is` can appear either in the parameter list of an operation declaration or in the declaration of a structure. In an operation declaration, the array and its *last* are parameters of the operation; in a structure declaration, the array and its *last* are members of the structure, and the array must be the last member.

The following declaration specifies that, at runtime, `nlast` will be the index of the last element to be passed in the array `narray`:

```
typedef struct {
    int nlast;
    char [last_is (nlast)] narray[];
    } name;
```

If an array has a *last*, the stub that sends the array uses the *last* to determine how many elements to marshall, and it embeds the element count in the transmitted representation of the array. The stub that receives the array uses this embedded count to determine how many elements it should unmarshall. Therefore, the *last*, whether a structure member or a parameter, must be available to the sending stub but need not be available to the receiving stub.

If the array and its *last* are members of a structure, this condition is automatically met because the array and the *last* are always sent together. However, if the array and its *last* are parameters of an operation, you must ensure that the *last* parameter travels with or before the array parameter: an `in` array requires an `in` *last*, but an `out` array can have either an `in` or an `out` *last*.

It is possible for a *last* to serve as both *last* and *max* for an array, as described in the next section.

7.1.1.2 The max_is Attribute – The `max_is` attribute enables a client program to indicate dynamically the maximum possible size of an array. This attribute informs the NIDL Compiler that, at runtime, *max* will be the maximum possible index of the array. The client program assigns the value of *max*; the server stub uses this value when it allocates storage for the ''surrogate'' copy of the array on the server side.

Like *last*, *max* is an index, not a count.

You typically apply `max_is` to open arrays that are returned by the server, but you can always omit it. If you omit `max_is` for an open array, the NIDL Compiler uses the *last* of the array as its *max*, as though you had declared `max_is (`*last*`)`.

Like `last_is`, `max_is` can appear in an operation declaration or in a structure declaration. In an operation declaration, the array and its *max* are parameters of the operation; in a structure declaration, the array and its *max* are members of the structure, and the array must be the last member.

The following declaration specifies both `max_is` and `last_is` attributes for the array `parray`:

```
typedef struct {
    int pmax;
    int plast;
    int [max_is(pmax), last_is(plast)] parray[];
    } pixels;
```

Since the client program supplies *max* for use by the server stub, *max* must always pass from client to server and therefore must have at least the `in` attribute. If you omit the `max_is` attribute and allow a *last* to serve as a *max*, this directional requirement applies to the *last.*

One implication of the preceding paragraph is that a structure containing an open array can never be simply an `out`. If you intend the array to pass in the `out` direction only, the interface definition should declare the structure as both `in` and `out`, and the client program should set the input value of *last* to prevent the client stub from marshalling data; in the C syntax of NIDL, arrays are zero-based, so the input value of *last* should be –1.

7.1.2 The primes Interface Definition

Example 7-1 shows the NIDL definition for the `primes` interface. This definition contains only one declaration, that of the `primes$gen` operation. The operation passes input and output in the array `values`.

Example 7-1: The primes.idl Interface Definition

```
%c
[uuid(443d5a1a4000.0d.00.00.fe.da.00.00.00), version(1)]
interface primes
{
[idempotent]
void primes$gen(
    handle_t     [in] h,
    int          [in, out] *last,
    int          [in] max,
    status_$t    [comm_status, out] *st,
    int          [in, out, last_is(last), max_is(max)] values[]
    );
    /* the first element of values[] will be used
        to hold an input parameter */
}
```

The empty brackets indicate that `values` is an open array. The array, its *last*, and its *max* are all parameters of the `primes$gen` operation.

This interface definition also illustrates use of the `comm_status` parameter attribute. If a communications error occurs during a `primes$gen` call, a cleanup handler inserted by the NIDL Compiler in the client stub handles the error and passes the error code to the client in the `st` status parameter. Chapter 5 discusses status parameters.

7.1.3 The primes Client Module

Example 7-2 shows excerpts from the client module, `client.c`.

The client initializes `values` to a length of 1000 elements. It asks the user to specify the integer up to which prime numbers will be generated, and it assigns this integer to the first element of `values`.

The client sets `last` to 0, so that only one element will pass as input to the server. When it calls `primes$gen`, the client supplies 999 as the `max` parameter, to ensure that, on return, the array will not exceed the space allocated for it.

When `primes$gen` returns, the client prints the array elements whose indexes range from 0 to `last`.

Example 7-2: Excerpts from the client.c Module for primes

```
...
#define MAXVALS 1000
...
main()
{
    handle_t h;
    status_$t st;
...
    ndr_$long_int values[MAXVALS], last;
    char buf[100];
    int i;
...
    printf("Generate primes up to what integer: ");
    gets(buf);
    values[0] = (ndr_$long_int)atoi(buf);
    last = 0;   /* marshall only the first element of the array */
    primes$gen(h, &last, MAXVALS-1, &st, values);
...
    printf("Primes are:\n");
    for (i = 0; i <= last; i++) printf("%d ", values[i]);
    printf("\n");
}
```

7.1.4 The primes Manager Module

Example 7-3 shows the manager module, `manager.c`.

The manager routine `primes$gen` checks integers for primeness and assigns prime numbers to elements of `values`. It quits when it reaches the limit specified on input by the client or when it reaches the array element with index `max`. Before it returns, `primes$gen` sets `last` to the index of the last element in `value`.

Example 7-3: The manager.c Module for primes

```
#include "primes.h"

globaldef primes_v1$epv_t primes_v1$manager_epv  {primes$gen};

void primes$gen(h, last, max, status, values)
handle_t h;
status_$t *status;
ndr_$long_int *last, max, values[];
{
    ndr_$long_int n, highest = values[0], index = 0;
```

Example 7-3: (continued)

```
    for (n = 2; n <= highest; n++)
        if (is_prime(n)) {
            values[index++] = n;
            if (index > max) break;
        }
    *last = index-1;
    status->all = status_$ok;
    return;
}

static int is_prime(n)
ndr_$long_int n;
{
    int i;

    for (i = n/2; i > 1; i--)
        if (i*(n/i) == n) return 0;
    return 1;
}
```

7.1.5 Related Examples

The `xmitas` and `sparse` examples, described in Section 7.2, apply `last_is` to fixed arrays and also show how to pass an array as a member of a structure.

7.2 Data Type Conversion

The NIDL `transmit_as` attribute lets you associate a **transmitted type** that stubs pass over the network with a **presented type** that clients and servers manipulate. You write routines to convert between the presented and transmitted types, and you link those routines with the stubs. Chapter 4 describes the use of `transmit_as` in NIDL definitions. This section lists the requirements for the conversion routines and presents two examples: one that uses type conversion to pass a complex data type and one that uses type conversion for efficiency.

7.2.1 Type Conversion Routines

When you associate a transmitted type with a presented type, you must write four routines to perform conversion and to manage storage for the types. This section specifies C prototypes for these routines; in the prototypes, `PRES` is the name of the presented type and `TRANS` is the name of the transmitted type. The `PRES_to_xmit_rep` routine allocates storage for the transmitted type and converts from the presented type to the transmitted type:

```
void PRES_to_xmit_rep (presented,transmitted)
    PRES presented;
    TRANS **transmitted;
```

The `PRES_from_xmit_rep` routine allocates storage for the presented type and converts from the transmitted type to the presented type:

```
void PRES_from_xmit_rep (transmitted, presented)
    TRANS *transmitted;
    PRES *presented;
```

The `PRES_free` routine frees any storage that has been allocated for the presented type by `PRES_from_xmit_rep`:

```
void PRES_free (presented)
    PRES presented;
```

The `PRES_free_xmit_rep` routine frees any storage that has been allocated for the transmitted type by `PRES_to_xmit_rep`:

```
void PRES_free_xmit_rep (transmitted)
    TRANS *transmitted;
```

7.2.2 Using Type Conversion to Pass Complex Types

The NIDL Compiler cannot generate stub code to marshall and unmarshall complex types such as trees, linked lists, and structures that contain pointers. Any data type containing a pointer not ''at top level'' is complex.

The `xmitas` example uses type conversion to pass a linked list as an open array. The client and server manipulate the linked list type. The client and server stubs transmit arrays over the network.

This section discusses the interface definition and `util.c` module for `xmitas`.

7.2.3 The xmitas Interface Definition

Example 7-4 shows the NIDL definition for the `xmitas` interface.

Example 7-4: The xmitas.idl Interface Definition

```
%c
[uuid(441f8a28a000.0d.00.00.fe.da.00.00.00), version(1)]
interface xmitas
{
    const int MAXELEMENTS = 100;     /* maximum size of list */

    typedef struct {
        int last;
        int [last_is(last)] values[MAXELEMENTS];
    } trans_t;

    typedef [transmit_as(trans_t)] struct {
        int value;
        list_t *next;
    } list_t;

    [idempotent]
        int xmitas$sum(handle_t [in] h, list_t [in] list);
}
```

The transmitted type, `trans_t`, is a structure whose members are the integer `last` and the integer array `values`. Though `values` has a declared length, the `last_is` attribute is supplied so that no more elements than necessary are passed.

The presented type, `list_t`, is a linked list structure whose members are the integer `value` and the pointer `next`, which points to the next `list_t`.

There is one operation in the `xmitas` interface, `xmitas$sum`. Its inputs are `h` (a handle) and `list` (a linked list). The operation returns an integer that is the sum of the values in `list`.

7.2.4 The xmitas util.c Module

Figure 7-5 shows the `util.c` module, which contains routines to convert between the `list_t` and `trans_t` types and to allocate and free storage for those types.

Example 7-5: The util.c Module for xmitas

```
#include <stdio.h>
#include "xmitas.h"

static void free_list_recursively();     /* auxiliary function */

void list_t_to_xmit_rep(list, xmit_struct) [1]
list_t list;
trans_t **xmit_struct;
{
    int count = 0;
    list_t *lp = &list;

    /* allocate the structure */
    *xmit_struct = (trans_t *)malloc(sizeof(trans_t));

    /* copy the values from the list to the array */
    while (lp) {
        (*xmit_struct)->values[count++] = lp->value;
        lp = lp->next;
    }
    (*xmit_struct)->last = (ndr_$long_int)(count-1);
}

void list_t_from_xmit_rep(xmit_struct, list) [2]
trans_t *xmit_struct;
list_t *list;
{
    int index = 0;

    /* reconstruct the linked list from the array */
    do {
        list->value = xmit_struct->values[index++];
        if (index <= xmit_struct->last)
            list->next = (list_t *)malloc(sizeof(list_t));
        else list->next = NULL;

        list = list->next;
    } while (index <= xmit_struct->last);
}

void list_t_free(list) [3]
list_t list;
{
    free_list_recursively(list.next);
}

void list_t_free_xmit_rep(xmit_struct) [4]
trans_t *xmit_struct;
{
    free(xmit_struct);
}

static void free_list_recursively(l)
list_t *lp;
{
    if (lp->next) free_list_recursively(lp->next);
    free(lp);
}

char *error_text(st)
status_$t st;
```

Example 7-5: (continued)

```
{
    static char buff[200];
    extern char *error_$c_text();
    return (error_$c_text(st, buff, sizeof buff));
}
```

1. The first routine, `list_t_to_xmit_rep`, allocates storage for the structure to be transmitted and then copies values from the linked list into the array. It sets `(*xmit_struct)->last` to the index of the last element that it copied to `(*xmit_struct)->values`.

2. The second routine, `list_t_from_xmit_rep`, copies values from the transmitted array into the linked list, allocating additional storage as it builds the list, until it reaches the array element with index `last`.

3. Any storage allocated by `list_t_from_xmit_rep` for the linked list is freed by `list_t_free`.

4. Any storage allocated by `list_t_to_xmit_rep` is freed by `list_t_free_xmit_rep`.

7.2.5 Using Type Conversion for Efficiency

The `sparse` example uses type conversion to transmit arrays in a run-length-encoded format. The code supplies routines to encode and decode the arrays. The stubs present sparse arrays to the client and server but pass compact arrays over the network.

This subsection discusses the interface definition and `util.c` module for `sparse`.

7.2.5.1 The sparse Interface Definition – Figure 7-6 shows the NIDL definition for the `sparse` interface.

Example 7-6: The sparse.idl Interface Definition

```
%c
[uuid(442548088000.0d.00.00.fe.da.00.00.00), version(1)]
interface sparse
{
    const int ARRAY_SIZE = 1000;
    const int CARRAY_SIZE = 2000;[1]
    /* worst case: twice the original size */

    /* a run-length-encoded representation of an array */

    typedef struct {
        int last;
        int [last_is(last)] data[CARRAY_SIZE];[2]
    } compress_t;

    /* this type will be transmitted as a more compact type */
    typedef [transmit_as(compress_t)] int compress_array[ARRAY_SIZE];[3]

    /* this type will be transmitted as is */
    typedef int nocompress_array[ARRAY_SIZE];[4]

    [idempotent]
        int sparse$compress_sum([5]
            handle_t [in] h,
            compress_array [in] array
```

Example 7-6: (continued)

```
            );

    [idempotent]
        int sparse$nocompress_sum([6]
            handle_t [in] h,
            nocompress_array [in] array
            );
}
```

[1] In the worst case, encoding doubles the length of an array, so the declared length of the compact array is twice that of the sparse array.

[2] Because we expect the compact array to be shorter we give it the `last_is` attribute and embed it in the `compress_t` structure with a `last`.

[3] The example declares two sparse array types: `compress_array` has `compress_t` as its transmitted form.

[4] The array `nocompress_array` is transmitted unchanged.

[5] Both of the operations in the `sparse` interface take a sparse array as input and return the sum of its elements. The operation `sparse$compress_sum` passes its inputs in a compact array.

[6] The operation `sparse$nocompress_sum` passes a sparse array.

7.2.5.2 The sparse util.c Module – Example 7-7 shows the `util.c` module, which contains the conversion routines for the `sparse` example. These routines are similar to those for the `xmitas` example.

Example 7-7: The util.c Module for sparse

```
#include <stdio.h>
#include "sparse.h"

void compress_array_to_xmit_rep(array, xmit_struct) [1]
compress_array array;
compress_t **xmit_struct;
{
    int rep, val, index = 0, pos = 0;

    /* allocate the structure */
    *xmit_struct  (compress_t *)malloc(sizeof(struct compress_t));

    /* run-length encode the array */
    do {
        rep = 0;
        val = array[pos];
        while (pos < ARRAY_SIZE && array[pos] == val) {
            pos++;
            rep++;
        }
        (*xmit_struct)->data[index] = rep;
        (*xmit_struct)->data[index+1] = val;
        index += 2;
    } while (pos < ARRAY_SIZE);

    (*xmit_struct)->last = index-1;[2]
}

void compress_array_from_xmit_rep(xmit_struct, array) [3]
compress_t *xmit_struct;
compress_array *array;
```

Example 7-7: (continued)

```
{
    int index, rep, count = 0;

    for (index = 0; index < xmit_struct->last; index+=2)
        for (rep = 0; rep < xmit_struct->data[index]; rep++)
            (*array)[count++] = xmit_struct->data[index+1];
}
void compress_array_free(object) [4]
compress_array object;
{
    /* no freeing is appropriate here */
}
void compress_array_free_xmit_rep(xmit_struct) [5]
compress_t *xmit_struct;
{
    free(xmit_struct);
}
char *error_text(st)
status_$t st;
{
    static char buff[200];
    extern char *error_$c_text();

    return (error_$c_text(st, buff, sizeof buff));
}
```

[1] The `compress_array_to_xmit_rep` routine allocates storage for the compact array and then encodes the sparse array.

[2] The routine sets `(*xmit_struct)->last` to the index of the last element that it copied to `(*xmit_struct)->data`, so that no more elements are passed than necessary.

[3] The `compress_array_from_xmit_rep` routine decodes the compact array, reconstructing the sparse array. Storage for the sparse array has already been allocated, so this routine does not perform any allocation.

[4] Since `compress_array_from_xmit_rep` did not allocate any storage, `compress_array_free` does not need to free any and thus is defined as a null operation.

[5] Storage allocated by `compress_array_to_xmit_rep` is freed by `compress_array_free_xmit_rep`.

7.2.5.3 **Restrictions –** You cannot use a data type with the `transmit_as` attribute as an element of an array or as a member of a structure or union. In effect, you can use a type with `transmit_as` only as an operation parameter.

A data type with the `transmit_as` attribute cannot serve as the transmitted type for another type.

7.3 Automatic Binding

Automatic binding allows a client to represent objects with generic handles rather than RPC handles. The data type of a generic handle must have the `handle` type attribute. The generic handle can be either a first parameter in each operation (an explicit handle) or a global variable in the client (an implicit handle).

Since the RPC runtime library uses only RPC handles, you must supply an autobinding routine that generates RPC handles from generic handles. The client stub invokes the autobinding routine each time the client makes a remote procedure call. In addition, you supply an autounbinding routine that performs any necessary cleanup (for instance, freeing the RPC handle) after the remote call returns.

7.3.1 Automatic Binding Activity

If an application uses automatic binding, the following occurs when the client makes a remote procedure call:

1. The client makes a remote procedure call, through the client switch, to the stub. The client provides a generic handle either as the first parameter of the call (an explicit handle) or through a global variable (an implicit handle).
2. The stub calls the autobinding procedure, passing to it the generic handle.
3. The autobinding procedure returns an RPC handle to the stub.
4. The stub uses the RPC handle as a parameter to the `rpc_$sar` library routine.
5. The `rpc_$sar` routine returns the server response to the stub.
6. The stub calls the autounbinding procedure, passing to it the RPC handle.
7. The autounbinding procedure frees the RPC handle and any unneeded resources associated with the generic handle.
8. The stub returns to the client.

7.3.2 Autobinding and Autounbinding Routines

When you use a generic handle type, you must write autobinding and autounbinding routines. This example shows the autobinding routine for UUIDs from the bank example. (Example 7-8 shows the entire routine.) The routine generates an RPC handle from an object UUID and returns the RPC handle:

```
handle_t uuid_$t_bind(object)
uuid_$t object;
```

The next examples show C prototypes for these routines; in the prototypes, *GENERIC* is the name of the generic handle type (replacing `uuid_$t` in the previous example). The autobinding routine *GENERIC*`_bind` generates an RPC handle from a generic handle and returns the RPC handle:

```
handle_t GENERIC_bind (g-handle)
GENERIC g-handle ;
```

The autounbinding routine *GENERIC*`_unbind` takes two inputs, a generic handle and the RPC handle that was generated from it, and has no outputs:

```
void GENERIC_unbind (g-handle, rpc-handle)
GENERIC g-handle;
handle_t rpc-handle );
```

An autounbinding routine typically frees the RPC handle and any unneeded resources associated with the generic handle, but it is not required to do anything.

7.3.3 Automatic Binding in the bank Example

Examples 7-8 and 7-9 show the autobinding and autounbinding routines from the `bank` example.

These routines, defined in the `uuidbind.c` module, enable the `bank` example to use UUIDs as generic handles. They maintain a cache of handles to save the expense of invoking `lb_$lookup_object` and `rpc_$bind` every time the client makes a remote procedure call; this approach is particularly useful in applications where the client tends to make several calls to access the same object. The file `nbase.idl` defines the UUID data type, `uuid_$t`, and assigns to this type the `handle` type attribute.

7.3.3.1 The bank Autobinding Routine – The autobinding routine, `uuid_$t_bind`, searches the cache for an RPC handle that matches the generic handle (the object UUID). If there is no matching handle in the cache, it calls `lb_$lookup_object` to get the location of the object and calls `rpc_$bind` to create a new handle. It uses `rpc_$dup_handle` to return a copy of the handle.

Each handle in the cache has an associated reference count. When all copies of a handle have been freed, meaning that its binding is not in use, the ''original'' handle is kept available but is considered ''collectible.'' If its entry in the cache is needed for a new handle, it can be freed.

Example 7-8: An Autobinding Routine for UUIDs

```
/*
 * Table mapping UUIDs into RPC handles.
 */

static struct db_entry {
    boolean  valid;           /* Is this entry valid? */
    uuid_$t  obj;             /* Object UUID */
    handle_t handle;          /* RPC handle for the object */
    unsigned short refcnt;    /* # of references on this entry */
} uuid_db[MAX_ENTRIES];

/*
 * Autobinding procedure for type "uuid_$t".
 */

handle_t uuid_$t_bind(object)
uuid_$t object;
{
    short i, invalid_i = -1, collectible_i = -1;
    lb_$entry_t lb_entry;
    unsigned long n_results;
    status_$t st;
    lb_$lookup_handle_t lookup_handle = lb_$default_lookup_handle;

    /*
     * Scan the table for an entry that has a matching UUID.  If
     * we find one, return the handle that's stored there.  While
     * scanning, keep note of the last invalid entry (i.e. one that
     * is unused) and the last collectible entry (i.e. one that has
     * an object and handle but isn't being referenced by anyone).
     */
    for (i = 0; i < MAX_ENTRIES; i++) {
        struct db_entry *db = &uuid_db[i];
        if (! db->valid)
            invalid_i = i;
        else {
```

Example 7-8: (continued)

```
            if (bcmp(&db->obj, &object, sizeof object) == 0) {
                db->refcnt++;
                return (rpc_$dup_handle(db->handle, &st));
            }
            if (db->refcnt == 0)
                collectible_i = i;
        }
    }
    /*
     * Didn't find a match in the table.
     * Ask the LB for the location.
     */
    lb_$lookup_object(&object, &lookup_handle, 1L, &n_results,
            &lb_entry, &st);
    if (st.all != status_$ok || n_results <= 0) {
        fprintf(stderr,
                "(uuid_$t_bind) Lookup failed, n_results%ld\n",
                n_results);
        pfm_$signal(st);
    }
    /*
     * Decide whether we have an entry to use.
     * Free the current handle if we're collecting the entry.
     */
    if (invalid_i != -1)
        i = invalid_i;
    else if (collectible_i != -1) {
        i=  collectible_i;
        rpc_$free_handle(uuid_db[i].handle, &st);
    }
    else {
        fprintf(stderr, "(uuid_$t_bind) No space in cache\n");
        abort();
    }
    /*
     * Fill in the entry with our values.
     */
    uuid_db[i].obj    = object;
    uuid_db[i].valid  = true;
    uuid_db[i].refcnt = 1;
    /*
     * Make an RPC handle for the object and location and return it.
     */
    uuid_db[i].handle  rpc_$bind(&object, &lb_entry.saddr,
            lb_entry.saddr_len, &st);
    if (st.all != status_$ok)
        pfm_$signal(st);
    return (rpc_$dup_handle(uuid_db[i].handle, &st));
}
```

7.3.3.2 The bank Autounbinding Routine – The autounbinding routine, `uuid_$t_unbind`, uses `rpc_$free_handle` to free a copy of the RPC handle that matches the generic handle and decrements the reference count of the generic handle.

Example 7-9: An Autounbinding Routine for UUIDs

```
/*
 * Autounbinding procedure for type "uuid_$t".
 */

void uuid_$t_unbind(object, handle) [1]
uuid_$t object;
handle_t handle;
{
    unsigned short i;
    status_$t st;

    /*
     * Scan the table looking for the handle.
     */
    for (i = 0; i < MAX_ENTRIES; i++) {
        struct db_entry *db = &uuid_db[i];

        if (db->valid && db->handle == handle) {
            rpc_$free_handle(handle, &st); [2]
            db->refcnt--; [3]
            return;
        }
    }

    fprintf(stderr,
        "(uuid_$t_bind) tried to free a handle we didn't return\n");
    abort();
}
```

$\boxed{1}$ The autounbinding routine `uuid_$t_unbind` takes two arguments–an object (of type `uuid_t$` and a handle of type `handle_t`.

$\boxed{2}$ The routine uses `rpc_$free_handle` to free a copy of the RPC handle that matches the generic handle.

$\boxed{3}$ The routine then decrements the reference count of the handle.

7.4 Multiple Interface Versions

DECrpc allows a single server to simultaneously export several versions of an interface. The `binopmv` example, an extension of the `binop_lu` example described in Chapter 3, illustrates this feature.

There are two versions of the `binopmv` interface. The first version is essentially identical to the `binop_lu` interface; the second version has one additional operation.

The `binopmv` example actually does not require a server that exports both versions of the interface. Chapter 5 describes a way to add operations to interfaces while maintaining backward compatibility. However, `binopmv` illustrates the most general way to compatibly modify an interface.

This section describes the interface definitions, the client modules, the server module, and the manager module for `binopmv`.

7.4.1 The binopmv Interface Definitions

The `binopmv` example has two interface definition files, named `vers1.idl` and `vers2.idl`.

7.4.1.1 The vers1.idl Interface Definition

The vers1.idl Interface Definition – Example 7-10 shows `vers1.idl`, the NIDL definition for version 1 of the `binopmv` interface. This interface definition declares one operation, `binopmv$add`.

Example 7-10: The vers1.idl Interface Definition for binopmv

```
%c
[uuid(4433af7ed000.0d.00.00.fe.da.00.00.00), version(1)]
interface binopmv
{
[idempotent]
    void binopmv$add(
        handle_t [in] h,
        long [in] a,
        long [in] b,
        long [out] *c
        );
}
```

7.4.1.2 The vers2.idl Interface Definition

The vers2.idl Interface Definition – Example 7-11 shows `vers2.idl`, the NIDL definition for version 2 of the `binopmv` interface. The definitions for the two versions of `binopmv` specify the same interface UUID and the same interface name, but different version numbers.

The definition for version 2 declares two operations, `binopmv$add` and `binopmv$sub`.

Example 7-11: The vers2.idl Interface Definition for binopmv

```
%c
[uuid(4433af7ed000.0d.00.00.fe.da.00.00.00), version(2)]
interface binopmv
{
[idempotent]
    void binopmv$add(
        handle_t [in] h,
        long [in] a,
        long [in] b,
        long [out] *c
        );
[idempotent]
    void binopmv$sub(
        handle_t [in] h,
        long [in] a,
        long [in] b,
        long [out] *c
        );
}
```

7.4.2 Compiling the Interface Definitions

When you compile interface definitions for an application whose server will export multiple interface versions, you must specify the NIDL Compiler `-m` option.

If invoked with `-m`, the NIDL Compiler appends the version number to the interface name when it generates identifiers in the stub and header files. In effect, different versions of an interface have different names.

The nidl(1ncs) reference page describes all of the NIDL Compiler options.

Table 7-1 lists the identifiers that the NIDL Compiler generates for the binopmv example. These identifiers are all generated from the interface name and the version number.

Table 7-1: Identifiers in the binopmv Example

Component	Identifier for Version 1	Identifier for Version 2
EPV type	binopmv_v1$epv_t	binopmv_v2$epv_t
Client EPV	binopmv_v1$client_epv	binopmv_v2$client_epv
Server EPV	binopmv_v1$server_epv	binopmv_v2$server_epv
Interface specifier	binopmv_v1$if_spec	binopmv_v2$if_spec

7.4.3 The binopmv Client Modules

There are two client programs. The first, client1.c, uses version 1 of the interface and calls binopmv$add. The second, client2.c, uses version 2 of the interface and calls both binopmv$add and binopmv$sub.

In most respects, the client1.c and client2.c programs are similar to the binop_lu client described in Chapter 3, so this discussion concentrates on the client program's use of multiple interface versions.

7.4.3.1 Header Files – Each client includes the header file for its version of the interface as shown in the following examples.

This example shows the include file for client1.c:

```
#include "vers1.h"
```

This example shows the include file for client2.c:

```
#include "vers2.h"
```

7.4.3.2 Location Broker Lookup Criteria – The clients perform Location Broker lookups by interface. Each client supplies to lb_$lookup_interface the id member of the if_spec for its version of the interface.

This example shows the lb_$lookup_interface call for client1.c:

```
lb_$lookup_interface(&binopmv_v1$if_spec.id, &lookup_handle, 1L,
                     &nresults, &entry, &st);
```

This example shows the lb_$lookup_interface call for client2.c:

```
lb_$lookup_interface(&binopmv_v2$if_spec.id, &lookup_handle, 1L,
                     &nresults, &entry, &st);
```

Although these lookup calls appear to be different, they are in effect identical because versions 1 and 2 of the interface have the same UUID. Hence, the lookup calls will return information about all servers for binopmv, regardless of version. Each client must either check that a server exports the correct version or deal with possible version mismatches.

7.4.3.3 Checking Interface Versions – After a binopmv client has obtained the Location Broker entry for a binopmv server, the client binds its handle to the location of the server and then checks that the server exports a matching version of the interface. Example 7-12 shows the version checking code in client1.c; client2.c contains essentially the same code.

Example 7-12: Version Checking Code in the client1.c Module for binopmv

```
...
#include "vers1.h"
...
#define VERSION 1    /* version of interface requested */
...
    handle_t h;
    status_$t st;
    rrpc_$interface_vec_t ifs;
    unsigned long lastif;
    int k, passes, found_version;
...
    /* check for appropriate version */
    rrpc_$inq_interfaces(h, 2L, ifs, (ndr_$long_int *)&lastif, &st); [1]
    for (k = 0, found_version = 0; k <= lastif; k++) [2]
        if (ifs[k].vers == VERSION) found_version = 1;
    if (!found_version) {
        fprintf(stderr, "Couldn't get version %d\n", VERSION);
        exit(1);
    }
    else printf("Found version %d\n", VERSION);
...
```

[1] The client calls rrpc_$inq_interfaces to obtain an rrpc_$interface_vec_t , an array of interface specifiers for the interfaces exported by the server.

[2] The client code checks the vers member of each interface specifier against its own version until it finds a match.

7.4.4 The binopmv Server Module

The server module, server.c, largely resembles the binop_lu server described in Chapter 3, but does all of its registrations and unregistrations twice, once for each interface version.

7.4.4.1 Registrations and Unregistrations – Example 7-13 shows the registration and unregistration code in server.c.

Example 7-13: Registrations and Unregistrations in the server.c Module for binopmv

```
...
#include "vers1.h" [1]
#include "vers2.h"

globalref uuid_$t uuid_$nil;
globalref binopmv_v1$epv_t binopmv_v1$manager_epv; [2]
globalref binopmv_v2$epv_t binopmv_v2$manager_epv;
```

Example 7-13: (continued)

```
...
    status_$t st;
    socket_$addr_t loc;
    unsigned long llen;
    lb_$entry_t lb_entry[2];
    pfm_$cleanup_rec crec;
...
    /* register version 1... */

    rpc_$register_mgr(&uuid_$nil, &binopmv_v1$if_spec, 3
         binopmv_v1$server_epv,
         (rpc_$mgr_epv_t)&binopmv_v1$manager_epv, &st);

    /* ...and version 2 with the runtime library */

    rpc_$register_mgr(&uuid_$nil, &binopmv_v2$if_spec, 4
         binopmv_v2$server_epv,
         (rpc_$mgr_epv_t)&binopmv_v2$manager_epv, &st);

    /* register version 1 with the lb */

    lb_$register(&uuid_$nil, &uuid_$nil, &binopmv_v1$if_spec.id, 0L, 5
         (ndr_$char *)"binopmv example (v1)", &loc, llen,
         &lb_entry[0], &st);

    /* ...and version 2 with the lb */

    lb_$register(&uuid_$nil, &uuid_$nil, &binopmv_v2$if_spec.id, 0L, 6
         (ndr_$char *)"binopmv example (v2)", &loc, llen,
         &lb_entry[1], &st);

    st = pfm_$cleanup(&crec); 7
    if (st.all ! pfm_$cleanup_set) {
        status_$t stat;
        fprintf(stderr, "Server received signal - %s\n",
            error_text(st));
        lb_$unregister(&lb_entry[0], &stat);
        lb_$unregister(&lb_entry[1], &stat);
        rpc_$unregister(&binopmv_v1$if_spec, &stat);
        rpc_$unregister(&binopmv_v2$if_spec, &stat);
        pfm_$signal(st);
    }
...
```

1 The server includes the header files for both versions of the interface.

2 The server declares two manager DPVs as external variables.

These EPVs are defined in the manager module. Their names resemble those of the client and server EPVs, but this is merely by convention. Manager EPV names are arbitrary, since they appear only in server and manager code that you write, not in code that the NIDL Compiler generates.

3 Since it exports several interface versions, the `binopmv` server must register each of its manager versions with the RPC runtime library at its (the server's) host. These registrations enable the runtime library to dispatch incoming requests to the correct version of the manager.

4 This call registers the second version with the runtime library.

5 The server also registers twice with the Location Broker. These registrations supply the same UUID to the Location Broker, and hence are indistinguishable to a client performing lookups. Each entry has a different annotation.

6 This call registers the second version with the Location Broker.

$\boxed{7}$ Before it calls `rpc_$listen` to begin accepting requests, the server sets a cleanup handler. If it is signaled, the server removes all of its registrations before it exits.

7.4.5 The binopmv Manager Module

Figure 7-14 shows `manager.c`, the manager module for `binopmv`. This module contains all the code to implement both versions of `binopmv`.

Example 7-14: The manager.c Module for binopmv

```
#include "vers1.h" $\boxed{1}$
#include "vers2.h"

globaldef binopmv_v1$epv_t binopmv_v1$manager_epv =  $\boxed{2}$
    {binopmv$add}; $\boxed{3}$
globaldef binopmv_v2$epv_t binopmv_v2$manager_epv  = $\boxed{4}$
    {binopmv$add, binopmv$sub}; $\boxed{5}$

void binopmv$add(h, a, b, c)
handle_t h;
ndr_$long_int a, b, *c;
{
    *c  a + b;
}

void binopmv$sub(h, a, b, c)
handle_t h;
ndr_$long_int a, b, *c;
{
    *c  a - b;
}
```

$\boxed{1}$ The manager includes both versions of the header file.

$\boxed{2}$ This global definition defines the manager EPV for version 1.

$\boxed{3}$ The EPV for version 1 lists only one operation.

$\boxed{4}$ This global definition defines the manager EPV for version 2.

$\boxed{5}$ The EPV for version 2 lists two operations.

7.4.6 Changing Operations in Interfaces with Multiple Versions

In the `binopmv` example, version 1 and version 2 can share the manager routine for `binopmv$add` because the operation is identical in the two versions. If an operation has different signatures or implementations in two versions of the interface, you must write two manager routines for the operation.

Suppose you are changing the implementation of `binopmv$add` between versions 1 and 2, and you are building a server that exports both versions. You must give distinct names such as `binopmv_v1$add` and `binopmv_v2$add` to the two versions of the manager routine. Because these names are not declared in the `vers1.h` and `vers2.h` header files that the NIDL Compiler generates, you must declare them in the manager module.

Example 7-15 shows what a `binopmv` manager with two versions of `binopmv$add` might look like.

Example 7-15: A Manager Module with Two Versions of an Operation

```
#include "vers1.h"
#include "vers2.h"

void binopmv_v1$add();
void binopmv_v2$add();

globaldef binopmv_v1$epv_t binopmv_v1$manager_epv
    {binopmv_v1$add};
globaldef binopmv_v2$epv_t binopmv_v2$manager_epv
    {binopmv_v2$add, binopmv$sub};

void binopmv_v1$add(h, a, b, c)     /* "old implementation" */[1]
handle_t h;
ndr_$long_int a, b, *c;
{
    *c  a + b;
}

void binopmv_v2$add(h, a, b, c)     /* "new implementation" */[1]
handle_t h;
ndr_$long_int a, b, *c;
{
    *c = b + a;
}

void binopmv$sub(h, a, b, c)
handle_t h;
ndr_$long_int a, b, *c;
{
    *c = a - b;
}
```

[1] In this manager, the two versions of the add operation have different names and trivially different implementations. Clients of either interface version continue to invoke the operation by its name in the interface definition, `binopmv$add`.

Of course, if an operation has a different signature as well as a different implementation in two versions of an interface, the manager routines and the interface definitions must reflect this difference.

7.4.7 Constants and Types in Interfaces with Multiple Versions

When you define a manager EPV, you can declare either that two versions of an interface will share a manager routine (as in Example 7-14) or that they will use different manager routines (as in Example 7-15). Thus, the names of the manager routines in a server will not conflict. The names of constants and types, however, can conflict.

If you declare the same type in two versions of an interface definition, the NIDL Compiler emits a C `typedef` declaration for the type in both of the C header files it generates. When you build a server program that exports both interface versions, the server includes both header files, and hence the type declarations are duplicated. Most C compilers reject such duplicate type declarations.

To avoid conflicts of type names, extract type declarations that are shared by the two versions of the interface and put these declarations in a ''version-independent'' interface definition that is imported by the two ''version-specific'' interface definitions. When you compile the definitions, the NIDL Compiler emits directives in the version-specific header files to include the version-independent header file. In effect, a server that exports both versions of the interface includes this file twice, but every header file generated by the NIDL Compiler contains conditional statements to ensure that its contents are read only once, and therefore no declarations are duplicated.

If you declare a constant in two versions of an interface definition, the NIDL Compiler emits a C preprocessor `#define` directive for the constant in both of the C header files it generates. Though most C preprocessors accept the resulting duplication, it is better practice to define each constant only once, so we recommend that you keep shared constants together with shared types in a separate interface definition file. Example 7-16 shows what an interface definition file for shared types and constants might look like. The ''interface'' requires a name but no attributes.

Example 7-16: An Interface Definition File for Shared Types and Constants

```
%c
interface sharedstuff
{
const VSIZE 1024;

typedef struct {
    int vlast;
    float [last_is(vlast)] varray [VSIZE];
    } values;
}
```

7.5 Multiple Managers

DECrpc allows one server to implement an interface for several object types. A separate manager implements each combination of interface and type. The server registers its objects and their types with the RPC runtime library and the Location Broker; it registers its managers with the RPC runtime library. This section describes the `stacks` example, in which a server manages two types of stacks, one based on lists and one based on arrays.

7.5.1 The stacks Interface Definition

Example 7-17 shows `stacks.idl`, the NIDL definition for the `stacks` interface. There are operations to initialize a stack, to push a value onto a stack, and to pop a value off a stack. Since the interface definition is purely syntactic, it does not indicate in any way the existence of two types of stacks. Different object types require different implementations of operations, but not different signatures.

When you compile `stacks.idl`, specify the NIDL Compiler `-m` option. The `nidl` reference description describes the NIDL Compiler options.

Example 7-17: The stacks.idl Interface Definition

```
%c
[uuid(4438675bf000.0d.00.00.fe.da.00.00.00), version(1)]
interface stacks
{
[idempotent]
    void stacks$init(
        handle_t [in] h
        );
```

Example 7-17: (continued)

```
/* stack functions return non-zero on error, zero otherwise */

int stacks$push(
    handle_t [in] h,
    int [in] value
    );

int stacks$pop(
    handle_t [in] h,
    int [out] *value
    );
}
```

7.5.2 The stacksdf.h Header File

Most of the examples in this book do not involve a particular object and hence specify `uuid_$nil` as the object identifier. The `bank` example, introduced to illustrate automatic binding, accesses two bank databases that are objects of the same type. The `stacks` example accesses two stacks that are objects of different types.

The `stacksdf.h` header file, shown in Example 7-18, defines symbolic constants to represent UUIDs for the two stacks (ASTACK and LSTACK) and their types (ASTACKT and LSTACKT). The replacement texts for these constants are C representations of UUIDs, which are generated by invoking `uuid_gen` with the `-C` option.

Example 7-18: The stacksdf.h Header File

```
/* the two stack objects and their types */

/* the array-based object */
#define ASTACK {0x44349d2c, 0x2000, 0x0000, 0x0d, \
                          {0x00, 0x00, 0xfe, 0xda, 0x00, 0x00, 0x00}}

#define ASTACKT{0x44349e25, 0x0000, 0x0000, 0x0d, \
                          {0x00, 0x00, 0xfe, 0xda, 0x00, 0x00, 0x00}}

/* the list-based object */
#define LSTACK {0x44349e48, 0x2000, 0x0000, 0x0d, \
                          {0x00, 0x00, 0xfe, 0xda, 0x00, 0x00, 0x00}}

#define LSTACKT{0x44349eed, 0x6000, 0x0000, 0x0d, \
                           {0x00, 0x00, 0xfe, 0xda, 0x00, 0x00, 0x00}}
```

7.5.3 The stacks Client Module

Example 7-19 shows excerpts from the client module, `client.c`. The client program lets the user access both types of stacks within one session; it maintains a separate handle for each stack. (Other clients discussed maintain only one handle.) The handles are kept in an array, as are the UUIDs for the stack types. For each type, the client:

1. Performs a Location Broker lookup by type
2. Scans the entries returned for one with the desired interface and address family
3. Binds a handle to represent the object and the location registered in the entry

When the client program calls `stacks$push` or `stacks$pop`, the object UUID in the handle determines the stack to be accessed.

Example 7-19: Excerpts from the client.c Module for stacks

```
...
#include "stacks.h"
#include "stackdf.h"
...
#define MAXENTRIES 5    /* how many L.B. entries we can handle */
...
main()
{
    handle_t handle[2];
    status_$t st;
    lb_$entry_t entries[MAXENTRIES];
...
    static uuid_$t types[2] = {ASTACKT, LSTACKT};
    int s, t, k, found_if;
    ndr_$long_int val;
    char command[100], which[100], value[100];
...
    /* bind handles for each object type */
    for (t = 0; t < 2; t++) {
        /* find lb entries for the type */
        lb_$lookup_type(&types[t], &lookup_handle, MAXENTRIES, &nresults,
                entries, &st);
        if (nresults < 1) {
            fprintf(stderr,
                    "Couldn't find interfaces for type[%d]\n", t);
            exit(1);
        }

        /* check for appropriate interface for the type */
        for (k = 0, found_if = 0; k < nresults; k++)
            if (uuid_$equal(&entries[k].obj_interface,
                    &stacks_v1$if_spec.id) &&
                socket_$valid_family(entries[k].saddr.family,&st))
{
                found_if = 1; /* found appropriate interface */
                break;
            }
        if (!found_if) {
            fprintf(stderr, "Couldn't find appropriate interface\n");
            exit(1);
        }

        /* bind handle */
        handle[t] = rpc_$bind(&entries[k].object,
            &entries[k].saddr, entries[k].saddr_len, &st);
    }
    printf("Initialize stack objects (y/n)? ");
    gets(command);
    if (*command != 'n' && *command != 'N') {
        stacks$init(handle[0]);
        stacks$init(handle[1]);
    }

    do {
        printf("push, pop, or quit: ");
        gets(command);

        if (!strcmp(command, "quit")) break;

        printf("astack or lstack: ");
        gets(which);

        if (!strcmp(which, "astack")) s = 0;
        else s = 1;

        if (!strcmp(command, "push")) {
```

Example 7-19: (continued)

```
      printf("value: ");
      gets(value);
      val  (ndr_$long_int)atoi(value);
      printf("Pushing %d onto %s...",
        val, s?"lstack":"astack");
      if (stacks$push(handle[s], val)) printf("stack full!\n");
      else printf("successful\n");
    }
    else if (!strcmp(command, "pop")) {
      printf("Popping off of %s...", s?"lstack":"astack");
      if (stacks$pop(handle[s], &val))
        printf("nothing on stack!\n");
      else printf("value is %d\n", val);
    }
  } while (strcmp(command, "quit"));
}
```

7.5.4 The stacks Server Module

The `server.c` module is linked together with two manager modules to form the `stacks` server program as shown in Example 7-20.

7.5.4.1 Registrations and Unregistrations – Example 7-20 shows the registration and unregistration code in `server.c`.

The `stacks` server offers access to both types of stacks. It registers the stack objects and types with the RPC runtime library and the Location Broker, and it registers its managers with the RPC runtime library.

The Location Broker registrations enable clients to look up the objects, types, and interfaces that the server supports, along with the location of the server.

Example 7-20: Registrations and Unregistrations in the server.c Module for stacks

```
...
#include "stackdf.h"
#include "stacks.h"
...
globalref stacks_v1$epv_t stacks_v1$amanager_epv; [1]
globalref stacks_v1$epv_t stacks_v1$lmanager_epv;
...
  status_$t st;
  lb_$entry_t lb_entry[2];
  pfm_$cleanup_rec crec;
  static uuid_$t astack = ASTACK, astackt = ASTACKT;
  static uuid_$t lstack = LSTACK, lstackt = LSTACKT;
...
  /* register manager and object for array-based stack object... */

  rpc_$register_mgr(&astackt, &stacks_v1$if_spec,   [2]
    stacks_v1$server_epv,
    (rpc_$mgr_epv_t)&stacks_v1$amanager_epv, &st);

  rpc_$register_object(&astack, &astackt, &st); [3]

  /* ...and list-based stack object with the runtime library */

  rpc_$register_mgr(&lstackt, &stacks_v1$if_spec, [4]
    stacks_v1$server_epv,
```

Example 7-20: (continued)

```
        (rpc_$mgr_epv_t)&stacks_v1$lmanager_epv, &st);
    rpc_$register_object(&lstack, &lstackt, &st);5

    /* register array-based stack object/interface... */

    lb_$register(&astack, &astackt, &stacks_v1$if_spec.id, 0L,
        (ndr_$char *)"astack example", &loc, llen, &lb_entry[0], &st); 6
    /* ...and list-based stack object/interface with the lb*/

    lb_$register(&lstack, &lstackt, &stacks_v1$if_spec.id, 0L,
        (ndr_$char *)"lstack example", &loc, llen, &lb_entry[1], &st); 7

    st = pfm_$cleanup(&crec); 8
    if (st.all ! pfm_$cleanup_set) {
        status_$t stat;
        fprintf(stderr, "Server received signal - %s\n",
            error_text(st));
        lb_$unregister(&lb_entry[0], &stat); 9
        lb_$unregister(&lb_entry[1], &stat);
        rpc_$unregister(&stacks_v1$if_spec, &stat); /* once for each */
        rpc_$unregister(&stacks_v1$if_spec, &stat); /*    manager    */
        pfm_$signal(st);
    }
...
```

1 The server module declares two manager EPVs as external variables.

2 The manager registrations (`rpc_$register_mgr` calls) tell the RPC runtime library what combination of interface and type each manager implements. When the server receives a remote procedure call from a client, the runtime library dispatches the call to the correct manager. This first call registers the manager for the array-based stack object.

3 The object registrations (`rpc_$register_object` calls) tell the RPC runtime library what objects the server supports and what the type of each object is. This first call registers the array-based stack object.

4 The second manager registration registers the manager for the list-based stack object.

5 The second object registration registers the list-based stack object with the runtime library.

6 The Location Broker registrations enable clients to look up the objects, types, and interfaces that the server supports, along with the location of the server. This call registers the array-based stack object/interface with the Location Broker.

7 The second call to `lb_$register` registers the array-based stack object/interface.

8 Before it calls `rpc_$listen` to begin accepting requests, the server sets a cleanup handler.

9 If the cleanup handler is signaled, the server removes all of its registrations before it exits.

7.5.5 The stacks Manager Modules

A separate manager module implements the `stacks` interface for each type of stack: `lmanager.c` (Example 7-21) manages stacks based on linked lists, and `amanager.c` (Example 7-22) manages stacks based on arrays.

Each manager module defines a manager EPV. The EPV specifies the names under which the `stacks` operations are implemented. Because both managers are being linked in one server, the two implementations of each operation have different names.

Example 7-21: The lmanager.c Manager Module for stacks

```
#include "stacks.h"

void stacks$lstack_init();
ndr_$long_int stacks$lstack_push(), stacks$lstack_pop();

globaldef stacks_v1$epv_t stacks_v1$lmanager_epv =
    {stacks$lstack_init, stacks$lstack_push, stacks$lstack_pop};

#define NULL (struct node *)0
extern struct node *malloc();

static struct node {
    ndr_$long_int value;
    struct node *next;
} the_stack;

void stacks$lstack_init(h)
handle_t h;
{
    the_stack.next = NULL;
}

ndr_$long_int stacks$lstack_push(h, value)
handle_t h;
ndr_$long_int value;
{
    struct node *head = malloc(sizeof(struct node));
    if (head == NULL) return -1;            /* stack is full */

    head->value = value;
    head->next = the_stack.next;
    the_stack.next = head;
    return 0;
}

ndr_$long_int stacks$lstack_pop(h, value)
handle_t h;
ndr_$long_int *value;
{
    struct node *head = the_stack.next;
    if (head == NULL) return -1;           /* stack is empty */

    *value  head->value;
    the_stack.next = head->next;
    free(head);
    return 0;
}
```

Example 7-22: The amanager.c Manager Module for stacks/

```
#include "stacks.h"

void stacks$astack_init();
ndr_$long_int stacks$astack_push(), stacks$astack_pop();

globaldef stacks_v1$epv_t stacks_v1$amanager_epv
    {stacks$astack_init, stacks$astack_push, stacks$astack_pop};

#define STACKSIZE    1000

static struct {
    int head;
```

Example 7-22: (continued)

```
    ndr_$long_int values[STACKSIZE];
} the_stack;

void stacks$astack_init(h)
handle_t h;
{
    the_stack.head = STACKSIZE;
}

ndr_$long_int stacks$astack_push(h, value)
handle_t h;
ndr_$long_int value;
{
    if (the_stack.head == 0) return -1;         /* stack is full */

    the_stack.values[--the_stack.head]  value;

    return 0;
}

ndr_$long_int stacks$astack_pop(h, value)
handle_t h;
ndr_$long_int *value;
{

    if (the_stack.head == STACKSIZE) return -1; /* stack is empty */
    *value = the_stack.values[the_stack.head++];
    return 0;
}
```

Glossary

address family
: A set of communications protocols that use a common addressing mechanism to identify endpoints. The terms *address family* and *protocol family* are used synonymously in this manual.

allocate a handle
: To create a Remote Procedure Call (RPC) handle that identifies an object but not a location. Such a handle is said to be *allocated* or *unbound.*

attributes
: Characteristic declared in the Network Interface Definition Language (NIDL). An interface itself can be described by five attributes: uuid, local, version, port, implicit_handle. Type declarations and operation declarations also have specified attributes: type and field.

automatic binding
: Binding technique, in which the client uses generic handles that are then converted to Remote Procedure Call (RPC) handles by automatic binding routines. In an application that uses automatic binding, the client does not manage the binding. The handle variable is generic, and the application developer must supply autobinding and autounbinding routines that convert generic handles (used by the client) to RPC handles (used by the RPC runtime library). *See also* **binding state.**

binding
: The representation of a server in a handle. To bind a handle or to set its binding is to establish this representation. *See also* **binding state** and **handle.**

binding state
: The amount of information in a handle. A Remote Procedure Call (RPC) handle can exist in three binding states: unbound, bound-to-host, and fully bound.

binding technique
: Determines whether the client uses Remote Procedure Call (RPC) handles directly or uses generic handles that are then converted to RPC handles. *See also* **manual binding** and **automatic binding**.

bound-to-host handle
: Handle that identifies an object and a host but does not identify the port number of the server that exports the requested interface. When a client uses a bound-to-host handle to make a remote procedure call, the Remote Procedure Call (RPC) runtime library sends a message to the Local Location Broker (LLB) forwarding port on the specified host. The LLB forwards the message to the server.

bound-to-server handle
: *See* **fully bound** and **binding state.**

broadcast
: To send a remote procedure call to all hosts in a network.

broker
: A server that manages information resources, as in a Location Broker.

client
: A process that uses resources. In the context of this manual, a program that makes remote procedure calls.

entry point vector (EPV)
: A record of pointers to the operations in an interface.

explicit handle
: A handle that is passed as an operation parameter, rather than represented as a global variable in the client process. *See also* **implicit handle**.

export an interface
: To provide the operations defined by an interface. A server exports an interface to a client.

forward
: Automatic dispatch of a request to a server that exports the requested interface for the requested object. The Local Location Broker (LLB) forwards remote procedure calls that are sent to the LLB forwarding port on a server host.

fully bound handle
: A Remote Procedure Call handle that identifies an object, a host, and a port.

generic handle
: Handle variables that are not of type `handle_t`, such as a pathname. *See also* **RPC handle**.

GLB *See* **Global Location Broker**.

Global Location Broker (GLB)
: A server that maintains global information about objects on a network or an internet. Part of the Location Broker, it runs as the `nrglbd` daemon.

handle
: A temporary local identifier for an object. A handle represents for a client process the object and a server that exports one or more interfaces to the object. A handle always represent the same object, but it may represent different servers at different times, or it may not specify a server at all. *See also* **binding.**

host
: A computer that is attached to a network.

host ID
: An identifier for a host. A host ID uniquely specifies a host within an address family on a network, but does not specify the network. A host ID may not be sufficient to establish communications with a host. *See also* **network ID**.

idempotent operation
: An operation whose results do not affect the results of any operation. For example, a call that reads a value is idempotent, but an operation that increments a value is not.

implement an interface
: To provide the routines that execute the operations in an interface. A manager implements one interface for one type.

implicit handle
: A handle that is represented as a global variable in the client process, rather than passed as an operation parameter. *See also* **explicit handle**.

import an interface
: To request the operations defined by an interface. A client imports an interface from a server. *See also* **export**.

interface
: A set of operations defined by the Network Interface Definition Language (NIDL).

interface UUID
: A Universal Unique Identifier (UUID) that permanently identifies a particular interface. Both the Remote Procedure Call (RPC) runtime library and the location broker use interface UUIDs to specify interfaces.

internet
: A collection of networks interconnected by gateways.

LB *See* **Location Broker**.

LLB *See* **Local Location Broker**.

Local Location Broker (LLB)
: A server that maintains information about objects on the local host. The LLB also provides the Location Broker forwarding facility.

Location Broker (LB)
: A set of software including the Local Location Broker, the Global Location Broker, and the Location Broker Client Agent. The Location Broker maintains information about the locations of objects.

Location Broker Client Agent
: Part of the Location Broker. Programs communicate with Global Location Brokers and Local Location Brokers by means of the Location Broker Client Agent.

manager
: A set of routines that implement the operations in one interface for objects of one type.

manual binding
: A binding technique in which the client uses Remote Procedure Call (RPC) handles.

marshall
: To copy data into a Remote Procedure Call (RPC) packet. Stubs perform marshalling. *See also* **unmarshall**.

network address
: A unique identifier (within an address family) for a specific host on a network or an internet. A network address is sufficient to identify a host, but it does not identify a communications endpoint within the host.

Network Computing System (NCS)
: A set of software components on which DECrpc is based. These components include the Remote Procedure Call runtime library, the Location Broker, and the NIDL Compiler.

Network Interface Definition Language (NIDL)
: A declarative language for the definition of interfaces. NIDL has two syntaxes, one resembling C and one resembling Pascal.

NIDL
: *See* **Network Interface Definition Language.**

NIDL Compiler
: An NCS tool that converts an interface definition written in Network Interface Definition Language (NIDL) into several program modules, including source code for client and server stubs. The NIDL Compiler accepts interface definitions written in either syntax of NIDL; it generates C source code and C or Pascal header files.

object
: An entity that is manipulated by well-defined operations. Disk files, printers, and array processors are examples of objects. Objects are accessed through interfaces. Every object has a type.

object UUID
: A Universal Unique Identifier (UUID) that identifies a particular object. Both the Remote Procedure Call (RPC) runtime library and the Location Broker use object UUIDs to identify objects.

opaque port
: A port that is dynamically assigned to a server by the Remote Procedure Call runtime library. The port number is said to be opaque because there is no need for either clients or servers to know the number. *See also* **well-known port.**

operation
: A procedure through which an object is accessed.

port
: A specific communications endpoint within a host. A port is identified by a port number. *See also* **socket.**

port number
: One of the three parts in a socket address. For example, the character string *77* might represent a port number, while *ip:wooster[77]* might represent a socket address.

protocol family
: A set of communications protocols, for example, the DARPA Internetwork Protocols. All members of a protocol family use a common addressing mechanism to identify endpoints. The terms *address family* and *protocol family* are used synonymously in this manual.

register an interface
: To make an interface known to the Remote Procedure Call (RPC) runtime library and thereby available to clients through the RPC mechanism. The `rpc_$register` call registers an interface.

register a manager
: To make a manager (the code that implements a particular interface for a particular type) known to the Remote Procedure Call (RPC) runtime library and thereby available to clients through the RPC mechanism. The `rpc_$register_mgr` call registers a manager.

register an object with the Location Broker
: To enter an object and its location in the Location Broker database. The `lb_$register` call registers an object with the Location Broker. A program can use Location Broker lookup calls to determine the location of a registered object.

register with the RPC runtime library
: Call to `rpc_$register` that allows your program to call routines in the Remote Procedure Call (RPC) runtime library. Initializes access to the runtime library.

remote procedure call
: An invocation of a remote operation. You can make remote procedure calls between processes on different hosts or on the same host.

Remote Procedure Call (RPC) runtime library
: The set of `rpc_$` system calls that DECrpc provides to implement its remote procedure call mechanism.

RPC *See* **Remote Procedure Call.**

RPC handle
: A Remote Procedure Call (RPC) handle is a pointer to an opaque data structure containing the information needed to access an object. The name for this pointer type is `handle_t`.

server
: A process that implements interfaces. In the context of this manual, a server whose procedures can be invoked from remote hosts. A server exports one or more interfaces for one or more objects.

set a binding
: To set the representation of a server location in a Remote Procedure Call (RPC) handle.

signature
: The syntax of an operation, that is, its name, the data type it returns, and the order and types of its parameters. The definition of an operation specifies only its signature, not its implementation.

socket
: A communications endpoint in the form of a message queue. A socket is identified by a socket address.

socket address
: A data structure that uniquely identifies a specific communications endpoint. A socket address consists of a port number and a network address.

stub
: A program module that transfers remote procedure calls and responses between a client and a server. Stubs perform marshalling, unmarshalling, and data format conversion. Both clients and servers have stubs. The NIDL Compiler generates client and server stub code from an interface definition.

transmitted type
: For data types with the `transmit_as` attribute, the data type that stubs pass over the network. Stubs invoke conversion routines to convert the transmitted type to a presented type, which is manipulated by clients and servers.

type
: A class of object. All objects of a specific type can be accessed through the same interface or interfaces.

type UUID
: A Universal Unique Identifier (UUID) that permanently identifies a particular type. Both the Remote Procedure Call (RPC) runtime library and the Location Broker use type UUIDs to specify types.

unbound handle
: A Remote Procedure Call (RPC) handle that identifies an object but not a location. Synonymous with *allocated handle.*

Universal Unique Identifier (UUID)
: An identifier used by DECrpc to identify interfaces, objects, and types.

unmarshall
: To copy data from a Remote Procedure Call (RPC) packet. Stubs perform unmarshalling. *See also* **marshall.**

well-known port
: A port whose port number is part of the definition of an interface. Clients of the interface always send to that port; servers always listen on that port. *See also* **opaque port**.

Index

How to Order Additional Documentation

Technical Support

If you need help deciding which documentation best meets your needs, call 800-343-4040 before placing your electronic, telephone, or direct mail order.

Electronic Orders

To place an order at the Electronic Store, dial 800-234-1998 using a 1200- or 2400-baud modem from anywhere in the USA, Canada, or Puerto Rico. If you need assistance using the Electronic Store, call 800-DIGITAL (800-344-4825).

Telephone and Direct Mail Orders

Your Location	Call	Contact
Continental USA, Alaska, or Hawaii	800-DIGITAL	Digital Equipment Corporation P.O. Box CS2008 Nashua, New Hampshire 03061
Puerto Rico	809-754-7575	Local Digital Subsidiary
Canada	800-267-6215	Digital Equipment of Canada Attn: DECdirect Operations KAO2/2 P.O. Box 13000 100 Herzberg Road Kanata, Ontario, Canada K2K 2A6
International	————	Local Digital subsidiary or approved distributor
Internal*	————	SSB Order Processing - WMO/E15 *or* Software Supply Business Digital Equipment Corporation Westminster, Massachusetts 01473

* For internal orders, you must submit an Internal Software Order Form (EN-01740-07).

Reader's Comments

ULTRIX
DECrpc Programming Guide
AA-PBKYA-TE

Please use this postage-paid form to comment on this manual. If you require a written reply to a software problem and are eligible to receive one under Software Performance Report (SPR) service, submit your comments on an SPR form.

Thank you for your assistance.

Please rate this manual:	Excellent	Good	Fair	Poor
Accuracy (software works as manual says)	☐	☐	☐	☐
Completeness (enough information)	☐	☐	☐	☐
Clarity (easy to understand)	☐	☐	☐	☐
Organization (structure of subject matter)	☐	☐	☐	☐
Figures (useful)	☐	☐	☐	☐
Examples (useful)	☐	☐	☐	☐
Index (ability to find topic)	☐	☐	☐	☐
Page layout (easy to find information)	☐	☐	☐	☐

What would you like to see more/less of? ______________________________

What do you like best about this manual? ______________________________

What do you like least about this manual? ______________________________

Please list errors you have found in this manual:

Page	Description

Additional comments or suggestions to improve this manual:

What version of the software described by this manual are you using? __________

Name/Title ______________________________ Dept. __________

Company ______________________________ Date __________

Mailing Address ______________________________

______________ Email ______________ Phone __________

Do Not Tear – Fold Here and Tape

digital™

NO POSTAGE
NECESSARY
IF MAILED IN THE
UNITED STATES

BUSINESS REPLY MAIL
FIRST-CLASS MAIL PERMIT NO. 33 MAYNARD MA

POSTAGE WILL BE PAID BY ADDRESSEE

DIGITAL EQUIPMENT CORPORATION
OPEN SOFTWARE PUBLICATIONS MANAGER
ZKO3-2/Z04
110 SPIT BROOK ROAD
NASHUA NH 03062-9987

Do Not Tear – Fold Here

Cut
Along
Dotted
Line