sun® microsystems

Network Programming

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Network Services

This guide gives an overview of the network services available in the Sun 4.0 release. To appreciate the design of these services, it's necessary to see that SunOS is *structurally* a network UNIX system, and is designed to evolve as network technology changes.

SunOS originally diverged from the 4.2BSD UNIX system, a system that already strained at the limits of the UNIX system's original simplicity of design. It was with 4.2BSD that many of the network services found in SunOS were first introduced. Fortunately, the Berkeley designers found alternatives to wedging everything into the kernel. They implemented network services by offloading certain jobs to specialized daemons (server processes) working in close cooperation with the kernel, rather than by adding all new code to the kernel itself. SunOS has continued this line of development. Its expanding domain of network services is uniformly built upon a daemon (server) based architecture. This is true of the most fundamental network services — the Network File System (NFS)[1] and the portmapper — as well as of basic system services like the network naming service (The Yellow Pages: YP), the Remote Execution Facility (REX), the Network Lock Manager, and the Status Monitor.

Terminology

A machine that provides resources to the network is called a "server", while a machine that employs these resources is called a "client". A machine may be both a server and a client, and when NFS resources (files and directories) are at issue, often is. A person logged in on a client machine is a "user", while a program or set of programs that run on a client is an "application". There is a distinction between the code implementing the operations of a filesystem, (called "filesystem operations") and the data making up the filesystem's structure and contents (called "filesystem data").

Network services are added to SunOS by means of server processes that are based upon Sun's RPC (Remote Procedure Call) mechanism. These servers are executed on all machines that provide the service. Each server communicates with the kernel proper and with its fellows on other machines as necessary to get its job done. Sun daemons differ significantly from those that were inherited from Berkeley in that they are all based on RPC. As a consequence, they automatically benefit from the services provided by RPC, and the External Data

[1] The NFS is somewhat of a special case here because— at least in SunOS—much of its code is in the kernel.

Representation (XDR) that it, in turn, is built upon — for example, the data portability provided by XDR and RPC's authentication system.

Anything built with RPC/XDR is automatically a network application, as is anything that stores data in NFS files, even if it doesn't use RPC. Furthermore, insofar as network applications can presume the functionality of other network applications and call upon their services, all network applications are network services as well. The XDR/RPC/NFS environment then, is inherently *extensible*. New network services can be easily added by building upon the foundation already in place. In SunOS, then, network services are analogous to UNIX commands — anyone can add one, and when they do they are effectively extending the "system".

The Major Network Services

The *Remote Procedure Call (RPC)* facility is a library of procedures that provide a means whereby one process (the caller process) can have another process (the server process) execute a procedure call, as if the caller process had executed the procedure call in its own address space (as in the local model of a procedure call). Because the caller and the server are now two separate processes, they no longer have to live on the same physical machine.

The *External Data Representation (XDR)*is a specification for the portable data transmission standard. Together with RPC, it provides a kind of standard I/O library for interprocess communication. Thus programmers now have a standardized access to sockets without having to be concerned about the low-level details of socket-based IPC.

The *Network File System (NFS)*, is an operating system-independent service which allows users to mount directories, even root directories, across the network, and then to treat those directories as if they were local. There is also an option for a secure mount involving DES authentication of user and host—for more information about it, see the *Secure Networking Features* chapter of *Security Features Guide.*

The *portmapper* is a utility service that all other services use. It's a kind of registrar that keeps track of the correspondence between ports (logical communications channels) and services on a machine, and provides a standard way for a client to look up the port number of any remote program supported by the server.

Sun's *Yellow Pages (YP)* is a network service designed to ease the job of administering the large networks that NFS encourages. The YP is a replicated, read-only, database service. Network file system clients use it to access network-wide data in a manner that is entirely independent of the relative locations of the client and the server. The YP database typically provides password, group, network, and host information.

As part of its System V compatibility program, Sun now supports System-V (SVID) compatible advisory file and record locking for both local and NFS mounted files. User programs simply issue `lockf()` and `fcntl()` system calls to set and test file locks — these calls are then processed by *Network Lock Manager* daemons, which maintain order at the network level, even in the face of multiple machine crashes.

The lock-manager daemons are able to manage machine crashes because they are based upon a general purpose *Network Status Monitor*. This monitor provides a mechanism by which network applications can detect machine reboots and trigger application-specific recovery mechanisms. NFS is therefore equipped with a flexible fault-tolerant recovery capability.

There are other network services — NeWS and REX[2] are two obvious examples — and there are many others that are certainly services in the broad sense. This section, however, is intended as an introduction, and it covers only the fundamental services noted above.

Note: ND Elimination

This release is the first that supports diskless Sun workstations entirely by way of the NFS protocol. Previous releases depended on Sun's proprietary ND protocol to support diskless machines.

The elimination of ND made a number of improvements possible:

- Network administration is easier. It's no longer necessary to guess at the disk utilization appropriate to a diskless client when installing or reconfiguring it.
- For this same reason, and because diskless clients now have root file systems on their servers, rather than ND partitions, individual systems can be more easily tuned for maximum efficiency.
- The system provides better support for heterogeneity. Because all client filesystem resources — the root filesystem, swap, and home directories — exist on the server as normal directories and files, the server can more easily support clients with different architectures.
- The network software no longer contains proprietary code.

NOTE *In order to serve diskless clients, NFS servers now allow client root processes access to the client root file systems.*

1.1. Network Programming Manual Overview

This *Network Programming* manual is divided into three parts.

PART ONE, which you are now reading, focuses on Sun's network programming mechanisms. It includes:

- This *Network Services* overview, which attempts to introduced the fundamental network services without dealing with any protocol or implementation related issues.
- The `rpcgen` *Programming Guide*, which introduces the `rpcgen` protocol compiler and the C-like language that it uses to specify RPC applications and define network data. In almost all cases, `rpcgen` will allow network applications developers to avoid the use of lower-level RPC mechanisms.

[2] These, however, are not *fundamental* network services, in the same sense as RPC or the NFS. REX, for example, cannot be guaranteed to be portable to a non-UNIX environment. This is true because the executability of a program depends on many environmental factors — from machine architecture to operating-system services — that are not universally available.

- The *Remote Procedure Call Programming Guide*, is intended for programmers who wish to understand the lower-level RPC mechanisms. Readers are assumed to be familiar with the C language and to have a working knowledge of network theory.

- The *External Data Representation: Sun Technical Notes*, which introduces XDR and explains the justification for its "canonical" approach to network data interchange. This section also gives Sun implementation information and a few examples of advanced XDR usage.

PART TWO includes a number of number of protocol specifications. One of these, the *External Data Representation Protocol Specification*, has been accepted (as of the date of this printing) as an ARPA RFC (Request for Comments). These protocol specifications include:

- The *External Data Representation Protocol Specification*, which includes a complete specification of XDR data types, a discussion of the XDR approach and a number of examples of XDR usage.

- The *Remote Procedure Call Protocol Specification*, which includes a discussion of the RPC model, a detailed treatment of the RPC authentication facilities and a complete specification of the portmapper Protocol.

- The *Network File System: Version 2 Protocol Specification*, which includes a complete specification of the Mount Protocol, as well as the NFS specification itself.

PART THREE documents Berkeley style, socket-Based Inter-Process Communications. In includes:

- *A Socket-Based Interprocess Communications Tutorial*, which assumes little more that basic networking concepts and introduces socket-based IPC. Includes many examples.

- *An Advanced Socket-Based Interprocess Communications Tutorial*, which takes up where the *Tutorial* leaves off.

- *Berkeley-Style IPC Implementation Notes*, which describes the low-level networking primitives (e.g. `accept()`, `bind()` and `select()`) which originated with the 4.2BSD UNIX system. This document is of interest primarily to system programmers and aspiring UNIX gurus.

1.2. Sun's Network File System

Sun's Network File System is a facility for sharing files in a heterogeneous environment of machines, operating systems, and networks. Sharing is accomplished by mounting a remote filesystem, then reading or writing files in place. The NFS is open-ended, and users are encouraged to interface it with other systems.

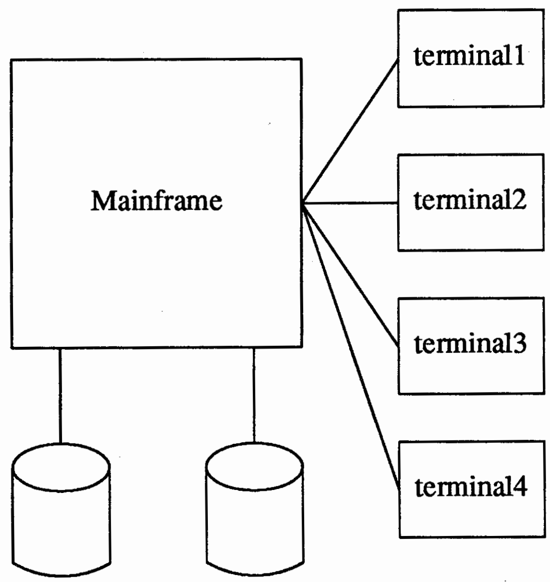
The NFS was *not* designed by extending SunOS onto the network — such an approach was considered unacceptable because it would mean that every computer on the network would have to run SunOS. Instead, operating-system independence was taken an an NFS design goal, along with machine independence, crash recovery, transparent access and high performance. The NFS was thus designed as a network services, and not as a distributed operating system.

As such, it is able to support distributed applications without restricting the network to a single operating system.

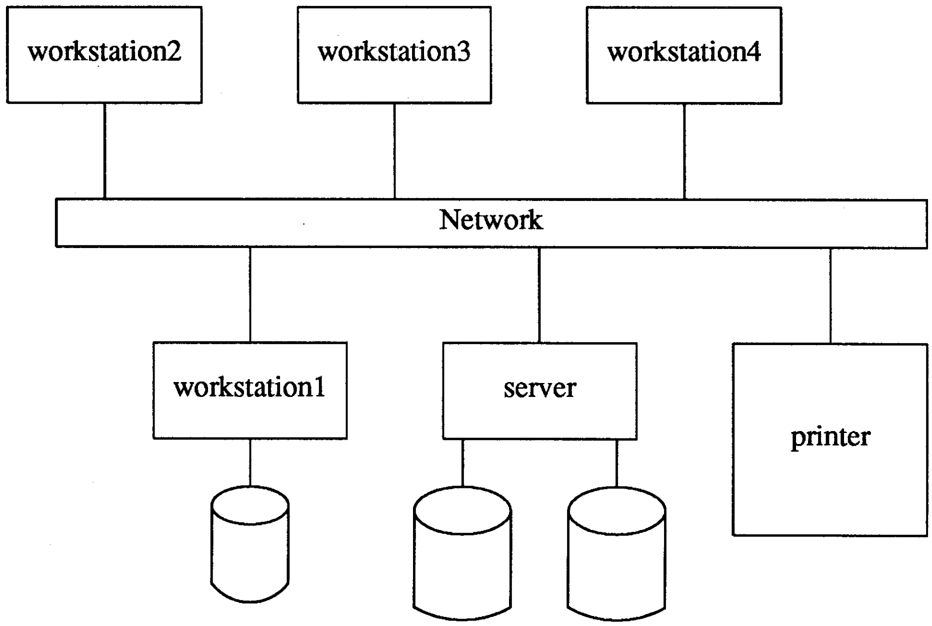
Sun's implementation of the NFS is integrated with the SunOS kernel for reasons of efficiency, although such close integration is not strictly necessary. Other vendors will make different choices, as dictated by their operating environments and applications. And because of NFS's open design, all these applications will be able to work together on a single network.

Computing Environments

The traditional timesharing environment looks like this:



The major problem with this environment is competition for CPU cycles. The workstation environment solves that problem, but requires more disk drives. A network environment looks like this:



Sun's goal with NFS was to make all disks available as needed. Individual workstations have access to all information residing anywhere on the network. Printers and supercomputers may also be available somewhere on the network.

Example NFS usage

This section gives three examples of NFS usage.

Example 1: Mounting a Remote Filesystem

Suppose your machine name is `client`, that you want to read some on-line manual pages, and that these pages are not available on your server machine, named `server`, but are available on another machine named `docserv`. Mount the directory containing the manuals as follows:

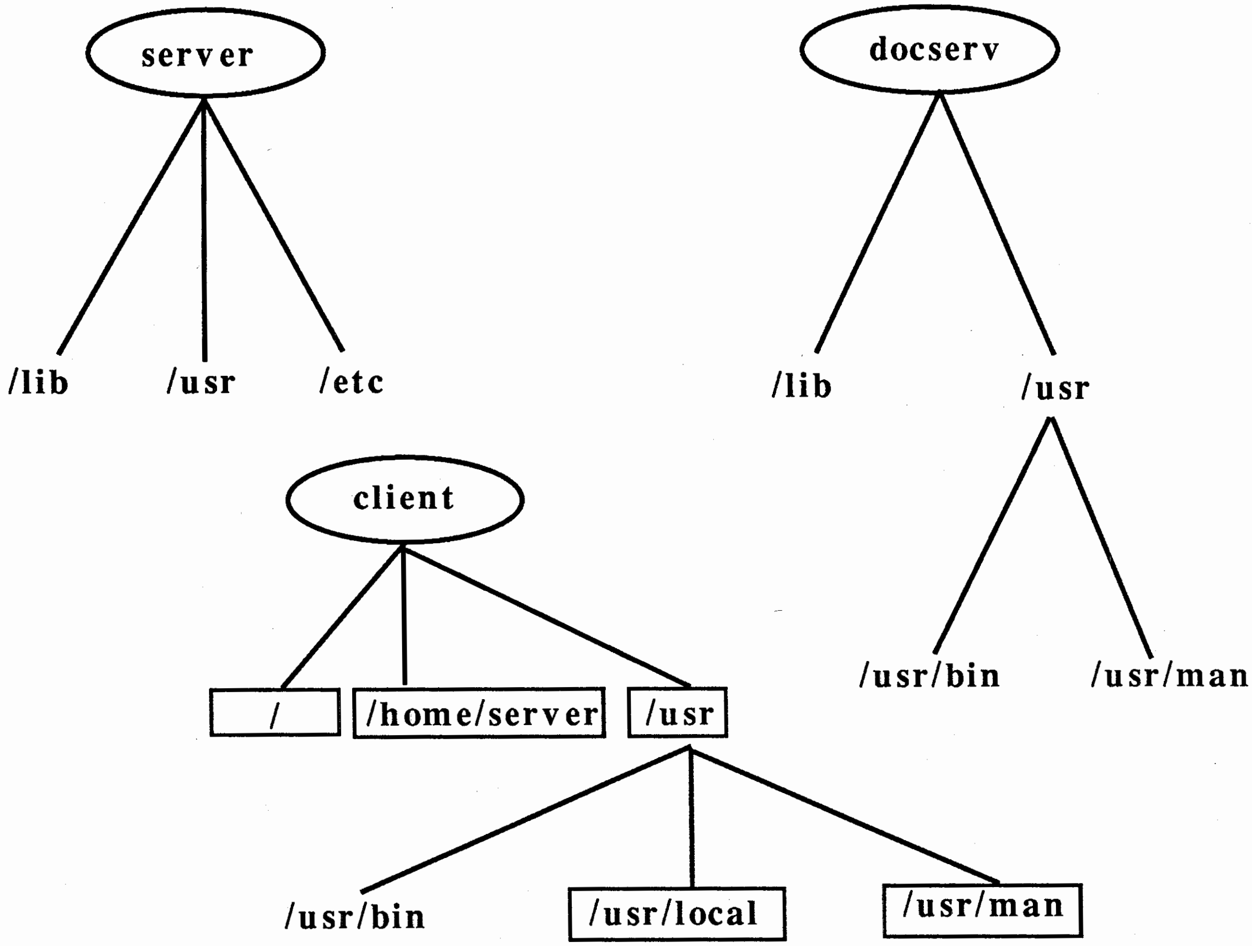
```
client# /usr/etc/mount docserv:/usr/man /usr/man
```

Note that you have to be superuser in order to do this. Now you can use the `man` command whenever you want. Try running the `mount -p` command (on `client`) after you've mounted the remote filesystem. Its output will look something like this:

```
server:/roots/client    /               nfs  rw,hard       0 0
server:/usr             /usr            nfs  ro            0 0
server:/home/server     /home/server    nfs  rw,bg         0 0
server:/usr/local       /usr/local      nfs  ro,soft,bg    0 0
docserv:/usr/man        /usr/man        nfs  ro,soft,bg    0 0
```

You can remote mount not only filesystems, but also directory hierarchies inside filesystems. In this example, `/usr/man` is not a filesystem mount point — it's just a subdirectory within the `/usr` filesystem. Here's a diagram showing a few key directories of the three machines involved in this example. Ellipses represent machines, and NFS-mounted filesystems are shown boxed. There are five such boxed directories, corresponding to the five lines shown in the `mount -p` output above. The `docserv:/usr/man` directory is shown mounted as the `/usr/man` directory on `client`, as it would be by the `mount` command given above.

Figure 1-1 *An Example NFS Filesystem Hierarchy*



Example 2: Exporting a Filesystem

Suppose that you and a colleague need to work together on a programming project. The source code is on your machine, in the directory `/usr/proj`. It doesn't matter whether your workstation is a diskless node or has a local disk. Suppose that after creating the proper directory your colleague tried to remote mount your directory. Unless you have explicitly exported the directory, your colleague's remote mount will fail with a "permission denied" message.

To export a directory, first become superuser and then edit the `/etc/exports` file. If your colleague is on a machine named `cohort`, then you need to run `exportfs(8)` (after putting this line in `/etc/exports`):

```
/usr/proj        -access=cohort
```

If no explicit access is given for a directory, then the system allows anyone on the network to remote mount your directory. By giving explicit access to cohort, you have denied access to others. (For more details about the /etc/exports, see the exports(5) man page). The NFS mount request server mountd (see *The NFS Interface*, below) reads the /etc/xtab file whenever it receives a request for a remote mount. Now your cohort can remote mount the source directory by issuing this command:

```
cohort# /etc/mount client:/usr/proj /usr/proj
```

This, however, isn't the end of the story, since NFS requests are also checked at request time. If you do nothing, the accesses that you've established in your /etc/exports file will stay in effect, but you (and your programs) are free to change them at any time with the exportfs command and system call.

Since both you and your colleague will be able to edit files on /usr/proj, it would be best to use the sccs source code control system for concurrency control.

Example 3: Administering a Server Machine

System administrators must know how to set up the NFS server machine so that client workstations can mount all the necessary filesystems. You export filesystems (that is, make them available) by placing appropriate lines in the /etc/exports file. Here is a sample /etc/exports file for a typical server machine:

```
/                  -access=systems
/exec              -access=engineering:joebob:shilling
/usr               -access=engineering
/home/server       -access=engineering
/home/local.sun2 -access=engineering:athena
/home/local.sun3 -access=engineering
```

Machine names or netgroups, such as staff (see netgroup(5)) may be specified after the filesystem, in which case remote mounts are limited to machines that are a member of this netgroup. For the complete syntax of the /etc/exports file, see exports(5). At any time, the system administrator can see which filesystems are remote mounted by executing the showmount command.

NFS Architecture

Transparent Information Access

Users are able to get directly to the files they want without knowing the network address of the data. To the user, all NFS-mounted filesystems look just like private disks. There's no apparent difference between reading or writing a file on a local disk, and reading or writing a file on a disk in the next building. Information on the network is truly distributed.

Different Machines and Operating Systems

No single vendor can supply tools for all the work that needs to get done, so appropriate services must be integrated on a network. NFS provides a flexible, operating system-independent platform for such integration.

Easily Extensible

A distributed system must have an architecture that allows integration of new software technologies without disturbing the extant software environment. Since the NFS network-services approach does not depend on pushing the operating system onto the network, but instead offers an extensible set of protocols for data exchange, it supports the flexible integration of new software.

Ease of Network Administration

The administration of large networks can be complicated and time-consuming, yet they should (ideally) be *at least* as easy to administer as a set of local filesystems on a timesharing system. The UNIX system has a convenient set of maintenance commands developed over the years, and the Yellow Pages (YP), a NFS-based network database service, has allowed them to be adapted and extended for the purpose of administering a network of machines. The YP also allows certain aspects of network administration to be centralized onto a small number of file servers, e.g. only server disks must be backed up in networks of diskless clients. An overview of the YP facility is presented in the *The Yellow Pages Database Service* section of this manual.

The YP interface is implemented using RPC and XDR, so it is available to non-UNIX operating systems and non-Sun machines. YP servers do not interpret data, so it is easy for new databases to be added to the YP service without modifying the servers.

Reliability

NFS's reliability derives from the robustness of the 4.2BSD filesystem, from the stateless NFS protocol[3], and from the daemon-based methodology by which network services like file and record locking are provided. See *The Network Lock Manager* for more details on locking. In addition, the file server protocol is designed so that client workstations can continue to operate even when the server crashes and reboots. Sun achieves continuation after reboot without making assumptions about the reliability of the underlying server hardware.

The major advantage of a stateless server is robustness in the face of client, server, or network failures. Should a client fail, it is not necessary for a server (or human administrator) to take any action to continue normal operation. Should a server or the network fail, it is only necessary that clients continue to attempt to complete NFS operations until the server or network gets fixed. This robustness is especially important in a complex network of heterogeneous systems, many of which are not under the control of a disciplined operations staff, and which may be running untested systems often rebooted without warning.

High Performance

The flexibility of the NFS allows configuration for a variety of cost and performance trade-offs. For example, configuring servers with large, high-performance disks, and clients with no disks, may yield better performance at lower cost than having many machines with small, inexpensive disks. Furthermore, it is possible to distribute the filesystem data across many servers and get the added benefit of multiprocessing without losing transparency. In the case of read-only files, copies can be kept on several servers to avoid bottlenecks.

[3] The NFS protocol is *stateless* because each transaction stands on its own. The server doesn't have to remember anything — about clients or files — between transactions.

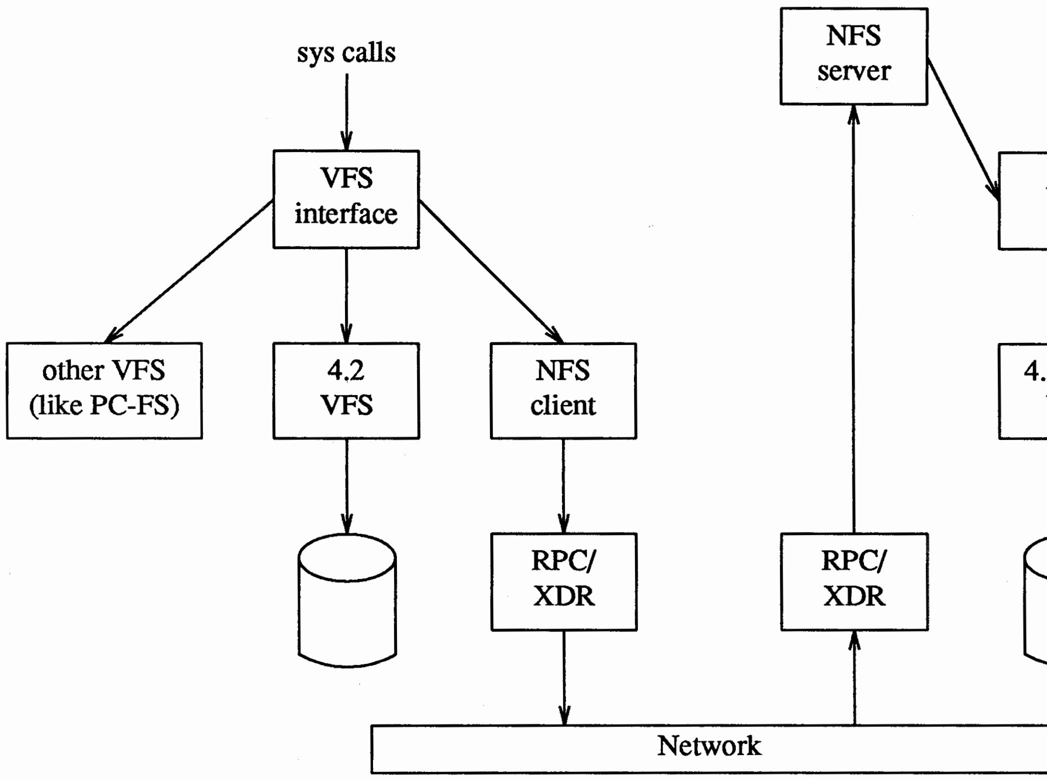
Sun has also added several performance enhancements to the NFS, such as "fast paths" for key operations, asynchronous service of multiple requests, disk-block caching , and asynchronous read-ahead and write-behind. The fact that caching and read-ahead occur on both client and server effectively increases the cache size and read-ahead distance. Caching and read-ahead do not add state to the server; nothing (except performance) is lost if cached information is thrown away. In the case of write-behind, both the client and server attempt to flush critical information to disk whenever necessary, to reduce the impact of an unanticipated failure; clients do not free write-behind blocks until the server confirms that the data is written.

The Sun NFS Implementation

In the Sun NFS implementation, there are three entities to be considered: the operating system interface, the *virtual file system (VFS)* , interface, and the network file system (NFS) interface. The UNIX operating system interface has been preserved in the Sun implementation of the NFS, thereby insuring compatibility for existing applications.

The VFS is best seen as a layer that Sun has wrapped around the traditional UNIX filesystem. This traditional filesystem is composed of directories and files, each of which has a corresponding `inode` (index node), containing administrative information about the file, such as location, size, ownership, permissions, and access times. Inodes are assigned unique numbers within a filesystem, but a file on one filesystem could have the same number as a file on another filesystem. This is a problem in a network environment, because remote filesystems need to be mounted dynamically, and numbering conflicts would cause havoc. To solve this problem, Sun designed the VFS, which is based on a data structure called a `vnode`. In the VFS, files are guaranteed to have unique numerical designators, even within a network. Vnodes cleanly separate filesystem operations from the semantics of their implementation. Above the VFS interface, the operating system deals in `vnodes`; below this interface, the filesystem may or may not implement `inodes`. The VFS interface can connect the operating system to a variety of filesystems (for example, 4.2 BSD or MS-DOS). A local VFS connects to filesystem data on a local device.

The remote VFS defines and implements the NFS interface on the basis of the RPC and XDR mechanisms. The figure below shows the flow of a request from a client (at the top left) to a collection of filesystems.



In the case of access through a local VFS, requests are directed to filesystem data on devices connected to the client machine. In the case of access through a remote VFS, the request is passed through the RPC and XDR layers onto the net. In the current implementation, Sun uses the UDP/IP protocols and the Ethernet. On the server side, requests are passed through the RPC and XDR layers to an NFS server; the server uses `vnodes` to access one of its local VFSs and service the request. This path is retraced to return results.

Sun's implementation of the NFS provides five types of transparency:

1. *Filesystem Type:* The `vnode`, in conjunction with one or more local VFSs (and possibly remote VFSs) permits an operating system (hence client and application) to interface transparently to a variety of filesystem types.

2. *Filesystem Location:* Since there is no differentiation between a local and a remote VFS, the location of filesystem data is transparent.

3. *Operating System Type:* The RPC mechanism allows interconnection of a variety of operating systems on the network, and makes the operating system type of a remote server transparent.

4. *Machine Type:* The XDR definition facility allows a variety of machines to communicate on the network and makes the machine type of a remote server transparent.

5. *Network Type:* RPC and XDR can be implemented for a variety of transport protocols, thereby making the network type transparent.

Simpler NFS implementations are possible at the expense of some advantages of the Sun version. In particular, a client (or server) may be added to the network by implementing one side of the NFS interface. An advantage of the Sun implementation is that the client and server sides are identical; thus, it is possible for any machine to be client, server, or both. Users at client machines with disks can arrange to share over the NFS without having to appeal to a system administrator or configure a different system on their workstation.

The NFS Interface

As mentioned in the preceding section, a major advantage of the NFS is the ability to mix filesystems. In keeping with this, Sun encourages other vendors to develop products to interface with Sun network services. RPC and XDR have been placed in the public domain, and serve as a standard for anyone wishing to develop applications for the network. Furthermore, the NFS interface itself is open and can be used by anyone wishing to implement an NFS client or server for the network.

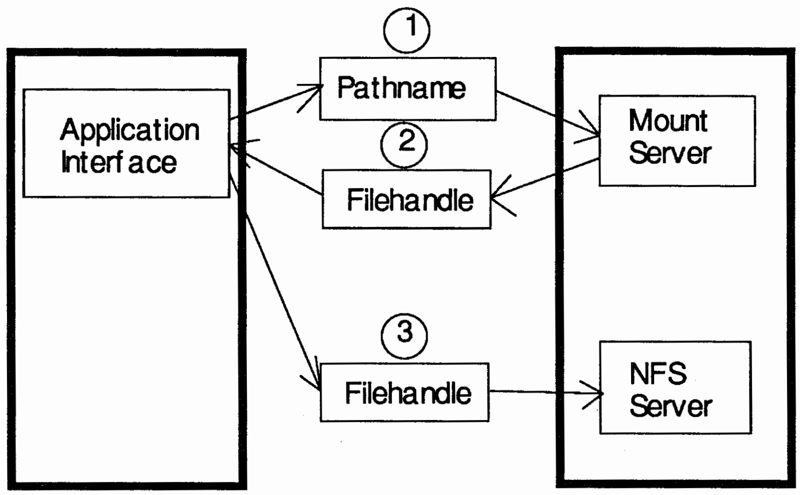
The NFS and the Mount Protocol

The NFS interface defines traditional filesystem operations for reading directories, creating and destroying files, reading and writing files, and reading and setting file attributes. The interface is designed so that file operations address files with an uninterpreted identifier called a *filehandle*, a starting byte address, and a length in bytes. NFS *never* deals with pathnames, only with filehandles. It gets those filehandles from mount.

More precisely, NFS never *interprets* pathnames. Some NFS procedures take pathname arguments, but they are just strings to NFS.

Given a filehandle for a directory, a client program can use NFS procedures to get other filehandles and thereby navigate throughout the directories and files of a filesystem. A client must, however, get its first filehandle for a filesystem by using RPC to call the mount server. Mount will return a filehandle that grants access to the filesystem. Figure *1-2* shows the interaction between a client program, a mount server, and an NFS server. Note that the only interface between a mount server and an NFS server is a common filehandle.

Figure 1-2 *Mount and NFS Servers*



Legend:
1. Client sends pathname to mount server
2. Mount server returns corresponding filehandle
3. Client sends filehandle to NFS server

Pathname Parsing

Although many operating systems have analogs to the hierarchical NFS directory and file structure, the conventions used by operating systems to formulate pathnames vary considerably. To accommodate the many possible path naming conventions, the mount procedure is not defined in the NFS protocol but in a separate mount protocol. At present, there is one mount protocol, the UNIX mount protocol, but others can be defined as necessary. The `mount` procedure in the UNIX mount protocol converts a UNIX pathname into a filehandle. If local pathnames can be reasonably mapped to UNIX pathnames, an NFS server developer may wish to implement the UNIX mount protocol, even though the server runs on a different operating system. This approach makes the server immediately usable by clients that use the UNIX protocol and eliminates the need to develop a new `mount` command for UNIX-based clients. Alternatively, a server developer can obtain a new remote program number from Sun and define a new mount protocol. For example, the `mount` procedure in a VMS Mount protocol would take a VMS file specification rather than a UNIX pathname. Mount protocols are not mutually exclusive; a server could, for example, support the UNIX protocol for UNIX clients and a Multics protocol for Multics clients. Both protocols would return filehandles defined by the NFS implementation on their server.

The mount protocols remove pathname parsing from the NFS protocol, so that a single NFS protocol can work with multiple operating systems. This means that users and client programs need to know the details of a server's path naming conventions only when mounting a filesystem. Different server path naming conventions therefore typically have little impact on users.

Because mounts are relatively infrequent operations, mount servers can be implemented outside of operating system kernels without materially affecting overall file system performance. Because user-level code is easier to write and far easier to debug than kernel code, mount servers are fairly simple to put together.

Export and Mount Lists

Technically, a mount protocol needs to define only a `mount` procedure that bootstraps the first filehandle for a filesystem. (By convention, a mount protocol should also define a NULL procedure). However, adding other procedures can simplify network management. As a convenience to clients, a mount protocol might provide a procedure that returns a list of filesystems exported by a server. Another useful item is a mount list, a list of clients and the pathnames they have mounted from the server. The UNIX mount protocol defines a mount list and a procedure called `readmount()` that returns the list. With the help of `readmount()`, an administrator can notify the clients of a server that is about to be shut down.

Note that a mount list makes a mount server stateful. Recall, however, that the business of a mount server is to translate pathnames into filehandles; the state represented by a mount list does not affect a server's ability to operate correctly. Neither servers nor clients need take any action to update or rebuild a mount list after a crash. Mount server users should regard the mount and export lists provided by a mount server as "accessories" that are usually, but not necessarily, accurate.

UNIX Mount Protocol Procedures

The mount protocol consists of the six remote procedures listed in Table *1-1*. The `mount()` procedure transforms a UNIX pathname into a filehandle which the client can then pass to the associated NFS server. The pathname passed to the mount procedure usually refers to a directory, often the root directory of a filesystem, but it can name a file instead. In addition to returning the filehandle, `mount` adds the client's host name and the pathname to its mount list. The `readmount()` procedure returns the server's mount list. `unmount()` removes an entry from the server's mount list and `unmountall()` removes all of a client's mount list entries. The `readexport()` procedure returns the server's export list.

Table 1-1 *Mount Remote Procedures, Version 1*

Number	*Name*	*Description*
0	`null`	Do nothing
1	`mount`	Return filehandle for pathname
2	`readmount`	Return mount list
3	`unmount`	Remove mount list entry
4	`unmountall`	Clear mount list
5	`readexport`	Return export list

A Stateless Protocol

The NFS interface is defined so that a server can be *stateless*. This means that a server does not have to remember from one transaction to the next anything about its clients, transactions completed or files operated on. For example, there is no `open()` operation, as this would imply state in the server; of course, the UNIX interface uses an `open()` operation, but the information in the UNIX operation is remembered by the client for use in later NFS operations.

An interesting problem occurs when a UNIX application unlinks an open file. This is done to achieve the effect of a temporary file that is automatically removed when the application terminates. If the file in question is served by the NFS, the call to `unlink()` will remove the file, since the server does not remember that the file is open. Thus, subsequent operations on the file will fail. In order to avoid state on the server, the client operating system detects the situation, renames the file rather than unlinking it, and unlinks the file when the application terminates. In certain failure cases, this leaves unwanted "temporary" files on the server; these files are removed as a part of periodic filesystem maintenance.

Another example of the advantages gained by having the NFS interface to the UNIX system without introducing state is the `mount` command. A UNIX client of the NFS "builds" its view of the filesystem on its local devices using the `mount` command; thus, it is natural for the UNIX client to initiate its contact with the NFS and build its view of the filesystem on the network with an extended `mount` command. This `mount` command does not imply state in the server, since it only acquires information for the client to establish contact with a server. The `mount` command may be issued at any time, but is typically executed as a part of client initialization. The corresponding `umount` command is only an informative message to the server, but it does change state in the client by modifying its view of the filesystem on the network.

The major advantage of a stateless server is robustness in the face of client, server or network failures. Should a client fail, it is not necessary for a server (or human administrator) to take any action to continue normal operation. Should a server or the network fail, it is only necessary that clients continue to attempt to complete NFS operations until the server or network is fixed. This robustness is especially important in a complex network of heterogeneous systems, many of which are not under the control of a disciplined operations staff and may be running untested systems and/or may be rebooted without warning.

An NFS server can be a client of another NFS server. However, a server will not act as an intermediary between a client and another server. Instead, a client may ask what remote mounts the server has and then attempt to make similar remote mounts. The decision to disallow intermediary servers is based on several factors. First, the existence of an intermediary will impact the performance characteristics of the system; the potential performance implications are so complex that it seems best to require direct communication between a client and server. Second, the existence of an intermediary complicates access control; it is much simpler to require a client and server to establish direct agreements for service. Finally, disallowing intermediaries prevents cycles in the service arrangements; Sun prefers this to detection or avoidance schemes.

The NFS currently implements UNIX file protection by making use of the authentication mechanisms built into RPC. This retains transparency for clients and applications that make use of UNIX file protection. Although the RPC definition allows other authentication schemes, their use may have adverse effects on transparency.

Note that the NFS, although very UNIXlike, is *not* a UNIX filesystem per se — there are cases in which its behavior differs from that which would be expected of the UNIX system proper:

- The guaranteed APPEND_MODE is the most striking of these differences, for it simply is not supported by NFS.

Note: Network access to devices such as tape drivers is a good idea, but it is best implemented as a separate network service whose requirement for stateful operation is kept separate from network access to files.

- The "special file" device abstraction — inherently stateful as it is — is supported for remote mounts only when both the client and the server are running system software release 3.2 or later. In other cases, devices are implemented in a local `/dev` virtual file system.
- There are also minor incompatibilities between NFS and UNIX file-system interfaces that are dictated by the very nature of remote NFS mounts. For example, a local NFS daemon simply can't tell that a remote disk partition is full until the remote NFS daemon tells it so. Rather than wait for a positive confirm on every write — a strategy that would impose unacceptable performance problems — the local NFS code caches writes and returns to its caller. If a remote error occurs, it gets reported back as soon as possible, but not as immediately as would a local disk.

File locking and other inherently stateful functionality has been omitted from the base NFS definition. In this way, Sun has been able to preserve a simple, general interface that can be implemented by a wide variety of customers. File locking has been provided as a NFS-compatible network service, and Sun is considering doing the same for other other features that inherently imply state and/or distributed synchronization. These features, too, will be kept separate from the base NFS definition. In any case, the open nature of the RPC and NFS interfaces means that customers and users who need stateful or complex features can implement them "beside" or "within" the NFS.

Note: Non-NFS Network Operations

Sun supports a small number of non-NFS networking operations that are useful for temporary inter-host connections, isolated file transfers, and access to non-UNIX systems (e.g. TOPS-10 machines on the Arpanet). These operations include `rcp`, `rlogin`, `rsh`, `ftp`, `telnet`, and `tftp`.

- `rcp` is a remote copy utility program that uses BSD networking facilities to copy files from one machine to another. The `rcp` user supplies the path name of a file on a remote machine, and receives a stream of bytes in return. Access control is based on the client's login name and host name.

  The major problem with `rcp` is that it's not transparent to the user, who winds up with a redundant copy of the transferred file. With the NFS, by contrast, only one copy of the file is necessary. Another problem is that `rcp` does nothing but copy files. To use it a a model for additional network services would be to introduce a remote command for every regular command: for example, `rdiff` to perform differential file comparisons across machines. By providing for the sharing of filesystems, NFS makes this unnecessary.

- `rlogin` allows the user to log into a remote machine, directly accessing both its processor and its mounted file systems. It remains useful in NFS-based networks because, with it, users can directly execute commands on remote machines over the network.

- `rsh` allows the user to execute a command on a remote machine. If no command is specified, `rsh` is equivalent to `rlogin`. Unlike the REX-based `on` command, `rsh` does not make a great effort to copy the users local environment to the remote machine before executing the command.

- `ftp` is very much like `rcp`, in that it supports file copying between machines. However, `ftp` is more general that `rcp`, and is not restricted to copies between two UNIX systems.

- `telnet` communicates with another host using the TELNET protocol. It isn't used much because `rlogin` is the standard mechanism for local inter-host communication.

- `tftp` is like `ftp`, expect that it is simpler and less reliable. This is because `tftp`'s transfer protocol is very simple; it is less robust that `ftp`'s protocol, and offers fewer options.

1.3. The Portmapper

Client programs need a way to find server programs; that is, they need a way to look up and find the *port* numbers of server programs.[4] Network transport services do not provide such a service; they merely provide process-to-process message transfer across a network. A message typically contains a transport address which contains a network number, a host number, and a port number. (A port is a logical communications channel in a host — by waiting on a port, a process receives messages from the network).

[4] The naming of services by way of the port-number segment of their IP address is mandated by the Internet protocols. Given this, clients face the problem of determining which ports are associated with the services they wish to use.

How a process waits on a port varies from one operating system to the next, but all provide mechanisms that suspend a process until a message arrives at a port. Thus, messages are not sent across networks to receiving processes, but rather to the ports at which receiving processes wait for messages. Ports are valuable because the allow message receivers to be specified in a way that is independent of the conventions of the receiving operating system. The portmapper protocol defines a network service that provides a standard way for clients to look up the port number of any remote program supported by a server. Because it can be implemented on any transport that provides the equivalent of ports, it provides a single solution to a general problem that works for all clients, all servers and all networks.

Port Registration

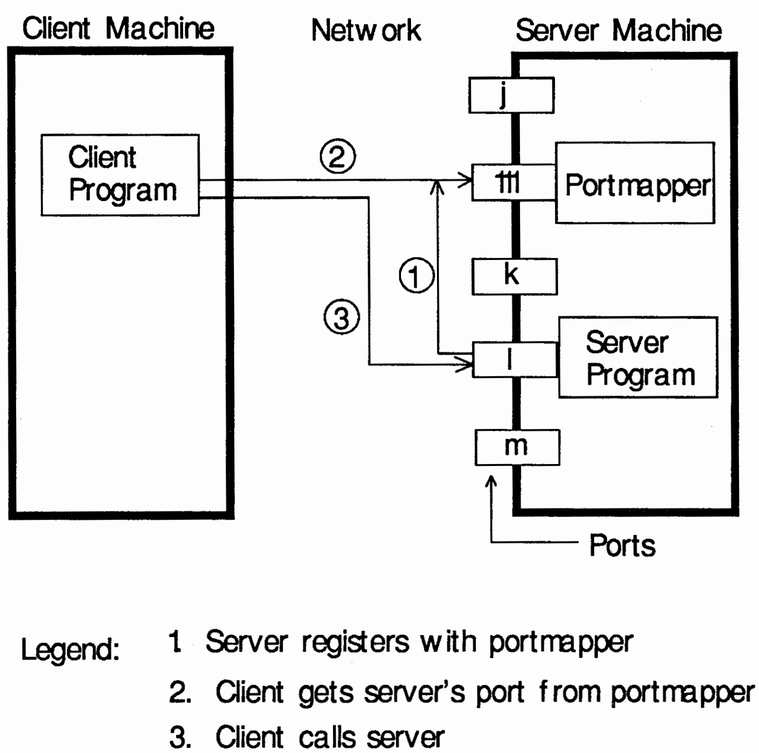
Every portmapper on every host is associated with port number 111. The portmapper is the only network service that must have such a well-known (dedicated) port. Other network services can be assigned port numbers statically or dynamically so long as they register their ports with their host's portmapper. For example, a server program based on Sun's RPC library typically gets a port number at run time by calling an RPC library procedure. Note that a given network service can be associated with port number 256 on one server and with port number 885 on another; on a given host, a service can be associated with a different port every time its server program is started. Delegating port-to-remote program mapping to portmappers also automates port number administration. Statically mapping ports and remote programs in a file duplicated on each client would require updating all mapping files whenever a new remote program was introduced to a network. (The alternative of placing the port-to-program mappings in a shared NFS file would be too centralized, and if the fileserver went down the whole network would go down with it).

The port-to-program mappings which are maintained by the portmapper server are called a *portmap*. The portmapper is started automatically whenever a machine is booted. As shown in the *Typical Portmapping Sequence* figure, below, both server programs and client programs call portmapper procedures.[5] As part of its initialization, a server program calls its host's portmapper to create a portmap entry. Whereas server programs call portmappers to update portmap entries, clients call portmappers to query portmap entries. To find a remote program's port, a client sends and RPC call message to a server's portmapper; if the remote program is supported on the server, the portmapper returns the relevant port number in an RPC reply message. The client program can then send RPC call messages to the remote program's port. A client program can minimize its portmapper calls by caching the port numbers of recently called remote programs.

NOTE *Note that the portmapper provides and inherently stateful service because a portmap is a set of associations between registrants and ports.*

[5] Although client and server programs and client and server machines are usually distinct, they need not be. A server program can also be a client program, as when an NFS server calls a portmapper server. Likewise, when a client program directs a "remote" procedure call to its own machine, the machine acts as both client and server.

Figure 1-3 *Typical Portmapping Sequence*



The portmapper protocol (for details, see the *Port Mapper Program Protocol* section of the *Remote Procedure Calls: Protocol Specification* chapter) provides a procedure, `callit()`, by which the portmapper can assist a client in making a remote procedure call. A client program passes the target procedure's program number, version number, procedure number (for a discussion of these numbers, see the *Remote Procedure Call Programming Guide* chapter) and arguments in an RPC call message. `callit()` looks up the target procedure's port number in the portmap and sends an RPC call message to the target procedure including in it the arguments received from the client. When the target procedure returns results to `callit()`, `callit()` returns the results to the client program; also returned is the target procedure's port number so the client can subsequently call the target procedure directly

Note that, because every instance of a remote program can be mapped to a different port on every server, a client has no way to broadcast a remote procedure call directly. However, the portmapper `callit()` procedure can be used to broadcast a remote procedure call indirectly, since all portmappers are associated with port number 111. One way for a client to find a server running a remote program is to broadcast a call to `callit()`, asking it to call procedure 0 of the desired remote program. If this call is broadcast to all servers, the first reply received is likely to be from the server with the lightest workload.

The Sun RPC library provides an interface to all portmapper procedures. Some of the RPC library procedures also call portmappers automatically on behalf of client and server programs.

1.4. The Yellow Pages Database Service

This chapter explains Sun's network database mechanism, the Yellow Pages (YP). Although it is not intended exclusively for system administrators, it leans towards their concerns. The Yellow Pages permit password information and host addresses for an entire network to be held in a single database, and, by so doing, greatly ease system and network administration.

What Are The Yellow Pages?

The Yellow Pages constitute a distributed network lookup service:

- YP is a lookup service: it maintains a set of databases for querying. Programs can ask for the value associated with a particular key, or all the keys, in a database.
- YP is a network service: programs need not know the location of data, or how it is stored. Instead, they use a network protocol to communicate with a database server that knows those details.
- YP is distributed: databases are fully replicated on several machines, known as YP servers. Servers propagate updated databases among themselves, ensuring consistency. At steady state, it doesn't matter which server answers a request; the answer is the same everywhere.

Yellow Pages Maps

The Yellow Pages serve information stored in YP *maps*. Each map contains a set of keys and associated values. For example, the `hosts` map contains (as keys) all host names on a network, and (as values) the corresponding Internet addresses. Each YP map has a *mapname*, used by programs to access data in the map. Programs must know the format of the data in the map. Most maps are derived from ASCII files formerly found in `/etc/passwd`, `/etc/group`, `/etc/hosts`, `/etc/networks`, and other files in `/etc`. The format of data in the YP map is in most cases identical to the format of the ASCII file. Maps are implemented by `dbm(3X)` files located in subdirectories of `/etc/yp` on YP server machines.

The relationship between a YP map and the standard UNIX `/etc` file which it relates to varies from map to map. Some files (e.g. `/etc/hosts`, are *replaced* by their corresponding YP maps, while some (e.g. `/etc/passwd` are merely *augmented*. For more information, see the Yellow Pages section of *Network Programming*.

Maps sometimes have nicknames. Although the `ypcat` command is a general YP database print program, it knows about the standard files in the YP. Thus `ypcat hosts` is translated into `ypcat hosts.byaddr`, since there is no file called `hosts` in the YP. The command `ypcat -x` furnishes a list of expanded nicknames.

Yellow Pages Domains

A YP *domain* is a named set of YP maps. Taken together, these maps define a distinct network namespace and locate a distinct area of administrative control. YP domains differ from both Internet domains and `sendmail` domains, which define similar kinds of administrative loci in their respective (IP and electronic mail) networks. A given host will typically fall within all three domains, but these domains will not typically coincide. A YP domain is implemented as a directory in `/etc/yp` containing a set of maps.

You can determine your YP domain by executing the `domainname` command. A domain name is required for retrieving data from a YP database. For instance, if your YP domain is `sun` and you want to find the Internet address of host `dbserver`, you must ask YP for the value associated with the key `dbserver` in the map `hosts.byname` within the YP domain `sun`. Each machine on the network belongs to a default domain, which is set at boot time. Diskfull machines have their default domains set by a call to the `domainname` command made from `/etc/rc.local`. Diskless clients have it set as the result of a consultation with the `bootparams(5)` server.

A YP server holds all the maps of a YP domain in a subdirectory of `/etc/yp`, named after the domain. In the example above, maps for the `sun` domain would be held in `/etc/yp/sun`. A given host can contain maps for more than one YP domain.

Servers and Clients

Servers provide resources, while clients consume them. The terms "server" and "client" do not necessarily indicate machines. Consider both the NFS (network file system), and the YP:

NFS The NFS allows client machines to mount remote filesystems and access files in place, provided a server machine has exported the filesystem. However, a server that exports filesystems may also mount remote filesystems exported by other machines, thus becoming a client. So a given machine may be both server and client, or client only, or server only.

YP The YP server, by contrast, is a process rather than a machine, A process can request information out of the YP database, obviating the need to have such information on every machine. All processes that make use of YP services are YP clients. Sometimes clients are served by YP servers on the same machine, but other times by YP servers running on another machine. If a remote machine running a YP server process crashes, client processes can obtain YP services from another machine. Thus, the network YP service will remain available even if an individual YP host machine goes down.

Masters and Slaves

YP servers containing copies of the same databases can be spread throughout a network. When an arbitrary machine wants information in one of the YP databases, it makes an RPC call to one of the YP servers to get it. For any YP map, one YP server is designated as the *master* — the only one whose database may be modified. The other YP servers are *slaves*, and they are automatically updated from time to time to keep their information in sync with that of the master.

All changes to a YP map should be made on the machine which is the master YP server for that map. The changes will then propagate to the slaves. A newly built map is timestamped internally when it's created by `makedbm`. If you build a YP map on a slave server, you will temporarily break the YP update algorithm, and will have to get all versions in synch manually. Moral: after you decide which server is the master, do all database updates and builds there, not on slaves.

A given server may even be master with regard to one map, and slave with regard to another. This can get confusing quickly. Thus, its recommended that a single server be master for all maps created by `ypinit` in a single domain. Here we are assuming this simple case, in which one server is the master for all maps in a database.

Naming

Imagine a company with two different networks, each of which has its own separate list of hosts and passwords. Within each network, user names, numerical user IDs, and host names are unique. However, there is duplication between the two networks. If these two networks are ever connected, chaos could result. The host name, returned by the `hostname` command and the `gethostname()` system call, may no longer uniquely identify a machine. Thus a new command and system call, `domainname` and `getdomainname()` have been added. In the example above, each of the two networks could be given a different domain name. However, it is always simpler to use a single domain whenever possible.

The relevance of domains to YP is that data is stored in `/etc/yp/`*domainname*. In particular, a machine can contain data for several different domains.

Data Storage

The data in YP maps is stored as `dbm` format databases. (See `dbm`(3X)). Thus the database `hosts.byname` for the domain `sun` is stored as `/etc/yp/sun/hosts.byname.pag` and `/etc/yp/sun/hosts.byname.dir`. The command `makedbm` takes an ASCII file such as `/etc/hosts` and converts it into a `dbm` file suitable for use by the YP. However, system administrators normally use the makefile in `/etc/yp` to create new `dbm` files (read on for details). This makefile in turn calls `makedbm`.

Servers

To become a server, a machine must contain the YP databases, and must also be running the YP daemon `ypserv`. The `ypinit` command invokes this daemon automatically. It also takes a flag saying whether you are creating a master or a slave. When updating the master copy of a database, you can force the change to be propagated to all the slaves with the `yppush` command. This pushes the information out to all the slaves. Conversely, from a slave, the `ypxfr` command gets the latest information from the master. The makefile in `/etc/yp` first executes `makedbm` to make a new database, and then calls `yppush` to propagate the change throughout the network.

Clients

Remember that a client machine (which is not a server) does not access local copies of /etc files, but rather makes an RPC call to a YP server each time it needs information from a YP database. The ypbind daemon remembers the name of a server. When a client boots, ypbind broadcasts asking for the name of the YP server. Similarly, ypbind broadcasts asking for the name of a new YP server if the old server crashes. The ypwhich command gives the name of the server that ypbind currently points at.

Since client machines don't have entire copies of files in the YP, the commands ypcat and ypmatch have been provided. As you might guess, ypcat passwd is equivalent to cat /etc/passwd. To look for someone's password entry, searching through the password file no longer suffices; you have to issue one of the following commands

```
example% ypcat passwd | grep username
example% ypmatch username passwd
```

where you replace username with the login name you're searching for.

Default YP Files

By default, Sun workstations have a number of files from /etc in their YP: /etc/passwd, /etc/group, /etc/hosts, /etc/networks, /etc/services, /etc/protocols, and /etc/ethers. In addition, there is the netgroup(5), file, which defines network wide groups, and used for permission checking when doing remote mounts, remote logins, and remote shells.

Library routines such as getpwent(), getgrent(), and gethostent() have been rewritten to take advantage of the YP. Thus, C programs that call these library routines will have to be relinked in order to function correctly.

Hosts

The hosts file is stored as two different YP maps. The first, hosts.byname, is indexed by hostname. The second, hosts.byaddr, is indexed by Internet address. Remember that this actually expands into four files, with suffixes .pag, and .dir. When a user program calls the library routine gethost-byname(), a single RPC call to a server retrieves the entry from the hosts.byname file. Similarly, gethostbyaddr() retrieves the entry from the hosts.byaddr file. If the YP is not running (which is caused by commenting ypbind out of the /etc/rc file), then gethostbyname() will read the /etc/hosts files, just as it always has.

Normally, the hosts file for the YP will be the same as the /etc/hosts file on the machine serving as a YP master. In this case, the makefile in /etc/yp will check to see if /etc/hosts is newer than the dbm file. If it is, it will use a simple sed script to recreate hosts.byname and hosts.byaddr, run them through makedbm and then call yppush See ypmake for details.

Passwd

The passwd file is similar to the hosts file. It exists as two separate files, passwd.byname and passwd.byuid. The ypcat program prints it, and ypmake updates it. However, if getpwent always went directly to the YP as does gethostent, then everyone would be forced to have an identical password file. Consequently, getpwent reads the local /etc/passwd file, just as it always did. But now it interprets "+" entries in the password file to mean, interpolate entries from the YP database. If you wrote a simple program using getpwent to print out all the entries from your password file, it would print out a virtual password file: rather than printing out + signs, it would print out whatever entries the local password file included from the YP database.

Others

Of the other files in /etc, /etc/group is treated like /etc/passwd, in that getgrent() will only consult the YP if explicitly told to do so by the /etc/group file. The files /etc/networks, /etc/services, /etc/protocols, /etc/ethers, and /etc/netgroup are treated like /etc/hosts: for these files, the library routines go directly to the YP, without consulting the local files.

Changing your passwd

To change data in the YP, the system administrator must log into the master machine, and edit databases there; ypwhich -m tells where the master server is. However, since changing a password is so commonly done, the yppasswd command has been provided to change your YP password. It has the same user interface as the passwd command. This command will only work if the yppasswdd server has been started up on the YP master server machine.

1.5. The Network Lock Manager

SunOS includes a NFS-compatible Network Lock Manager (see the *lockd(8C)* man page for more details) that supports the lockf()/fcntl(), System V style of advisory file and record locking over the network. System V locks are generally considered superior to 4.3BSD locks, implemented with the flock() system call, for they provide record level, and not merely file level, locking. Record level locking is essential for database systems. Sun does support flock() for use on individual machines, but flock() is not intended to be used across the network. flock() locks exclude only other processes on the same machine. There is no interaction between flock() and lockf().

Locking prevents multiple processes from modifying the same file at the same time, and allows cooperating processes to synchronize access to shared files. The user interfaces with Sun's network locking service by way of the standard lockf() system-call interface, and rarely requires any detailed knowledge of how it works. The kernel maps user calls to flock() and fcntl() into RPC-based messages to the local lock manager (or, if the files in question are on RFS-mounted filesystems, into calls to RFS[6]). The fact that the file system may be spread across multiple machines is really not a complication — until a crash occurs.

All computers crash from time to time, and in an NFS environment, where multiple machines can have access to the same file at the same time, the process of

[6] RFS is AT&T's *Remote File Sharing*. A Sun-compatible version is available as an unbundled product.

recovering from a crash is necessarily more complex than in a non-network environment. Furthermore, locking is *inherently stateful*. If a server crashes, clients with locked files must be able to recover their locks. If a client crashes, its servers must have the sense to hold the client's locks while it recovers. And, to preserve NFS's overall transparency, the recovery of lost locks must not require the intervention of the applications themselves. This is accomplished as follows:

- Basic file access operations, such as read and write, use a stateless protocol (the NFS protocol). All interactions between NFS servers and clients are atomic — the server doesn't remember anything about its clients from one interaction to the next. In the case of a server crash, client applications will will simply sleep until it comes back up and their NFS operations can complete.

- *Stateful services* (those that require the server to maintain client information from one transaction to the next) such as the locking service, are not part of the NFS per se. They are separate services that use the status monitor (see *The Network Status Monitor*) to ensure that their implicit network state information remains consistent with the real state of the network. There are two specific state-related problems involved in providing locking in a network context:

  1) if the client has crashed, the lock can be held forever by the server

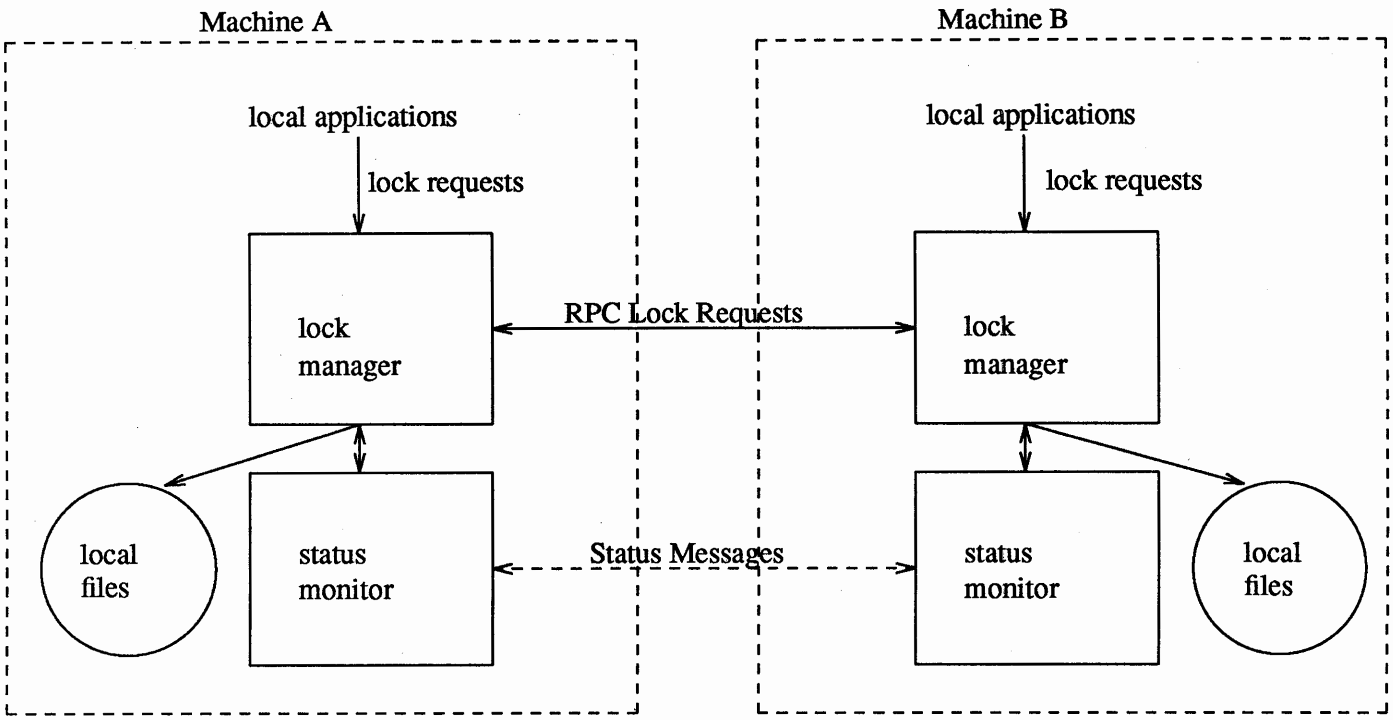
  2) if the server has crashed, it loses its state (including all its lock information) when it recovers.

  The Network Lock Manager solves both of these problems by cooperating with the Network Status Monitor to ensure that it's notified of relevant machine crashes. Its own protocol then allows it to recover the lock information it needs when crashed machines recover.

The lock manager and the status monitor are both network-service daemons — they run at user level, but they are essential to the kernel's ability to provide fundamental network services, and they are therefore run on all network machines. Like other network-service daemons — which provide, for example, remote-execution services (`rexd`) and remote-login services (`rlogind`) — they are best seen as extensions to the kernel which, for reasons of space, efficiency and organization, are implemented as daemons. Application programs that need a network service can either call the appropriate daemon directly with RPC/XDR, or use a system call (like `lockf()`) to call the kernel. In this later case, the kernel will use RPC to call the daemon. The network daemons communicate among themselves with RPC (see *The Locking Protocol* for some details of the lock manager protocol). It should be noted that the daemon-based approach to network services allows for tailoring by users who need customized services. It's possible, for example, for users to alter the lock manager to provide locking in a different style.

The following figure depicts the overall architecture of the locking service.

Figure 1-4 *Architecture of the Locking Service*



At each server site, a lock manager process accepts lock requests, made on behalf of client processes by a remote lock manager, or on behalf of local processes by the kernel. The client and server lock managers communicate with RPC calls. Upon receiving a remote lock request for a machine that it doesn't already hold a lock on, the lock manager registers its interest in that machine with the local status monitor, and waits for that monitor to notify it that the machine is up. The monitor continues to watch the status of registered machines, and notifies the lock manager is one of them is rebooted (after a crash). If the lock request is for a local file, the lock manager tries to satisfy it, and communicates back to the application along the appropriate RPC path.

The crash recovery procedure is very simple. If the failure of a client is detected, the server releases the failed client's locks, on the assumption that the client application will request locks again as needed. If the recovery (and, by implication, the crash) of a server is detected, the client lock manager retransmits all lock requests previously granted by the recovered server. This retransmitted information is used by the server to reconstruct its locking state. See below for more details.

The locking service, then, is essentially stateless. Or to be more precise, its state information is carefully circumscribed within a pair of system daemons that are set up for automatic, application-transparent crash recovery. If a server crashes, and thus loses its state, it expects that its clients will be be notified of the crash and send it the information that it needs to reconstruct its state. The key in this approach is the status monitor, which the lock manager uses to detect both client and server failures.

The Locking Protocol

The lock style implemented by the network lock manager is that specified in the *AT&T System V Interface Definition*, (see the `lockf(2)` and `fcntl(2)` man pages for details). There is no interaction between the lock manager's locks and `flock()`-style locks, which remain supported, but which should be used for non-network applications only.

Locks are presently advisory only, on the (well supported) assumption that cooperating processes can do whatever they wish without mandatory locks. Besides, mandatory locks pose serious security problems — if `/etc/passwd` is locked against reading, the whole system freezes. (See the `fcntl(2)` man page for more information about advisory locks).

There are four basic kernel to Lock Manager requests:

`KLM_LOCK`
: Lock the specified record.

`KLM_UNLOCK`
: Unlock the specified record.

`KLM_TEST`
: Test if the specified record is locked.

`KLM_CANCEL`
: Cancel an outstanding lock request.

Despite the fact that the network lock managers adheres to the `lockf()/fcntl()` semantics, there are a few subtle points about its behavior that deserve mention. These arise directly from the nature of the network:

- The first and most important of these has to do with crashes. When an NFS-client goes down, the lock managers on all of its servers are notified by their status monitors, and they simply releases its locks, on the assumption that it will request them again when it wants them. When a server crashes, however, matters are different: the clients will wait for it to come back up, and when it does, its lock manager will give the client lock managers a grace period to submit lock reclaim requests, and during this period will accept only reclaim requests. The client status monitors will notify their respective lock managers when the server recovers. The default grace period is 45 seconds.

- It is possible that, after a server crash, a client will not be able to recover a lock that it had on a file on that server. This can happen for the simple reason that another process may have beaten the recovering application process to the lock. In this case the `SIGLOST` signal will be sent to the process (the default action for this signal is to kill the application).

- The local lock manager does not reply to the kernel lock request until the server lock manager has gotten back to it. Further, if the lock request is on a server new to the local lock manager, the lock manager registers its interest in that server with the local status monitor and waits for its reply. Thus, if either the status monitor or the server's lock manager are unavailable, the reply to a lock request for remote data is delayed until it becomes available.

1.6. The Network Status Monitor

The Network Status Monitor (see the *statd(8C)* man page for more details) was introduced with the lock manager, which relies heavily on it to maintain the inherently stateful locking service within the stateless NFS environment. However, the status monitor is very general, and can also be used to support other kinds of stateful network services and applications. Normally, crash recovery is one of the most difficult aspects of network application development, and requires a major design and installation effort. The status monitor makes it more or less routine.

It is anticipated that, in the future, new network services, some of them stateful, will be introduced into the Sun system. These services will use the status monitor to keep up with the state of the network and to cope with machine crashes.

The status monitor works by providing a general framework for collecting network status information. Implemented as a daemon that runs on all network machines, it implements a simple protocol which allows applications to easily monitor the status of other machines. Its use improves overall robustness, and avoids situations in which applications running of different machines (or even on the same machine) come to disagree about the status of a site — a potentially dangerous situation that can lead to inconsistencies in many applications.

Applications using the status monitor do so by registering with it the machines that they are interested in. The monitor then tracks the status of those machines, and when one of them crashes[7] it notifies the interested applications to that effect, and they then take whatever actions are necessary to reestablish a consistent state.

There are several major advantages to this approach:

- Only applications that use stateful services must pay the overhead — in time and in code — of dealing with the status monitor.
- The implementation of stateful network applications is eased, since the status monitor shields application developers from the complexity of the network.

[7] Actually, when one of them recovers from a crash.

PART ONE: Network Programming

2

rpcgen Programming Guide

2

rpcgen Programming Guide

2.1. The rpcgen Protocol Compiler

The details of programming applications to use Remote Procedure Calls can be overwhelming. Perhaps most daunting is the writing of the XDR routines necessary to convert procedure arguments and results into their network format and vice-versa.

Fortunately, `rpcgen(1)` exists to help programmers write RPC applications simply and directly. `rpcgen` does most of the dirty work, allowing programmers to debug the main features of their application, instead of requiring them to spend most of their time debugging their network interface code.

`rpcgen` is a compiler. It accepts a remote program interface definition written in a language, called RPC Language, which is similar to C. It produces a C language output which includes stub versions of the client routines, a server skeleton, XDR filter routines for both parameters and results, and a header file that contains common definitions. The client stubs interface with the RPC library and effectively hide the network from their callers. The server stub similarly hides the network from the server procedures that are to be invoked by remote clients. `rpcgen`'s output files can be compiled and linked in the usual way. The developer writes server procedures—in any language that observes Sun calling conventions—and links them with the server skeleton produced by `rpcgen` to get an executable server program. To use a remote program, a programmer writes an ordinary main program that makes local procedure calls to the client stubs produced by `rpcgen`. Linking this program with `rpcgen`'s stubs creates an executable program. (At present the main program must be written in C). `rpcgen` options can be used to suppress stub generation and to specify the transport to be used by the server stub.

Like all compilers, `rpcgen` reduces development time that would otherwise be spent coding and debugging low-level routines. All compilers, including `rpcgen`, do this at a small cost in efficiency and flexibility. However, many compilers allow escape hatches for programmers to mix low-level code with high-level code. `rpcgen` is no exception. In speed-critical applications, hand-written routines can be linked with the `rpcgen` output without any difficulty. Also, one may proceed by using `rpcgen` output as a starting point, and then rewriting it as necessary. (If you need a discussion of RPC programming without `rpcgen`, see the next chapter, the *Remote Procedure Call Programming Guide*).

Converting Local Procedures into Remote Procedures

Assume an application that runs on a single machine, one which we want to convert to run over the network. Here we will demonstrate such a conversion by way of a simple example—a program that prints a message to the console:

```
/*
 * printmsg.c: print a message on the console
 */
#include <stdio.h>

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

	if (argc != 2) {
		fprintf(stderr, "usage: %s <message>\n", argv[0]);
		exit(1);
	}
	message = argv[1];

	if (!printmessage(message)) {
		fprintf(stderr, "%s: couldn't print your message\n",
			argv[0]);
		exit(1);
	}
	printf("Message Delivered!\n");
	exit(0);
}
/*
 * Print a message to the console.
 * Return a boolean indicating whether the message was actually printed.
 */
printmessage(msg)
	char *msg;
{
	FILE *f;

	f = fopen("/dev/console", "w");
	if (f == NULL) {
		return (0);
	}
	fprintf(f, "%s\n", msg);
	fclose(f);
	return(1);
}
```

And then, of course:

```
example% cc printmsg.c -o printmsg
example% printmsg "Hello, there."
Message delivered!
example%
```

If `printmessage()` was turned into a remote procedure, then it could be called from anywhere in the network. Ideally, one would just like to stick a keyword like `remote` in front of a procedure to turn it into a remote procedure. Unfortunately, we have to live within the constraints of the C language, since it existed long before RPC did. But even without language support, it's not very difficult to make a procedure remote.

In general, it's necessary to figure out what the types are for all procedure inputs and outputs. In this case, we have a procedure `printmessage()` which takes a string as input, and returns an integer as output. Knowing this, we can write a protocol specification in RPC language that describes the remote version of `printmessage()`. Here it is:

```
/*
 * msg.x: Remote message printing protocol
 */

program MESSAGEPROG {
    version MESSAGEVERS {
        int PRINTMESSAGE(string) = 1;
    } = 1;
} = 99;
```

Remote procedures are part of remote programs, so we actually declared an entire remote program here which contains the single procedure `PRINTMESSAGE`. This procedure was declared to be in version 1 of the remote program. No null procedure (procedure 0) is necessary because `rpcgen` generates it automatically.

Notice that everything is declared with all capital letters. This is not required, but is a good convention to follow.

Notice also that the argument type is "string" and not "char *". This is because a "char *" in C is ambiguous. Programmers usually intend it to mean a null-terminated string of characters, but it could also represent a pointer to a single character or a pointer to an array of characters. In RPC language, a null-terminated string is unambiguously called a "string".

There are just two more things to write. First, there is the remote procedure itself. Here's the definition of a remote procedure to implement the `PRINTMESSAGE` procedure we declared above.

```
/*
 * msg_proc.c: implementation of the remote procedure "printmessage"
 */

#include <stdio.h>
#include <rpc/rpc.h>      /* always needed    */
#include "msg.h"          /* msg.h will be generated by rpcgen */

/*
 * Remote verson of "printmessage"
 */
int *
printmessage_1(msg)
    char **msg;
{
    static int result; /* must be static! */
    FILE *f;

    f = fopen("/dev/console", "w");
    if (f == NULL) {
        result = 0;
        return (&result);
    }
    fprintf(f, "%s\n", *msg);
    fclose(f);
    result = 1;
    return (&result);
}
```

Notice here that the declaration of the remote procedure `printmessage_1()` differs from that of the local procedure `printmessage()` in three ways:

1. It takes a pointer to a string instead of a string itself. This is true of all remote procedures: they always take pointers to their arguments rather than the arguments themselves.
2. It returns a pointer to an integer instead of an integer itself. This is also generally true of remote procedures: they always return a pointer to their results.
3. It has an "_1" appended to its name. In general, all remote procedures called by `rpcgen` are named by the following rule: the name in the program definition (here `PRINTMESSAGE`) is converted to all lower-case letters, an underbar ("_") is appended to it, and finally the version number (here 1) is appended.

The last thing to do is declare the main client program that will call the remote procedure. Here it is:

```
/*
 * rprintmsg.c: remote version of "printmsg.c"
 */
#include <stdio.h>
#include <rpc/rpc.h>      /* always needed    */
```

```
#include "msg.h"          /* msg.h will be generated by rpcgen */

main(argc, argv)
    int argc;
    char *argv[];
{
    CLIENT *cl;
    int *result;
    char *server;
    char *message;

    if (argc != 3) {
        fprintf(stderr,
        "usage: %s host message\n", argv[0]);
        exit(1);
    }

    /*
     * Save values of command line arguments
     */
    server = argv[1];
    message = argv[2];

    /*
     * Create client "handle" used for calling MESSAGEPROG on the
     * server designated on the command line. We tell the RPC package
     * to use the "tcp" protocol when contacting the server.
     */
    cl = clnt_create(server, MESSAGEPROG, MESSAGEVERS,
     "tcp");
    if (cl == NULL) {
        /*
         * Couldn't establish connection with server.
         * Print error message and die.
         */
        clnt_pcreateerror(server);
        exit(1);
    }

    /*
     * Call the remote procedure "printmessage" on the server
     */
    result = printmessage_1(&message, cl);
    if (result == NULL) {
        /*
         * An error occurred while calling the server.
         * Print error message and die.
         */
        clnt_perror(cl, server);
        exit(1);
    }

    /*
     * Okay, we successfully called the remote procedure.
     */
    if (*result == 0) {
```

```
        /*
         * Server was unable to print our message.
         * Print error message and die.
         */
        fprintf(stderr, "%s: %s couldn't print your message\n",
            argv[0], server);
            exit(1);
    }
    /*
     * The message got printed on the server's console
     */
    printf("Message delivered to %s!\n", server);
    exit(0);
}
```

There are two things to note here:

1. First a client "handle" is created using the RPC library routine `clnt_create()`. This client handle will be passed to the stub routines which call the remote procedure.

2. The remote procedure `printmessage_1()` is called exactly the same way as it is declared in `msg_proc.c` except for the inserted client handle as the first argument.

Here's how to put all of the pieces together:

```
example%  rpcgen msg.x
example%  cc rprintmsg.c msg_clnt.c -o rprintmsg
example%  cc msg_proc.c msg_svc.c -o msg_server
```

Two programs were compiled here: the client program `rprintmsg` and the server program `msg_server`. Before doing this though, `rpcgen` was used to fill in the missing pieces.

Here is what `rpcgen` did with the input file `msg.x`:

1. It created a header file called `msg.h` that contained `#define`'s for `MESSAGEPROG`, `MESSAGEVERS` and `PRINTMESSAGE` for use in the other modules.

2. It created client "stub" routines in the `msg_clnt.c` file. In this case there is only one, the `printmessage_1()` that was referred to from the `printmsg` client program. The name of the output file for client stub routines is always formed in this way: if the name of the input file is `FOO.x`, the client stubs output file is called `FOO_clnt.c`.

3. It created the server program which calls `printmessage_1()` in `msg_proc.c`. This server program is named `msg_svc.c`. The rule for naming the server output file is similar to the previous one: for an input file called `FOO.x`, the output server file is named `FOO_svc.c`.

Now we're ready to have some fun. First, copy the server to a remote machine and run it. For this example, the machine is called "moon". Server processes are run in the background, because they never exit.

```
moon% msg_server &
```

Then on our local machine ("sun") we can print a message on "moon"s console.

```
sun% rprintmsg moon "Hello, moon."
```

The message will get printed to "moon"s console. You can print a message on anybody's console (including your own) with this program if you are able to copy the server to their machine and run it.

Generating XDR Routines

The previous example only demonstrated the automatic generation of client and server RPC code. `rpcgen` may also be used to generate XDR routines, that is, the routines necessary to convert local data structures into network format and vice-versa. This example presents a complete RPC service—a remote directory listing service, which uses `rpcgen` not only to generate stub routines, but also to generate the XDR routines. Here is the protocol description file.

```
/*
 * dir.x: Remote directory listing protocol
 */
const MAXNAMELEN = 255;       /* maximum length of a directory entry */

typedef string nametype<MAXNAMELEN>;     /* a directory entry */

typedef struct namenode *namelist;       /* a link in the listing */

/*
 * A node in the directory listing
 */
struct namenode {
    nametype name;       /* name of directory entry */
    namelist next;       /* next entry */
};

/*
 * The result of a READDIR operation.
 */
union readdir_res switch (int errno) {
case 0:
    namelist list;   /* no error: return directory listing */
default:
    void;          /* error occurred: nothing else to return */
};

/*
 * The directory program definition
 */
program DIRPROG {
    version DIRVERS {
```

```
        readdir_res
        READDIR(nametype) = 1;
    } = 1;
} = 76;
```

NOTE *Types (like* `readdir_res` *in the example above) can be defined using the "struct", "union" and "enum" keywords, but those keywords should not be used in subsequent declarations of variables of those types. For example, if you define a union "foo", you should declare using only "foo" and not "union foo". In fact,* `rpcgen` *compiles RPC unions into C structures and it is an error to declare them using the "union" keyword.*

Running `rpcgen` on `dir.x` creates four output files. Three are the same as before: header file, client stub routines and server skeleton. The fourth are the XDR routines necessary for converting the data types we declared into XDR format and vice-versa. These are output in the file `dir_xdr.c`.

Here is the implementation of the `READDIR` procedure.

```
/*
 * dir_proc.c: remote readdir implementation
 */
#include <rpc/rpc.h>
#include <sys/dir.h>
#include "dir.h"

extern int errno;
extern char *malloc();
extern char *strdup();

readdir_res *
readdir_1(dirname)
    nametype *dirname;
{
    DIR *dirp;
    struct direct *d;
    namelist nl;
    namelist *nlp;
    static readdir_res res; /* must be static! */

    /*
     * Open directory
     */
    dirp = opendir(*dirname);
    if (dirp == NULL) {
        res.errno = errno;
        return (&res);
    }

    /*
     * Free previous result
     */
    xdr_free(xdr_readdir_res, &res);
```

```
	/*
	 * Collect directory entries.
	 * Memory allocated here will be freed by xdr_free
	 * next time readdir_1 is called
	 */
	nlp = &res.readdir_res_u.list;
	while (d = readdir(dirp)) {
		nl = *nlp = (namenode *) malloc(sizeof(namenode));
		nl->name = strdup(d->d_name);
		nlp = &nl->next;
	}
	*nlp = NULL;

	/*
	 * Return the result
	 */
	res.errno = 0;
	closedir(dirp);
	return (&res);
}
```

Finally, there is the client side program to call the server:

```
/*
 * rls.c: Remote directory listing client
 */
#include <stdio.h>
#include <rpc/rpc.h>      /* always need this */
#include "dir.h"          /* will be generated by rpcgen */

extern int errno;

main(argc, argv)
	int argc;
	char *argv[];
{
	CLIENT *cl;
	char *server;
	char *dir;
	readdir_res *result;
	namelist nl;

	if (argc != 3) {
		fprintf(stderr, "usage: %s host directory\n",
		  argv[0]);
		exit(1);
	}

	/*
	 * Remember what our command line arguments refer to
	 */
	server = argv[1];
	dir = argv[2];

	/*
```

```
	 * Create client "handle" used for calling MESSAGEPROG on the
	 * server designated on the command line. We tell the RPC package
	 * to use the "tcp" protocol when contacting the server.
	 */
	cl = clnt_create(server, DIRPROG, DIRVERS, "tcp");
	if (cl == NULL) {
		/*
		 * Couldn't establish connection with server.
		 * Print error message and die.
		 */
		clnt_pcreateerror(server);
		exit(1);
	}

	/*
	 * Call the remote procedure readdir on the server
	 */
	result = readdir_1(&dir, cl);
	if (result == NULL) {
		/*
		 * An error occurred while calling the server.
		 * Print error message and die.
		 */
		clnt_perror(cl, server);
		exit(1);
	}
	/*
	 * Okay, we successfully called the remote procedure.
	 */
	if (result->errno != 0) {
		/*
		 * A remote system error occurred.
		 * Print error message and die.
		 */
		errno = result->errno;
		perror(dir);
		exit(1);
	}
	/*
	 * Successfully got a directory listing.
	 * Print it out.
	 */
	for (nl = result->readdir_res_u.list; nl != NULL;
	  nl = nl->next) {
		printf("%s\n", nl->name);
	}
	exit(0);
}
```

Compile everything, and run.

```
sun%  rpcgen dir.x
sun%  cc rls.c dir_clnt.c dir_xdr.c -o rls
sun%  cc dir_svc.c dir_proc.c dir_xdr.c -o dir_svc

sun%  dir_svc &

moon%  rls sun /usr/pub
.
..
ascii
eqnchar
greek
kbd
marg8
tabclr
tabs
tabs4
moon%
```

A final note about rpcgen: The client program and the server procedure can be tested together as a single program by simply linking them with each other rather than with the client and server stubs. The procedure calls will be executed as ordinary local procedure calls and the program can be debugged with a local debugger such as dbxtool. When the program is working, the client program can be linked to the client stub produced by rpcgen and the server procedures can be linked to the server stub produced by rpcgen.

NOTE *If you do this, you may want to comment out calls to RPC library routines, and have client-side routines call server routines directly.*

The C-Preprocessor

The C-preprocessor is run on all input files before they are compiled, so all the preprocessor directives are legal within a ".x" file. Four symbols may be defined, depending upon which output file is getting generated. The symbols are:

Symbol	*Usage*
RPC_HDR	for header-file output
RPC_XDR	for XDR routine output
RPC_SVC	for server-skeleton output
RPC_CLNT	for client stub output

Also, rpcgen does a little preprocessing of its own. Any line that begins with a percent sign is passed directly into the output file, without any interpretation of the line. Here is a simple example that demonstrates the preprocessing features.

```
/*
 * time.x: Remote time protocol
 */
program TIMEPROG {
        version TIMEVERS {
                unsigned int TIMEGET(void) = 1;
        } = 1;
} = 44;

#ifdef RPC_SVC
%int *
%timeget_1()
%{
%       static int thetime;
%
%       thetime = time(0);
%       return (&thetime);
%}
#endif
```

The '%' feature is not generally recommended, as there is no guarantee that the compiler will stick the output where you intended.

`rpcgen` Programming Notes

Timeout Changes

RPC sets a default timeout of 25 seconds for RPC calls when `clnt_create()` is used. This timeout may be changed using `clnt_control()`. Here is a small code fragment to demonstrate use of `clnt_control()`:

```
struct timeval tv;
CLIENT *cl;

cl = clnt_create("somehost", SOMEPROG, SOMEVERS, "tcp");
if (cl == NULL) {
    exit(1);
}
tv.tv_sec = 60; /* change timeout to 1 minute */
tv.tv_usec = 0;
clnt_control(cl, CLSET_TIMEOUT, &tv);
```

Handling Broadcast on the Server Side

When a procedure is known to be called via broadcast RPC, it is usually wise for the server to not reply unless it can provide some useful information to the client. This prevents the network from getting flooded by useless replies.

To prevent the server from replying, a remote procedure can return NULL as its result, and the server code generated by `rpcgen` will detect this and not send out a reply.

Here is an example of a procedure that replies only if it thinks it is an NFS server:

```
void *
reply_if_nfsserver()
{
    char notnull;    /* just here so we can use its address */

    if (access("/etc/exports", F_OK) < 0) {
        return (NULL);   /* prevent RPC from replying */
    }
    /*
     * return non-null pointer so RPC will send out a reply
     */
    return ((void *)&notnull);
}
```

Note that if procedure returns type "void *", they must return a non-NULL pointer if they want RPC to reply for them.

Other Information Passed to Server Procedures

Server procedures will often want to know more about an RPC call than just its arguments. For example, getting authentication information is important to procedures that want to implement some level of security. This extra information is actually supplied to the server procedure as a second argument. Here is an example to demonstrate its use. What we've done here is rewrite the previous `printmessage_1()` procedure to only allow root users to print a message to the console.

```
int *
printmessage_1(msg, rq)
    char **msg;
    struct svc_req  *rq;
{
    static in result;    /* Must be static */
    FILE *f;
    struct suthunix_parms *aup;

    aup = (struct authunix_parms *)rq->rq_clntcred;
    if (aup->aup_uid != 0) {
        result = 0;
        return (&result);
    }

    /*
     * Same code as before.
     */
}
```

RPC Language

RPC language is an extension of XDR language. The sole extension is the addition of the `program` type. For a complete description of the XDR language syntax, see the *External Data Representation Standard: Protocol Specification* chapter. For a description of the RPC extensions to the XDR language, see the *Remote Procedure Calls: Protocol Specification* chapter.

However, XDR language is so close to C that if you know C, you know most of it already. We describe here the syntax of the RPC language, showing a few examples along the way. We also show how the various RPC and XDR type definitions get compiled into C type definitions in the output header file.

Definitions

An RPC language file consists of a series of definitions.

```
definition-list:
    definition ";"
    definition ";" definition-list
```

It recognizes five types of definitions.

```
definition:
    enum-definition
    struct-definition
    union-definition
    typedef-definition
    const-definition
    program-definition
```

Structures

An XDR struct is declared almost exactly like its C counterpart. It looks like the following:

```
struct-definition:
    "struct" struct-ident "{"
        declaration-list
    "}"

declaration-list:
    declaration ";"
    declaration ";" declaration-list
```

As an example, here is an XDR structure to a two-dimensional coordinate, and the C structure that it gets compiled into in the output header file.

```
struct coord {                  struct coord {
     int x;         -->              int x;
     int y;                          int y;
};                              };
                                typedef struct coord coord;
```

The output is identical to the input, except for the added `typedef` at the end of the output. This allows one to use "coord" instead of "struct coord" when declaring items.

Unions

XDR unions are discriminated unions, and look quite different from C unions. They are more analogous to Pascal variant records than they are to C unions.

```
union-definition:
    "union" union-ident "switch" "(" declaration ")" "{"
        case-list
    "}"

case-list:
    "case" value ":" declaration ";"
    "default" ":" declaration ";"
    "case" value ":" declaration ";" case-list
```

Here is an example of a type that might be returned as the result of a "read data" operation. If there is no error, return a block of data. Otherwise, don't return anything.

```
union read_result switch (int errno) {
case 0:
    opaque data[1024];
default:
    void;
};
```

It gets compiled into the following:

```
struct read_result {
    int errno;
    union {
        char data[1024];
    } read_result_u;
};
typedef struct read_result read_result;
```

Notice that the union component of the output struct has the name as the type name, except for the trailing "_u".

Enumerations

XDR enumerations have the same syntax as C enumerations.

```
enum-definition:
    "enum" enum-ident "{"
        enum-value-list
    "}"

enum-value-list:
    enum-value
    enum-value "," enum-value-list

enum-value:
    enum-value-ident
    enum-value-ident "=" value
```

Here is a short example of an XDR enum, and the C enum that it gets compiled into.

```
enum colortype {              enum colortype {
     RED = 0,                      RED = 0,
     GREEN = 1,     -->            GREEN = 1,
     BLUE = 2                      BLUE = 2,
};                            };
                              typedef enum colortype colortype;
```

Typedef

XDR typedefs have the same syntax as C typedefs.

```
typedef-definition:
    "typedef" declaration
```

Here is an example that defines a `fname_type` used for declaring file name strings that have a maximum length of 255 characters.

```
typedef string fname_type<255>; --> typedef char *fname_type;
```

Constants

XDR constants symbolic constants that may be used wherever a integer constant is used, for example, in array size specifications.

```
const-definition:
    "const" const-ident "=" integer
```

For example, the following defines a constant `DOZEN` equal to 12.

```
const DOZEN = 12;  -->  #define DOZEN 12
```

Programs

RPC programs are declared using the following syntax:

```
program-definition:
    "program" program-ident "{"
        version-list
    "}" "=" value

version-list:
    version ";"
    version ";" version-list

version:
    "version" version-ident "{"
        procedure-list
    "}" "=" value

procedure-list:
    procedure ";"
    procedure ";" procedure-list

procedure:
    type-ident procedure-ident "(" type-ident ")" "=" value
```

For example, here is the time protocol, revisited:

```
/*
 * time.x: Get or set the time. Time is represented as number of seconds
 * since 0:00, January 1, 1970.
 */
program TIMEPROG {
    version TIMEVERS {
        unsigned int TIMEGET(void) = 1;
        void TIMESET(unsigned) = 2;
    } = 1;
} = 44;
```

This file compiles into #defines in the output header file:

```
#define TIMEPROG 44
#define TIMEVERS 1
#define TIMEGET 1
#define TIMESET 2
```

Declarations

In XDR, there are only four kinds of declarations.

```
declaration:
    simple-declaration
    fixed-array-declaration
    variable-array-declaration
    pointer-declaration
```

1) **Simple declarations** are just like simple C declarations.

```
simple-declaration:
    type-ident variable-ident
```

Example:

```
colortype color;    --> colortype color;
```

2) **Fixed-length Array Declarations** are just like C array declarations:

```
fixed-array-declaration:
    type-ident variable-ident "[" value "]"
```

Example:

```
colortype palette[8];    --> colortype palette[8];
```

3) **Variable-Length Array Declarations** have no explicit syntax in C, so XDR invents its own using angle-brackets.

```
variable-array-declaration:
    type-ident variable-ident "<" value ">"
    type-ident variable-ident "<" ">"
```

The maximum size is specified between the angle brackets. The size may be omitted, indicating that the array may be of any size.

```
int heights<12>;      /* at most 12 items */
int widths<>;         /* any number of items */
```

Since variable-length arrays have no explicit syntax in C, these declarations are actually compiled into "struct"s. For example, the "heights" declaration gets compiled into the following struct:

```
struct {
    u_int heights_len;   /* # of items in array */
    int *heights_val;    /* pointer to array */
} heights;
```

Note that the number of items in the array is stored in the "_len" component and the pointer to the array is stored in the "_val" component. The first part of each of these component's names is the same as the name of the declared XDR variable.

4) Pointer Declarations are made in XDR exactly as they are in C. You can't really send pointers over the network, but you can use XDR pointers for sending recursive data types such as lists and trees. The type is actually called "optional-data", not "pointer", in XDR language.

```
pointer-declaration:
    type-ident "*" variable-ident
```

Example:

```
listitem *next;  -->  listitem *next;
```

Special Cases

There are a few exceptions to the rules described above.

Booleans: C has no built-in boolean type. However, the RPC library does a boolean type called `bool_t` that is either `TRUE` or `FALSE`. Things declared as type `bool` in XDR language are compiled into `bool_t` in the output header file.

Example:

```
bool married;  -->  bool_t married;
```

Strings: C has no built-in string type, but instead uses the null-terminated "char *" convention. In XDR language, strings are declared using the "string" keyword, and compiled into "char *"s in the output header file. The maximum size contained in the angle brackets specifies the maximum number of characters allowed in the strings (not counting the `NULL` character). The maximum size may be left off, indicating a string of arbitrary length.

Examples:

```
string name<32>;  -->  char *name;
string longname<>;  -->  char *longname;
```

Opaque Data: Opaque data is used in RPC and XDR to describe untyped data, that is, just sequences of arbitrary bytes. It may be declared either as a fixed or variable length array.

```
Examples:
    opaque diskblock[512];   -->  char diskblock[512];

    opaque filedata<1024>;   -->  struct {
                                     u_int filedata_len;
                                     char *filedata_val;
                                  } filedata;
```

Voids: In a void declaration, the variable is not named. The declaration is just "void" and nothing else. Void declarations can only occur in two places: union definitions and program definitions (as the argument or result of a remote procedure).

3

Remote Procedure Call Programming Guide

3

Remote Procedure Call Programming Guide

This document assumes a working knowledge of network theory. It is intended for programmers who wish to write network applications using remote procedure calls (explained below), and who want to understand the RPC mechanisms usually hidden by the `rpcgen(1)` protocol compiler. `rpcgen` is described in detail in the previous chapter, the **rpcgen** *Programming Guide.*

NOTE *Before attempting to write a network application, or to convert an existing non-network application to run over the network, you may want to understand the material in this chapter. However, for most applications, you can circumvent the need to cope with the details presented here by using* `rpcgen`. *The Generating XDR Routines section of that chapter contains the complete source for a working RPC service—a remote directory listing service which uses* `rpcgen` *to generate XDR routines as well as client and server stubs.*

What are remote procedure calls? Simply put, they are the high-level communications paradigm used in SunOS. RPC presumes the existence of low-level networking mechanisms (such as TCP/IP and UDP/IP), and upon them it implements a logical client to server communications system designed specifically for the support of network applications. With RPC, the client makes a procedure call to send a data packet to the server. When the packet arrives, the server calls a dispatch routine, performs whatever service is requested, sends back the reply, and the procedure call returns to the client.

Layers of RPC

The RPC interface can be seen as being divided into three layers.[8]

The Highest Layer: The highest layer is totally transparent to the operating system, machine and network upon which is is run. It's probably best to think of this level as a way of *using* RPC, rather than as a *part of* RPC proper. Programmers who write RPC routines should (almost) always make this layer available to others by way of a simple C front end that entirely hides the networking.

To illustrate, at this level a program can simply make a call to `rnusers()`, a C routine which returns the number of users on a remote machine. The user is not explicitly aware of using RPC — they simply call a procedure, just as they would call `malloc()`.

[8] For a complete specification of the routines in the remote procedure call Library, see the `rpc(3N)` manual page.

The Middle Layer: The middle layer is really "RPC proper." Here, the user doesn't need to consider details about sockets, the UNIX system, or other low-level implementation mechanisms. They simply make remote procedure calls to routines on other machines. The selling point here is simplicity. It's this layer that allows RPC to pass the "hello world" test — simple things should be simple. The middle-layer routines are used for most applications.

RPC calls are made with the system routines `registerrpc()`, `callrpc()` and `svc_run()`. The first two of these are the most fundamental: `registerrpc()` obtains a unique system-wide procedure-identification number, and `callrpc()` actually executes a remote procedure call. At the middle level, a call to `rnusers()` is implemented by way of these two routines.

The middle layer is unfortunately rarely used in serious programming due to its inflexibility (simplicity). It does not allow timeout specifications or the choice of transport. It allows no UNIX process control or flexibility in case of errors. It doesn't support multiple kinds of call authentication. The programmer rarely needs all these kinds of control, but one or two of them is often necessary.

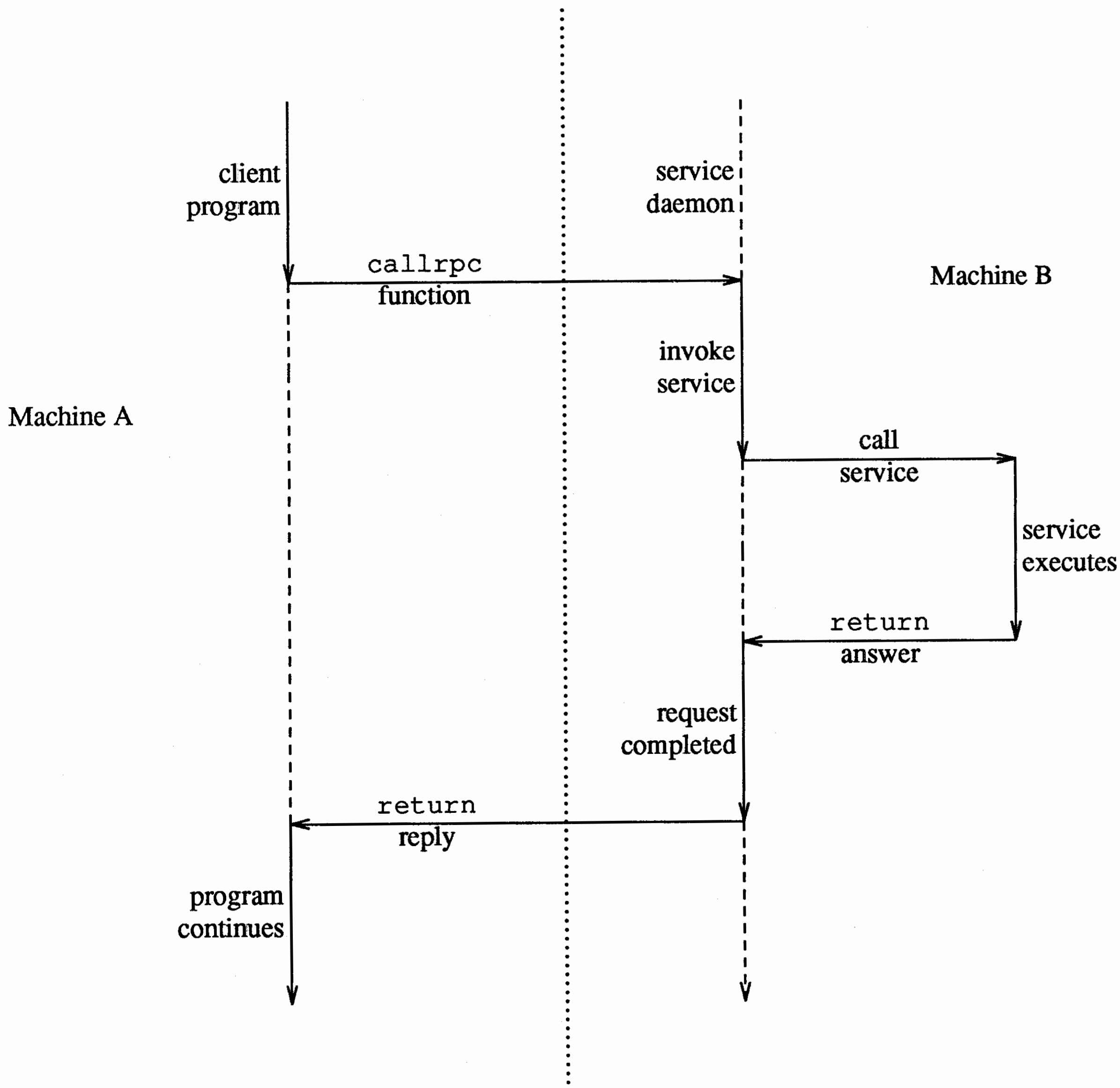
The Lowest Layer: The lowest layer does allow these details to be controlled by the programmer, and for that reason it is often necessary. Programs written at this level are also most efficient, but this is rarely a real issue — since RPC clients and servers rarely generate heavy network loads.

Although this document only discusses the interface to C, remote procedure calls can be made from any language. Even though this document discusses RPC when it is used to communicate between processes on different machines, it works just as well for communication between different processes on the same machine.

The RPC Paradigm

Here is a diagram of the RPC paradigm:

Figure 3-1 *Network Communication with the Remote Procedure Call*



3.1. Higher Layers of RPC

Highest Layer

Imagine you're writing a program that needs to know how many users are logged into a remote machine. You can do this by calling the RPC library routine `rnusers()`, as illustrated below:

```
#include <stdio.h>

main(argc, argv)
    int argc;
    char **argv;
{
    int num;

    if (argc != 2) {
        fprintf(stderr, "usage: rnusers hostname\n");
        exit(1);
    }
    if ((num = rnusers(argv[1])) < 0) {
        fprintf(stderr, "error: rnusers\n");
        exit(-1);
    }
    printf("%d users on %s\n", num, argv[1]);
    exit(0);
}
```

RPC library routines such as `rnusers()` are in the RPC services library `librpcsvc.a`. Thus, the program above should be compiled with

```
example% cc program.c -lrpcsvc
```

`rnusers()`, like the other RPC library routines, is documented in section 3R of the *System Services Overview*, the same section which documents the standard Sun RPC services. See the `intro(3R)` manual page for an explanation of the documentation strategy for these services and their RPC protocols.

Here are some of the RPC service library routines available to the C programmer:

Table 3-1 *RPC Service Library Routines*

Routine	*Description*
`rnusers`	Return number of users on remote machine
`rusers`	Return information about users on remote machine
`havedisk`	Determine if remote machine has disk
`rstats`	Get performance data from remote kernel
`rwall`	Write to specified remote machines
`yppasswd`	Update user password in Yellow Pages

Other RPC services — for example `ether()`, `mount`, `rquota()`, and `spray` — are not available to the C programmer as library routines. They do, however, have RPC program numbers so they can be invoked with `callrpc()`, which will be discussed in the next section. Most of them also have compilable `rpcgen(1)` protocol description files. (The `rpcgen` protocol compiler radically simplifies the process of developing network applications. See the **rpcgen** *Programming Guide* chapter for detailed information about `rpcgen` and `rpcgen` protocol description files).

Intermediate Layer

The simplest interface, which explicitly makes RPC calls, uses the functions `callrpc()` and `registerrpc()`. Using this method, the number of remote users can be gotten as follows:

```
#include <stdio.h>
#include <rpc/rpc.h>
#include <utmp.h>
#include <rpcsvc/rusers.h>

main(argc, argv)
    int argc;
    char **argv;
{
    unsigned long nusers;
    int stat;

    if (argc != 2) {
        fprintf(stderr, "usage: nusers hostname\n");
        exit(-1);
    }
    if (stat = callrpc(argv[1],
      RUSERSPROG, RUSERSVERS, RUSERSPROC_NUM,
      xdr_void, 0, xdr_u_long, &nusers) != 0) {
        clnt_perrno(stat);
        exit(1);
    }
    printf("%d users on %s\n", nusers, argv[1]);
    exit(0);
}
```

Each RPC procedure is uniquely defined by a program number, version number, and procedure number. The program number specifies a group of related remote procedures, each of which has a different procedure number. Each program also has a version number, so when a minor change is made to a remote service (adding a new procedure, for example), a new program number doesn't have to be assigned. When you want to call a procedure to find the number of remote users, you look up the appropriate program, version and procedure numbers in a manual, just as you look up the name of a memory allocator when you want to allocate memory.

The simplest way of making remote procedure calls is with the the RPC library routine `callrpc()`. It has eight parameters. The first is the name of the remote server machine. The next three parameters are the program, version, and procedure numbers—together they identify the procedure to be called. The fifth and sixth parameters are an XDR filter and an argument to be encoded and passed to the remote procedure. The final two parameters are a filter for decoding the results returned by the remote procedure and a pointer to the place where the procedure's results are to be stored. Multiple arguments and results are handled by embedding them in structures. If `callrpc()` completes successfully, it returns zero; else it returns a nonzero value. The return codes (of type cast into an integer) are found in `<rpc/clnt.h>`.

Since data types may be represented differently on different machines, `callrpc()` needs both the type of the RPC argument, as well as a pointer to the argument itself (and similarly for the result). For `RUSERSPROC_NUM`, the return value is an `unsigned long`, so `callrpc()` has `xdr_u_long()` as its first return parameter, which says that the result is of type `unsigned long`, and `&nusers` as its second return parameter, which is a pointer to where the long result will be placed. Since `RUSERSPROC_NUM` takes no argument, the argument parameter of `callrpc()` is `xdr_void()`.

After trying several times to deliver a message, if `callrpc()` gets no answer, it returns with an error code. The delivery mechanism is UDP, which stands for User Datagram Protocol. Methods for adjusting the number of retries or for using a different protocol require you to use the lower layer of the RPC library, discussed later in this document. The remote server procedure corresponding to the above might look like this:

```
char *
nuser(indata)
    char *indata;
{
    unsigned long nusers;

    /*
     * Code here to compute the number of users
     * and place result in variable nusers.
     */
    return((char *)&nusers);
}
```

It takes one argument, which is a pointer to the input of the remote procedure call (ignored in our example), and it returns a pointer to the result. In the current version of C, character pointers are the generic pointers, so both the input argument and the return value are cast to `char *`.

Normally, a server registers all of the RPC calls it plans to handle, and then goes into an infinite loop waiting to service requests. In this example, there is only a single procedure to register, so the main body of the server would look like this:

```
#include <stdio.h>
#include <rpc/rpc.h>
#include <utmp.h>
#include <rpcsvc/rusers.h>

char *nuser();

main()
{
    registerrpc(RUSERSPROG, RUSERSVERS, RUSERSPROC_NUM,
        nuser, xdr_void, xdr_u_long);
    svc_run();      /* Never returns */
    fprintf(stderr, "Error: svc_run returned!\n");
```

```
        exit(1);
}
```

The `registerrpc()` routine registers a C procedure as corresponding to a given RPC procedure number. The first three parameters, `RUSERPROG`, `RUSERSVERS`, and `RUSERSPROC_NUM` are the program, version, and procedure numbers of the remote procedure to be registered; `nuser()` is the name of the local procedure that implements the remote procedure; and `xdr_void()` and `xdr_u_long()` are the XDR filters for the remote procedure's arguments and results, respectively. (Multiple arguments or multiple results are passed as structures).

Only the UDP transport mechanism can use `registerrpc()`; thus, it is always safe in conjunction with calls generated by `callrpc()`.

WARNING

Warning: the UDP transport mechanism can only deal with arguments and results less than 8K bytes in length.

After registering the local procedure, the server program's main procedure calls `svc_run()`, the RPC library's remote procedure dispatcher. It is this function that calls the remote procedures in response to RPC call messages. Note that the dispatcher takes care of decoding remote procedure arguments and encoding results, using the XDR filters specified when the remote procedure was registered.

Assigning Program Numbers

Program numbers are assigned in groups of `0x20000000` according to the following chart:

```
       0x0 - 0x1fffffff Defined by Sun
0x20000000 - 0x3fffffff Defined by user
0x40000000 - 0x5fffffff Transient
0x60000000 - 0x7fffffff Reserved
0x80000000 - 0x9fffffff Reserved
0xa0000000 - 0xbfffffff Reserved
0xc0000000 - 0xdfffffff Reserved
0xe0000000 - 0xffffffff Reserved
```

Sun Microsystems administers the first group of numbers, which should be identical for all Sun customers. If a customer develops an application that might be of general interest, that application should be given an assigned number in the first range. The second group of numbers is reserved for specific customer applications. This range is intended primarily for debugging new programs. The third group is reserved for applications that generate program numbers dynamically. The final groups are reserved for future use, and should not be used.

To register a protocol specification, send a request by network mail to `rpc@sun`, or write to:

RPC Administrator
Sun Microsystems
2550 Garcia Ave.
Mountain View, CA 94043

Please include a compilable `rpcgen` ".x" file describing your protocol. You will be given a unique program number in return.

The RPC program numbers and protocol specifications of standard Sun RPC services can be found in the include files in `/usr/include/rpcsvc`. These services, however, constitute only a small subset of those which have been registered. The complete list of registered programs, as of the time when this manual was printed, is:

RPC Number	***Program***	***Description***
100000	PMAPPROG	*portmapper*
100001	RSTATPROG	*remote stats*
100002	RUSERSPROG	*remote users*
100003	NFSPROG	*nfs*
100004	YPPROG	*Yellow Pages*
100005	MOUNTPROG	*mount demon*
100006	DBXPROG	*remote dbx*
100007	YPBINDPROG	*yp binder*
100008	WALLPROG	*shutdown msg*
100009	YPPASSWDPROG	*yppasswd server*
100010	ETHERSTATPROG	*ether stats*
100011	RQUOTAPROG	*disk quotas*
100012	SPRAYPROG	*spray packets*
100013	IBM3270PROG	*3270 mapper*
100014	IBMRJEPROG	*RJE mapper*
100015	SELNSVCPROG	*selection service*
100016	RDATABASEPROG	*remote database access*
100017	REXECPROG	*remote execution*
100018	ALICEPROG	*Alice Office Automation*
100019	SCHEDPROG	*scheduling service*
100020	LOCKPROG	*local lock manager*
100021	NETLOCKPROG	*network lock manager*
100022	X25PROG	*x.25 inr protocol*
100023	STATMON1PROG	*status monitor 1*
100024	STATMON2PROG	*status monitor 2*
100025	SELNLIBPROG	*selection library*
100026	BOOTPARAMPROG	*boot parameters service*
100027	MAZEPROG	*mazewars game*
100028	YPUPDATEPROG	*yp update*
100029	KEYSERVEPROG	*key server*
100030	SECURECMDPROG	*secure login*
100031	NETFWDIPROG	*nfs net forwarder init*
100032	NETFWDTPROG	*nfs net forwarder trans*
100033	SUNLINKMAP_PROG	*sunlink MAP*

Table 3-1 *RPC Service Library Routines— Continued*

RPC Number	***Program***	***Description***
100034	NETMONPROG	*network monitor*
100035	DBASEPROG	*lightweight database*
100036	PWDAUTHPROG	*password authorization*
100037	TFSPROG	*translucent file svc*
100038	NSEPROG	*nse server*
100039	NSE_ACTIVATE_PROG	*nse activate daemon*
150001	PCNFSDPROG	*pc passwd authorization*
200000	PYRAMIDLOCKINGPROG	*Pyramid-locking*
200001	PYRAMIDSYS5	*Pyramid-sys5*
200002	CADDS_IMAGE	*CV cadds_image*
300001	ADT_RFLOCKPROG	*ADT file locking*

Passing Arbitrary Data Types

In the previous example, the RPC call passes a single `unsigned long`. RPC can handle arbitrary data structures, regardless of different machines' byte orders or structure layout conventions, by always converting them to a network standard called *External Data Representation* (XDR) before sending them over the wire. The process of converting from a particular machine representation to XDR format is called *serializing*, and the reverse process is called *deserializing*. The type field parameters of `callrpc()` and `registerrpc()` can be a built-in procedure like `xdr_u_long()` in the previous example, or a user supplied one. XDR has these built-in type routines:

```
xdr_int()        xdr_u_int()        xdr_enum()
xdr_long()       xdr_u_long()       xdr_bool()
xdr_short()      xdr_u_short()      xdr_wrapstring()
xdr_char()       xdr_u_char()
```

Note that the routine `xdr_string()` exists, but cannot be used with `callrpc()` and `registerrpc()`, which only pass two parameters to their XDR routines. `xdr_wrapstring()` has only two parameters, and is thus OK. It calls `xdr_string()`.

As an example of a user-defined type routine, if you wanted to send the structure

```
struct simple {
    int a;
    short b;
} simple;
```

then you would call `callrpc()` as

```
callrpc(hostname, PROGNUM, VERSNUM, PROCNUM,
        xdr_simple, &simple ...);
```

where `xdr_simple()` is written as:

```
#include <rpc/rpc.h>

xdr_simple(xdrsp, simplep)
    XDR *xdrsp;
    struct simple *simplep;
{
    if (!xdr_int(xdrsp, &simplep->a))
        return (0);
    if (!xdr_short(xdrsp, &simplep->b))
        return (0);
    return (1);
}
```

An XDR routine returns nonzero (true in the sense of C) if it completes successfully, and zero otherwise. A complete description of XDR is in the *XDR Protocol Specification* section of this manual, only few implementation examples are given here.

In addition to the built-in primitives, there are also the prefabricated building blocks:

```
xdr_array()         xdr_bytes()         xdr_reference()
xdr_vector()        xdr_union()         xdr_pointer()
xdr_string()        xdr_opaque()
```

To send a variable array of integers, you might package them up as a structure like this

```
struct varintarr {
    int *data;
    int arrlnth;
} arr;
```

and make an RPC call such as

```
callrpc(hostname, PROGNUM, VERSNUM, PROCNUM,
        xdr_varintarr, &arr...);
```

with `xdr_varintarr()` defined as:

```
xdr_varintarr(xdrsp, arrp)
	XDR *xdrsp;
	struct varintarr *arrp;
{
	return (xdr_array(xdrsp, &arrp->data, &arrp->arrlnth,
		MAXLEN, sizeof(int), xdr_int));
}
```

This routine takes as parameters the XDR handle, a pointer to the array, a pointer to the size of the array, the maximum allowable array size, the size of each array element, and an XDR routine for handling each array element.

If the size of the array is known in advance, one can use `xdr_vector()`, which serializes fixed-length arrays.

```
int intarr[SIZE];

xdr_intarr(xdrsp, intarr)
	XDR *xdrsp;
	int intarr[];
{
	int i;

	return (xdr_vector(xdrsp, intarr, SIZE, sizeof(int),
		xdr_int));
}
```

XDR always converts quantities to 4-byte multiples when serializing. Thus, if either of the examples above involved characters instead of integers, each character would occupy 32 bits. That is the reason for the XDR routine `xdr_bytes()`, which is like `xdr_array()` except that it packs characters; `xdr_bytes()` has four parameters, similar to the first four parameters of `xdr_array()`. For null-terminated strings, there is also the `xdr_string()` routine, which is the same as `xdr_bytes()` without the length parameter. On serializing it gets the string length from `strlen()`, and on deserializing it creates a null-terminated string.

Here is a final example that calls the previously written `xdr_simple()` as well as the built-in functions `xdr_string()` and `xdr_reference()`, which chases pointers:

```
struct finalexample {
    char *string;
    struct simple *simplep;
} finalexample;

xdr_finalexample(xdrsp, finalp)
    XDR *xdrsp;
    struct finalexample *finalp;
{

    if (!xdr_string(xdrsp, &finalp->string, MAXSTRLEN))
        return (0);
    if (!xdr_reference(xdrsp, &finalp->simplep,
      sizeof(struct simple), xdr_simple);
        return (0);
    return (1);
}
```

Note that we could as easily call `xdr_simple()` here instead of `xdr_reference()`.

3.2. Lowest Layer of RPC

In the examples given so far, RPC takes care of many details automatically for you. In this section, we'll show you how you can change the defaults by using lower layers of the RPC library. It is assumed that you are familiar with sockets and the system calls for dealing with them. If not, consult the *IPC Primer* section of this manual.

There are several occasions when you may need to use lower layers of RPC. First, you may need to use TCP, since the higher layer uses UDP, which restricts RPC calls to 8K bytes of data. Using TCP permits calls to send long streams of data. For an example, see the *TCP* section below. Second, you may want to allocate and free memory while serializing or deserializing with XDR routines. There is no call at the higher level to let you free memory explicitly. For more explanation, see the *Memory Allocation with XDR* section below. Third, you may need to perform authentication on either the client or server side, by supplying credentials or verifying them. See the explanation in the *Authentication* section below.

More on the Server Side

The server for the `nusers()` program shown below does the same thing as the one using `registerrpc()` above, but is written using a lower layer of the RPC package:

```
#include <stdio.h>
#include <rpc/rpc.h>
#include <utmp.h>
#include <rpcsvc/rusers.h>

main()
{
    SVCXPRT *transp;
```

```
    int nuser();

    transp = svcudp_create(RPC_ANYSOCK);
    if (transp == NULL){
        fprintf(stderr, "can't create an RPC server\n");
        exit(1);
    }
    pmap_unset(RUSERSPROG, RUSERSVERS);
    if (!svc_register(transp, RUSERSPROG, RUSERSVERS,
              nuser, IPPROTO_UDP)) {
        fprintf(stderr, "can't register RUSER service\n");
        exit(1);
    }
    svc_run();   /* Never returns */
    fprintf(stderr, "should never reach this point\n");
}

nuser(rqstp, transp)
    struct svc_req *rqstp;
    SVCXPRT *transp;
{
    unsigned long nusers;

    switch (rqstp->rq_proc) {
    case NULLPROC:
        if (!svc_sendreply(transp, xdr_void, 0))
            fprintf(stderr, "can't reply to RPC call\n");
        return;
    case RUSERSPROC_NUM:
        /*
         * Code here to compute the number of users
         * and assign it to the variable nusers
         */
        if (!svc_sendreply(transp, xdr_u_long, &nusers))
            fprintf(stderr, "can't reply to RPC call\n");
        return;
    default:
        svcerr_noproc(transp);
        return;
    }
}
```

First, the server gets a transport handle, which is used for receiving and replying to RPC messages. `registerrpc()` uses `svcudp_create()` to get a UDP handle. If you require a more reliable protocol, call `svctcp_create()` instead. If the argument to `svcudp_create()` is `RPC_ANYSOCK`, the RPC library creates a socket on which to receive and reply to RPC calls. Otherwise, `svcudp_create()` expects its argument to be a valid socket number. If you specify your own socket, it can be bound or unbound. If it is bound to a port by the user, the port numbers of `svcudp_create()` and `clnttcp_create()` (the low-level client routine) must match.

If the user specifies the RPC_ANYSOCK argument, the RPC library routines will open sockets. Otherwise they will expect the user to do so. The routines svcudp_create() and clntudp_create() will cause the RPC library routines to bind() their socket if it is not bound already.

A service may choose to register its port number with the local portmapper service. This is done is done by specifying a non-zero protocol number in svc_register(). Incidently, a client can discover the server's port number by consulting the portmapper on their server's machine. This can be done automatically by specifying a zero port number in clntudp_create() or clnttcp_create().

After creating an SVCXPRT, the next step is to call pmap_unset() so that if the nusers() server crashed earlier, any previous trace of it is erased before restarting. More precisely, pmap_unset() erases the entry for RUSERSPROG from the port mapper's tables.

Finally, we associate the program number for nusers() with the procedure nuser(). The final argument to svc_register() is normally the protocol being used, which, in this case, is IPPROTO_UDP. Notice that unlike registerrpc(), there are no XDR routines involved in the registration process. Also, registration is done on the program, rather than procedure, level.

The user routine nuser() must call and dispatch the appropriate XDR routines based on the procedure number. Note that two things are handled by nuser() that registerrpc() handles automatically. The first is that procedure NULLPROC (currently zero) returns with no results. This can be used as a simple test for detecting if a remote program is running. Second, there is a check for invalid procedure numbers. If one is detected, svcerr_noproc() is called to handle the error.

The user service routine serializes the results and returns them to the RPC caller via svc_sendreply(). Its first parameter is the SVCXPRT handle, the second is the XDR routine, and the third is a pointer to the data to be returned. Not illustrated above is how a server handles an RPC program that receives data. As an example, we can add a procedure RUSERSPROC_BOOL, which has an argument nusers(), and returns TRUE or FALSE depending on whether there are nusers logged on. It would look like this:

```
case RUSERSPROC_BOOL: {
    int bool;
    unsigned nuserquery;

    if (!svc_getargs(transp, xdr_u_int, &nuserquery) {
        svcerr_decode(transp);
        return;
    }
    /*
     * Code to set nusers = number of users
     */
    if (nuserquery == nusers)
        bool = TRUE;
```

```
    else
        bool = FALSE;
    if (!svc_sendreply(transp, xdr_bool, &bool)) {
        fprintf(stderr, "can't reply to RPC call\n");
        return (1);
    }
    return;
}
```

The relevant routine is `svc_getargs()`, which takes an `SVCXPRT` handle, the XDR routine, and a pointer to where the input is to be placed as arguments.

Memory Allocation with XDR

XDR routines not only do input and output, they also do memory allocation. This is why the second parameter of `xdr_array()` is a pointer to an array, rather than the array itself. If it is `NULL`, then `xdr_array()` allocates space for the array and returns a pointer to it, putting the size of the array in the third argument. As an example, consider the following XDR routine `xdr_chararr1()`, which deals with a fixed array of bytes with length `SIZE`:

```
xdr_chararr1(xdrsp, chararr)
    XDR *xdrsp;
    char chararr[];
{
    char *p;
    int len;

    p = chararr;
    len = SIZE;
    return (xdr_bytes(xdrsp, &p, &len, SIZE));
}
```

If space has already been allocated in *chararr*, it can be called from a server like this:

```
char chararr[SIZE];

svc_getargs(transp, xdr_chararr1, chararr);
```

If you want XDR to do the allocation, you would have to rewrite this routine in the following way:

```
xdr_chararr2(xdrsp, chararrp)
    XDR *xdrsp;
    char **chararrp;
{
    int len;

    len = SIZE;
    return (xdr_bytes(xdrsp, charrarrp, &len, SIZE));
}
```

Then the RPC call might look like this:

```
char *arrptr;

arrptr = NULL;
svc_getargs(transp, xdr_chararr2, &arrptr);
/*
 * Use the result here
 */
svc_freeargs(transp, xdr_chararr2, &arrptr);
```

Note that, after being used, the character array can be freed with `svc_freeargs()`. `svc_freeargs()` will not attempt to free any memory if the variable indicating it is NULL. For example, in the the routine `xdr_finalexample()`, given earlier, if `finalp->string` was NULL, then it would not be freed. The same is true for `finalp->simplep`.

To summarize, each XDR routine is responsible for serializing, deserializing, and freeing memory. When an XDR routine is called from `callrpc()`, the serializing part is used. When called from `svc_getargs()`, the deserializer is used. And when called from `svc_freeargs()`, the memory deallocator is used. When building simple examples like those in this section, a user doesn't have to worry about the three modes. See the *External Data Representation: Sun Technical Notes* chapter for examples of more sophisticated XDR routines that determine which of the three modes they are in and adjust their behavior accordingly.

The Calling Side

When you use `callrpc()`, you have no control over the RPC delivery mechanism or the socket used to transport the data. To illustrate the layer of RPC that lets you adjust these parameters, consider the following code to call the `nusers` service:

```
#include <stdio.h>
#include <rpc/rpc.h>
#include <utmp.h>
#include <rpcsvc/rusers.h>
#include <sys/socket.h>
#include <sys/time.h>
#include <netdb.h>

main(argc, argv)
```

```
	int argc;
	char **argv;
{
	struct hostent *hp;
	struct timeval pertry_timeout, total_timeout;
	struct sockaddr_in server_addr;
	int sock = RPC_ANYSOCK;
	register CLIENT *client;
	enum clnt_stat clnt_stat;
	unsigned long nusers;

	if (argc != 2) {
		fprintf(stderr, "usage: nusers hostname\n");
		exit(-1);
	}
	if ((hp = gethostbyname(argv[1])) == NULL) {
		fprintf(stderr, "can't get addr for %s\n",argv[1]);
		exit(-1);
	}
	pertry_timeout.tv_sec = 3;
	pertry_timeout.tv_usec = 0;
	bcopy(hp->h_addr, (caddr_t)&server_addr.sin_addr,
		hp->h_length);
	server_addr.sin_family = AF_INET;
	server_addr.sin_port =  0;
	if ((client = clntudp_create(&server_addr, RUSERSPROG,
	  RUSERSVERS, pertry_timeout, &sock)) == NULL) {
		clnt_pcreateerror("clntudp_create");
		exit(-1);
	}
	total_timeout.tv_sec = 20;
	total_timeout.tv_usec = 0;
	clnt_stat = clnt_call(client, RUSERSPROC_NUM, xdr_void,
		0, xdr_u_long, &nusers, total_timeout);
	if (clnt_stat != RPC_SUCCESS) {
		clnt_perror(client, "rpc");
		exit(-1);
	}
	clnt_destroy(client);
	close(sock);
	exit(0);
}
```

The low-level version of `callrpc()` is `clnt_call()`, which takes a `CLIENT` pointer rather than a host name. The parameters to `clnt_call()` are a `CLIENT` pointer, the procedure number, the XDR routine for serializing the argument, a pointer to the argument, the XDR routine for deserializing the return value, a pointer to where the return value will be placed, and the time in seconds to wait for a reply.

The `CLIENT` pointer is encoded with the transport mechanism. `callrpc()` uses UDP, thus it calls `clntudp_create()` to get a `CLIENT` pointer. To get

TCP (Transmission Control Protocol), you would use `clnttcp_create()`.

The parameters to `clntudp_create()` are the server address, the program number, the version number, a timeout value (between tries), and a pointer to a socket. The final argument to `clnt_call()` is the total time to wait for a response. Thus, the number of tries is the `clnt_call()` timeout divided by the `clntudp_create()` timeout.

Note that the `clnt_destroy()` call always deallocates the space associated with the `CLIENT` handle. It closes the socket associated with the `CLIENT` handle, however, only if the RPC library opened it. It the socket was opened by the user, it stays open. This makes it possible, in cases where there are multiple client handles using the same socket, to destroy one handle without closing the socket that other handles are using.

To make a stream connection, the call to `clntudp_create()` is replaced with a call to `clnttcp_create()`.

```
clnttcp_create(&server_addr, prognum, versnum, &sock,
               inputsize, outputsize);
```

There is no timeout argument; instead, the receive and send buffer sizes must be specified. When the `clnttcp_create()` call is made, a TCP connection is established. All RPC calls using that `CLIENT` handle would use this connection. The server side of an RPC call using TCP has `svcudp_create()` replaced by `svctcp_create()`.

```
transp = svctcp_create(RPC_ANYSOCK, 0, 0);
```

The last two arguments to `svctcp_create()` are send and receive sizes respectively. If '0' is specified for either of these, the system chooses a reasonable default.

3.3. Other RPC Features

This section discusses some other aspects of RPC that are occasionally useful.

Select on the Server Side

Suppose a process is processing RPC requests while performing some other activity. If the other activity involves periodically updating a data structure, the process can set an alarm signal before calling `svc_run()`. But if the other activity involves waiting on a a file descriptor, the `svc_run()` call won't work. The code for `svc_run()` is as follows:

```
void
svc_run()
{
    fd_set readfds;
    int dtbsz = getdtablesize();

    for (;;) {
        readfds = svc_fds;
        switch (select(dtbsz, &readfds, NULL,NULL,NULL)) {
```

```
            case -1:
                if (errno == EINTR)
                    continue;
                perror("select");
                return;
            case 0:
                break;
            default:
                svc_getreqset(&readfds);
            }
        }
}
```

You can bypass `svc_run()` and call `svc_getreqset()` yourself. All you need to know are the file descriptors of the socket(s) associated with the programs you are waiting on. Thus you can have your own `select()` that waits on both the RPC socket, and your own descriptors. Note that `svc_fds()` is a bit mask of all the file descriptors that RPC is using for services. It can change everytime that *any* RPC library routine is called, because descriptors are constantly being opened and closed, for example for TCP connections.

Broadcast RPC

The *portmapper* is a daemon that converts RPC program numbers into DARPA protocol port numbers; see the `portmap` man page. You can't do broadcast RPC without the portmapper. Here are the main differences between broadcast RPC and normal RPC calls:

1. Normal RPC expects one answer, whereas broadcast RPC expects many answers (one or more answer from each responding machine).
2. Broadcast RPC can only be supported by packet-oriented (connectionless) transport protocols like UPD/IP.
3. The implementation of broadcast RPC treats all unsuccessful responses as garbage by filtering them out. Thus, if there is a version mismatch between the broadcaster and a remote service, the user of broadcast RPC never knows.
4. All broadcast messages are sent to the portmap port. Thus, only services that register themselves with their portmapper are accessible via the broadcast RPC mechanism.
5. Broadcast requests are limited in size to the MTU (Maximum Transfer Unit) of the local network. For Ethernet, the MTU is 1500 bytes.

Broadcast RPC Synopsis

```
#include <rpc/pmap_clnt.h>
    . . .
enum clnt_stat  clnt_stat;
    . . .
clnt_stat = clnt_broadcast(prognum, versnum, procnum,
  inproc, in, outproc, out, eachresult)
    u_long     prognum;         /* program number */
    u_long     versnum;         /* version number */
    u_long     procnum;         /* procedure number */
    xdrproc_t  inproc;          /* xdr routine for args */
    caddr_t    in;              /* pointer to args */
    xdrproc_t  outproc;         /* xdr routine for results */
    caddr_t    out;             /* pointer to results */
    bool_t     (*eachresult)(); /* call with each result gotten */
```

The procedure `eachresult()` is called each time a valid result is obtained. It returns a boolean that indicates whether or not the user wants more responses.

```
bool_t done;
    . . .
done = eachresult(resultsp, raddr)
    caddr_t resultsp;
    struct sockaddr_in *raddr; /* Addr of responding machine */
```

If *done* is `TRUE`, then broadcasting stops and `clnt_broadcast()` returns successfully. Otherwise, the routine waits for another response. The request is rebroadcast after a few seconds of waiting. If no responses come back, the routine returns with `RPC_TIMEDOUT`.

Batching

The RPC architecture is designed so that clients send a call message, and wait for servers to reply that the call succeeded. This implies that clients do not compute while servers are processing a call. This is inefficient if the client does not want or need an acknowledgement for every message sent. It is possible for clients to continue computing while waiting for a response, using RPC batch facilities.

RPC messages can be placed in a "pipeline" of calls to a desired server; this is called batching. Batching assumes that: 1) each RPC call in the pipeline requires no response from the server, and the server does not send a response message; and 2) the pipeline of calls is transported on a reliable byte stream transport such as TCP/IP. Since the server does not respond to every call, the client can generate new calls in parallel with the server executing previous calls. Furthermore, the TCP/IP implementation can buffer up many call messages, and send them to the server in one `write()` system call. This overlapped execution greatly decreases the interprocess communication overhead of the client and server processes, and the total elapsed time of a series of calls.

Since the batched calls are buffered, the client should eventually do a nonbatched call in order to flush the pipeline.

A contrived example of batching follows. Assume a string rendering service (like a window system) has two similar calls: one renders a string and returns void results, while the other renders a string and remains silent. The service (using the TCP/IP transport) may look like:

```
#include <stdio.h>
#include <rpc/rpc.h>
#include <suntool/windows.h>

void windowdispatch();

main()
{
    SVCXPRT *transp;

    transp = svctcp_create(RPC_ANYSOCK, 0, 0);
    if (transp == NULL){
        fprintf(stderr, "can't create an RPC server\n");
        exit(1);
    }
    pmap_unset(WINDOWPROG, WINDOWVERS);
    if (!svc_register(transp, WINDOWPROG, WINDOWVERS,
      windowdispatch, IPPROTO_TCP)) {
        fprintf(stderr, "can't register WINDOW service\n");
        exit(1);
    }
    svc_run();  /* Never returns */
    fprintf(stderr, "should never reach this point\n");
}

void
windowdispatch(rqstp, transp)
    struct svc_req *rqstp;
    SVCXPRT *transp;
{
    char *s = NULL;

    switch (rqstp->rq_proc) {
    case NULLPROC:
        if (!svc_sendreply(transp, xdr_void, 0))
            fprintf(stderr, "can't reply to RPC call\n");
        return;
    case RENDERSTRING:
        if (!svc_getargs(transp, xdr_wrapstring, &s)) {
            fprintf(stderr, "can't decode arguments\n");
            /*
             * Tell caller he screwed up
             */
            svcerr_decode(transp);
            break;
        }
        /*
         * Code here to render the string s
```

```
         */
        if (!svc_sendreply(transp, xdr_void, NULL))
            fprintf(stderr, "can't reply to RPC call\n");
        break;
    case RENDERSTRING_BATCHED:
        if (!svc_getargs(transp, xdr_wrapstring, &s)) {
            fprintf(stderr, "can't decode arguments\n");
            /*
             * We are silent in the face of protocol errors
             */
            break;
        }
        /*
         * Code here to render string s, but send no reply!
         */
        break;
    default:
        svcerr_noproc(transp);
        return;
    }
    /*
     * Now free string allocated while decoding arguments
     */
    svc_freeargs(transp, xdr_wrapstring, &s);
}
```

Of course the service could have one procedure that takes the string and a boolean to indicate whether or not the procedure should respond.

In order for a client to take advantage of batching, the client must perform RPC calls on a TCP-based transport and the actual calls must have the following attributes: 1) the result's XDR routine must be zero (`NULL`), and 2) the RPC call's timeout must be zero.

Here is an example of a client that uses batching to render a bunch of strings; the batching is flushed when the client gets a null string (EOF):

```
#include <stdio.h>
#include <rpc/rpc.h>
#include <sys/socket.h>
#include <sys/time.h>
#include <netdb.h>
#include <suntool/windows.h>

main(argc, argv)
    int argc;
    char **argv;
{
    struct hostent *hp;
    struct timeval pertry_timeout, total_timeout;
    struct sockaddr_in server_addr;
    int sock = RPC_ANYSOCK;
    register CLIENT *client;
```

```
    enum clnt_stat clnt_stat;
    char buf[1000], *s = buf;

    if ((client = clnttcp_create(&server_addr,
      WINDOWPROG, WINDOWVERS, &sock, 0, 0)) == NULL) {
        perror("clnttcp_create");
        exit(-1);
    }
    total_timeout.tv_sec = 0;
    total_timeout.tv_usec = 0;
    while (scanf("%s", s) != EOF) {
        clnt_stat = clnt_call(client, RENDERSTRING_BATCHED,
            xdr_wrapstring, &s, NULL, NULL, total_timeout);
        if (clnt_stat != RPC_SUCCESS) {
            clnt_perror(client, "batched rpc");
            exit(-1);
        }
    }

    /* Now flush the pipeline */

    total_timeout.tv_sec = 20;
    clnt_stat = clnt_call(client, NULLPROC, xdr_void, NULL,
        xdr_void, NULL, total_timeout);
    if (clnt_stat != RPC_SUCCESS) {
        clnt_perror(client, "rpc");
        exit(-1);
    }
    clnt_destroy(client);
    exit(0);
}
```

Since the server sends no message, the clients cannot be notified of any of the failures that may occur. Therefore, clients are on their own when it comes to handling errors.

The above example was completed to render all of the (2000) lines in the file */etc/termcap*. The rendering service did nothing but throw the lines away. The example was run in the following four configurations: 1) machine to itself, regular RPC; 2) machine to itself, batched RPC; 3) machine to another, regular RPC; and 4) machine to another, batched RPC. The results are as follows: 1) 50 seconds; 2) 16 seconds; 3) 52 seconds; 4) 10 seconds. Running `fscanf()` on `/etc/termcap` only requires six seconds. These timings show the advantage of protocols that allow for overlapped execution, though these protocols are often hard to design.

Authentication

In the examples presented so far, the caller never identified itself to the server, and the server never required an ID from the caller. Clearly, some network services, such as a network filesystem, require stronger security than what has been presented so far.

In reality, every RPC call is authenticated by the RPC package on the server, and similarly, the RPC client package generates and sends authentication parameters. Just as different transports (TCP/IP or UDP/IP) can be used when creating RPC clients and servers, different forms of authentication can be associated with RPC clients; the default authentication type used as a default is type *none*.

The authentication subsystem of the RPC package is open ended. That is, numerous types of authentication are easy to support.

UNIX Authentication

The Client Side

When a caller creates a new RPC client handle as in:

```
clnt = clntudp_create(address, prognum, versnum,
             wait, sockp)
```

the appropriate transport instance defaults the associate authentication handle to be

```
clnt->cl_auth = authnone_create();
```

The RPC client can choose to use *UNIX* style authentication by setting `clnt->cl_auth` after creating the RPC client handle:

```
clnt->cl_auth = authunix_create_default();
```

This causes each RPC call associated with *clnt* to carry with it the following authentication credentials structure:

```
/*
 * UNIX style credentials.
 */
struct authunix_parms {
    u_long  aup_time;       /* credentials creation time */
    char    *aup_machname;  /* host name where client is */
    int     aup_uid;        /* client's UNIX effective uid */
    int     aup_gid;        /* client's current group id */
    u_int   aup_len;        /* element length of aup_gids */
    int     *aup_gids;      /* array of groups user is in */
};
```

These fields are set by `authunix_create_default()` by invoking the appropriate system calls. Since the RPC user created this new style of authentication, the user is responsible for destroying it with:

```
auth_destroy(clnt->cl_auth);
```

This should be done in all cases, to conserve memory.

The Server Side

Service implementors have a harder time dealing with authentication issues since the RPC package passes the service dispatch routine a request that has an arbitrary authentication style associated with it. Consider the fields of a request handle passed to a service dispatch routine:

```
/*
 * An RPC Service request
 */
struct svc_req {
    u_long   rq_prog;                 /* service program number */
    u_long   rq_vers;                 /* service protocol vers num */
    u_long   rq_proc;                 /* desired procedure number */
    struct opaque_auth rq_cred;       /* raw credentials from wire */
    caddr_t rq_clntcred;              /* credentials (read only) */
};
```

The `rq_cred` is mostly opaque, except for one field of interest: the style or flavor of authentication credentials:

```
/*
 * Authentication info. Mostly opaque to the programmer.
 */
struct opaque_auth {
    enum_t   oa_flavor;   /* style of credentials */
    caddr_t oa_base;      /* address of more auth stuff */
    u_int    oa_length;   /* not to exceed MAX_AUTH_BYTES */
};
```

The RPC package guarantees the following to the service dispatch routine:

1. That the request's `rq_cred` is well formed. Thus the service implementor may inspect the request's `rq_cred.oa_flavor` to determine which style of authentication the caller used. The service implementor may also wish to inspect the other fields of `rq_cred` if the style is not one of the styles supported by the RPC package.

2. That the request's `rq_clntcred` field is either `NULL` or points to a well formed structure that corresponds to a supported style of authentication credentials. Remember that only *unix* style is currently supported, so (currently) `rq_clntcred` could be cast to a pointer to an `authunix_parms` structure. If `rq_clntcred` is `NULL`, the service implementor may wish to inspect the other (opaque) fields of `rq_cred` in case the service knows about a new type of authentication that the RPC package does not know about.

Our remote users service example can be extended so that it computes results for all users except UID 16:

```
nuser(rqstp, transp)
    struct svc_req *rqstp;
    SVCXPRT *transp;
{
    struct authunix_parms *unix_cred;
    int uid;
    unsigned long nusers;

    /*
     * we don't care about authentication for null proc
     */
    if (rqstp->rq_proc == NULLPROC) {
        if (!svc_sendreply(transp, xdr_void, 0)) {
            fprintf(stderr, "can't reply to RPC call\n");
            return (1);
        }
        return;
    }
    /*
     * now get the uid
     */
    switch (rqstp->rq_cred.oa_flavor) {
    case AUTH_UNIX:
        unix_cred =
            (struct authunix_parms *)rqstp->rq_clntcred;
        uid = unix_cred->aup_uid;
        break;
    case AUTH_NULL:
    default:
        svcerr_weakauth(transp);
        return;
    }
    switch (rqstp->rq_proc) {
    case RUSERSPROC_NUM:
        /*
         * make sure caller is allowed to call this proc
         */
        if (uid == 16) {
            svcerr_systemerr(transp);
            return;
        }
        /*
         * Code here to compute the number of users
         * and assign it to the variable nusers
         */
        if (!svc_sendreply(transp, xdr_u_long, &nusers)) {
            fprintf(stderr, "can't reply to RPC call\n");
            return (1);
        }
        return;
    default:
```

```
        svcerr_noproc(transp);
        return;
    }
}
```

A few things should be noted here. First, it is customary not to check the authentication parameters associated with the NULLPROC (procedure number zero). Second, if the authentication parameter's type is not suitable for your service, you should call svcerr_weakauth(). And finally, the service protocol itself should return status for access denied; in the case of our example, the protocol does not have such a status, so we call the service primitive svcerr_systemerr() instead.

The last point underscores the relation between the RPC authentication package and the services; RPC deals only with *authentication* and not with individual services' *access control.* The services themselves must implement their own access control policies and reflect these policies as return statuses in their protocols.

DES Authentication

UNIX authentication is quite easy to defeat. Instead of using authunix_create_default(), one can call authunix_create() and then modify the RPC authentication handle it returns by filling in whatever user ID and hostname they wish the server to think they have. DES authentication is thus recommended for people who want more security than UNIX authentication offers.

The details of the DES authentication protocol are complicated and are not explained here. See the *Remote Procedure Calls: Protocol Specification* section for the details.

In order for DES authentication to work, the keyserv(8c) daemon must be running on both the server and client machines. The users on these machines need public keys assigned by the network administrator in the publickey(5) database. And, they need to have decrypted their secret keys using their login password. This automatically happens when one logs in using login(1), or can be done manually using keylogin(1). The *Network Services* chapter of *Network Programming* explains more how to setup secure networking.

Client Side

If a client wishes to use DES authentication, it must set its authentication handle appropriately. Here is an example:

```
cl->cl_auth =
    authdes_create(servername, 60, &server_addr, NULL);
```

The first argument is the network name or "netname" of the owner of the server process. Typically, server processes are root processes and their netname can be derived using the following call:

```
char servername[MAXNETNAMELEN];

host2netname(servername, rhostname, NULL);
```

Here, *rhostname* is the hostname of the machine the server process is running on. `host2netname()` fills in *servername* to contain this root process's netname. If the server process was run by a regular user, one could use the call `user2netname()` instead. Here is an example for a server process with the same user ID as the client:

```
char servername[MAXNETNAMELEN];

user2netname(servername, getuid(), NULL);
```

The last argument to both of these calls, `user2netname()` and `host2netname()`, is the name of the naming domain where the server is located. The `NULL` used here means "use the local domain name."

The second argument to `authdes_create()` is a lifetime for the credential. Here it is set to sixty seconds. What that means is that the credential will expire 60 seconds from now. If some mischievous user tries to reuse the credential, the server RPC subsystem will recognize that it has expired and not grant any requests. If the same mischievous user tries to reuse the credential within the sixty second lifetime, he will still be rejected because the server RPC subsystem remembers which credentials it has already seen in the near past, and will not grant requests to duplicates.

The third argument to `authdes_create()` is the address of the host to synchronize with. In order for DES authentication to work, the server and client must agree upon the time. Here we pass the address of the server itself, so the client and server will both be using the same time: the server's time. The argument can be `NULL`, which means "don't bother synchronizing." You should only do this if you are sure the client and server are already synchronized.

The final argument to `authdes_create()` is the address of a DES encryption key to use for encrypting timestamps and data. If this argument is `NULL`, as it is in this example, a random key will be chosen. The client may find out the encryption key being used by consulting the `ah_key` field of the authentication handle.

Server Side

The server side is a lot simpler than the client side. Here is the previous example rewritten to use `AUTH_DES` instead of `AUTH_UNIX`:

```
#include <sys/time.h>
#include <rpc/auth_des.h>
    . . .
    . . .
nuser(rqstp, transp)
```

```
    struct svc_req *rqstp;
    SVCXPRT *transp;
{
    struct authdes_cred *des_cred;
    int uid;
    int gid;
    int gidlen;
    int gidlist[10];
    /*
     * we don't care about authentication for null proc
     */

    if (rqstp->rq_proc == NULLPROC) { /*
        same as before */
    }

    /*
     * now get the uid
     */
    switch (rqstp->rq_cred.oa_flavor) {
    case AUTH_DES:
        des_cred =
            (struct authdes_cred *) rqstp->rq_clntcred;
        if (! netname2user(des_cred->adc_fullname.name,
            &uid, &gid, &gidlen, gidlist))
        {
            fprintf(stderr, "unknown user: %s0,
                des_cred->adc_fullname.name);
            svcerr_systemerr(transp);
            return;
        }
        break;
    case AUTH_NULL:
    default:
        svcerr_weakauth(transp);
        return;
    }

    /*
     * The rest is the same as before
     */
```

Note the use of the routine `netname2user()`, the inverse of `netname2user()`: it takes a network ID and converts to a unix ID. `netname2user()` also supplies the group IDs which we don't use in this example, but which may be useful to other UNIX programs.

Using Inetd

An RPC server can be started from `inetd`. The only difference from the usual code is that the service creation routine should be called in the following form:

```
transp = svcudp_create(0);      /* For UDP */
transp = svctcp_create(0,0,0); /* For listener TCP sockets */
transp = svcfd_create(0,0,0);  /* For connected TCP sockets */
```

since `inet` passes a socket as file descriptor 0. Also, `svc_register()` should be called as

```
svc_register(transp, PROGNUM, VERSNUM, service, 0);
```

with the final flag as 0, since the program would already be registered by `inetd`. Remember that if you want to exit from the server process and return control to `inet`, you need to explicitly exit, since `svc_run()` never returns.

The format of entries in `/etc/inetd.conf` for RPC services is in one of the following two forms:

```
p_name/version dgram  rpc/udp wait/nowait user server args
p_name/version stream rpc/tcp wait/nowait user server args
```

where *p_name* is the symbolic name of the program as it appears in `rpc(5)`, *server* is the program implementing the server, and *program* and *version* are the program and version numbers of the service. For more information, see `inetd.conf(5)`.

If the same program handles multiple versions, then the version number can be a range, as in this example:

```
rstatd/1-2 dgram rpc/udp wait root /usr/etc/rpc.rstatd
```

3.4. More Examples

Versions

By convention, the first version number of program `PROG` is `PROGVERS_ORIG` and the most recent version is `PROGVERS`. Suppose there is a new version of the `user` program that returns an `unsigned short` rather than a `long`. If we name this version `RUSERSVERS_SHORT`, then a server that wants to support both versions would do a double register.

```
if (!svc_register(transp, RUSERSPROG, RUSERSVERS_ORIG,
  nuser, IPPROTO_TCP)) {
    fprintf(stderr, "can't register RUSER service\n");
    exit(1);
}
if (!svc_register(transp, RUSERSPROG, RUSERSVERS_SHORT,
  nuser, IPPROTO_TCP)) {
    fprintf(stderr, "can't register RUSER service\n");
    exit(1);
}
```

Both versions can be handled by the same C procedure:

```
nuser(rqstp, transp)
    struct svc_req *rqstp;
    SVCXPRT *transp;
{
    unsigned long nusers;
    unsigned short nusers2;

    switch (rqstp->rq_proc) {
    case NULLPROC:
        if (!svc_sendreply(transp, xdr_void, 0)) {
            fprintf(stderr, "can't reply to RPC call\n");
            return (1);
        }
        return;
    case RUSERSPROC_NUM:
    /*
     * Code here to compute the number of users
     * and assign it to the variable nusers
     */
        nusers2 = nusers;
        switch (rqstp->rq_vers) {
        case RUSERSVERS_ORIG:
            if (!svc_sendreply(transp, xdr_u_long,
            &nusers)) {
                fprintf(stderr,"can't reply to RPC call\n");
            }
            break;
        case RUSERSVERS_SHORT:
            if (!svc_sendreply(transp, xdr_u_short,
            &nusers2)) {
                fprintf(stderr,"can't reply to RPC call\n");
            }
            break;
        }
    default:
        svcerr_noproc(transp);
        return;
    }
}
```

TCP

Here is an example that is essentially `rcp`. The initiator of the RPC `snd` call takes its standard input and sends it to the server `rcv`, which prints it on standard output. The RPC call uses TCP. This also illustrates an XDR procedure that behaves differently on serialization than on deserialization.

```
/*
 * The xdr routine:
 *          on decode, read from wire, write onto fp
 *          on encode, read from fp, write onto wire
```

```
*/
#include <stdio.h>
#include <rpc/rpc.h>

xdr_rcp(xdrs, fp)
    XDR *xdrs;
    FILE *fp;
{
    unsigned long size;
    char buf[BUFSIZ], *p;

    if (xdrs->x_op == XDR_FREE)/* nothing to free */
        return 1;
    while (1) {
        if (xdrs->x_op == XDR_ENCODE) {
            if ((size = fread(buf, sizeof(char), BUFSIZ,
              fp)) == 0 && ferror(fp)) {
                fprintf(stderr, "can't fread\n");
                return (1);
            }
        }
        p = buf;
        if (!xdr_bytes(xdrs, &p, &size, BUFSIZ))
            return 0;
        if (size == 0)
            return 1;
        if (xdrs->x_op == XDR_DECODE) {
            if (fwrite(buf, sizeof(char), size,
              fp) != size) {
                fprintf(stderr, "can't fwrite\n");
                return (1);
            }
        }
    }
}
```

```
/*
 * The sender routines
 */
#include <stdio.h>
#include <netdb.h>
#include <rpc/rpc.h>
#include <sys/socket.h>
#include <sys/time.h>

main(argc, argv)
    int argc;
    char **argv;
{
    int xdr_rcp();
    int err;
```

```
    if (argc < 2) {
        fprintf(stderr, "usage: %s servername\n", argv[0]);
        exit(-1);
    }
    if ((err = callrpctcp(argv[1], RCPPROG, RCPPROC,
      RCPVERS, xdr_rcp, stdin, xdr_void, 0) != 0)) {
        clnt_perrno(err);
        fprintf(stderr, "can't make RPC call\n");
        exit(1);
    }
    exit(0);
}

callrpctcp(host, prognum, procnum, versnum,
            inproc, in, outproc, out)
    char *host, *in, *out;
    xdrproc_t inproc, outproc;
{
    struct sockaddr_in server_addr;
    int socket = RPC_ANYSOCK;
    enum clnt_stat clnt_stat;
    struct hostent *hp;
    register CLIENT *client;
    struct timeval total_timeout;

    if ((hp = gethostbyname(host)) == NULL) {
        fprintf(stderr, "can't get addr for '%s'\n", host);
        return (-1);
    }
    bcopy(hp->h_addr, (caddr_t)&server_addr.sin_addr,
        hp->h_length);
    server_addr.sin_family = AF_INET;
    server_addr.sin_port =  0;
    if ((client = clnttcp_create(&server_addr, prognum,
      versnum, &socket, BUFSIZ, BUFSIZ)) == NULL) {
        perror("rpctcp_create");
        return (-1);
    }
    total_timeout.tv_sec = 20;
    total_timeout.tv_usec = 0;
    clnt_stat = clnt_call(client, procnum,
        inproc, in, outproc, out, total_timeout);
    clnt_destroy(client);
    return (int)clnt_stat;
}
```

```
/*
 * The receiving routines
 */
#include <stdio.h>
#include <rpc/rpc.h>
```

```
main()
{
    register SVCXPRT *transp;
     int rcp_service(), xdr_rcp();

    if ((transp = svctcp_create(RPC_ANYSOCK,
      BUFSIZ, BUFSIZ)) == NULL) {
        fprintf("svctcp_create: error\n");
        exit(1);
    }
    pmap_unset(RCPPROG, RCPVERS);
    if (!svc_register(transp,
      RCPPROG, RCPVERS, rcp_service, IPPROTO_TCP)) {
        fprintf(stderr, "svc_register: error\n");
        exit(1);
    }
    svc_run();   /* never returns */
    fprintf(stderr, "svc_run should never return\n");
}

rcp_service(rqstp, transp)
    register struct svc_req *rqstp;
    register SVCXPRT *transp;
{
    switch (rqstp->rq_proc) {
    case NULLPROC:
        if (svc_sendreply(transp, xdr_void, 0) == 0) {
            fprintf(stderr, "err: rcp_service");
            return (1);
        }
        return;
    case RCPPROC_FP:
        if (!svc_getargs(transp, xdr_rcp, stdout)) {
            svcerr_decode(transp);
            return;
        }
        if (!svc_sendreply(transp, xdr_void, 0)) {
            fprintf(stderr, "can't reply\n");
            return;
        }
        return (0);
    default:
        svcerr_noproc(transp);
        return;
    }
}
```

Callback Procedures

Occasionally, it is useful to have a server become a client, and make an RPC call back to the process which is its client. An example is remote debugging, where the client is a window system program, and the server is a debugger running on the remote machine. Most of the time, the user clicks a mouse button at the debugging window, which converts this to a debugger command, and then makes an RPC call to the server (where the debugger is actually running), telling it to execute that command. However, when the debugger hits a breakpoint, the roles are reversed, and the debugger wants to make an rpc call to the window program, so that it can inform the user that a breakpoint has been reached.

In order to do an RPC callback, you need a program number to make the RPC call on. Since this will be a dynamically generated program number, it should be in the transient range, `0x40000000 - 0x5fffffff`. The routine `gettransient()` returns a valid program number in the transient range, and registers it with the portmapper. It only talks to the portmapper running on the same machine as the `gettransient()` routine itself. The call to `pmap_set()` is a test and set operation, in that it indivisibly tests whether a program number has already been registered, and if it has not, then reserves it. On return, the `sockp` argument will contain a socket that can be used as the argument to an `svcudp_create()` or `svctcp_create()` call.

```
#include <stdio.h>
#include <rpc/rpc.h>
#include <sys/socket.h>

gettransient(proto, vers, sockp)
    int proto, vers, *sockp;
{
    static int prognum = 0x40000000;
    int s, len, socktype;
    struct sockaddr_in addr;

    switch(proto) {
        case IPPROTO_UDP:
            socktype = SOCK_DGRAM;
            break;
        case IPPROTO_TCP:
            socktype = SOCK_STREAM;
            break;
        default:
            fprintf(stderr, "unknown protocol type\n");
            return 0;
    }
    if (*sockp == RPC_ANYSOCK) {
        if ((s = socket(AF_INET, socktype, 0)) < 0) {
            perror("socket");
            return (0);
        }
        *sockp = s;
    }
    else
        s = *sockp;
```

```
    addr.sin_addr.s_addr = 0;
    addr.sin_family = AF_INET;
    addr.sin_port = 0;
    len = sizeof(addr);
    /*
     * may be already bound, so don't check for error
     */
    bind(s, &addr, len);
    if (getsockname(s, &addr, &len)< 0) {
        perror("getsockname");
        return (0);
    }
    while (!pmap_set(prognum++, vers, proto,
        ntohs(addr.sin_port))) continue;
    return (prognum-1);
}
```

NOTE *The call to* `ntohs()` *is necessary to ensure that the port number in* `addr.sin_port`, *which is in network byte order, is passed in host byte order (as* `pmap_set()` *expects). This works on all Sun machines. See the* `byteorder(3N)` *man page for more details on the conversion of network addresses from network to host byte order.*

The following pair of programs illustrate how to use the `gettransient()` routine. The client makes an RPC call to the server, passing it a transient program number. Then the client waits around to receive a callback from the server at that program number. The server registers the program `EXAMPLEPROG`, so that it can receive the RPC call informing it of the callback program number. Then at some random time (on receiving an `ALRM` signal in this example), it sends a callback RPC call, using the program number it received earlier.

```
/*
 * client
 */
#include <stdio.h>
#include <rpc/rpc.h>

int callback();
char hostname[256];

main()
{
    int x, ans, s;
    SVCXPRT *xprt;

    gethostname(hostname, sizeof(hostname));
    s = RPC_ANYSOCK;
    x = gettransient(IPPROTO_UDP, 1, &s);
    fprintf(stderr, "client gets prognum %d\n", x);
    if ((xprt = svcudp_create(s)) == NULL) {
        fprintf(stderr, "rpc_server: svcudp_create\n");
        exit(1);
```

```
    }
    /* protocol is 0 - gettransient does registering */
    (void)svc_register(xprt, x, 1, callback, 0);
    ans = callrpc(hostname, EXAMPLEPROG, EXAMPLEVERS,
        EXAMPLEPROC_CALLBACK, xdr_int, &x, xdr_void, 0);
    if ((enum clnt_stat) ans != RPC_SUCCESS) {
        fprintf(stderr, "call: ");
        clnt_perrno(ans);
        fprintf(stderr, "\n");
    }
    svc_run();
    fprintf(stderr, "Error: svc_run shouldn't return\n");
}

callback(rqstp, transp)
    register struct svc_req *rqstp;
    register SVCXPRT *transp;
{
    switch (rqstp->rq_proc) {
        case 0:
            if (!svc_sendreply(transp, xdr_void, 0)) {
                fprintf(stderr, "err: exampleprog\n");
                return (1);
            }
            return (0);
        case 1:
            if (!svc_getargs(transp, xdr_void, 0)) {
                svcerr_decode(transp);
                return (1);
            }
            fprintf(stderr, "client got callback\n");
            if (!svc_sendreply(transp, xdr_void, 0)) {
                fprintf(stderr, "err: exampleprog");
                return (1);
            }
    }
}
```

```
/*
 * server
 */
#include <stdio.h>
#include <rpc/rpc.h>
#include <sys/signal.h>

char *getnewprog();
char hostname[256];
int docallback();
int pnum;          /* program number for callback routine */

main()
```

```
{
    gethostname(hostname, sizeof(hostname));
    registerrpc(EXAMPLEPROG, EXAMPLEVERS,
      EXAMPLEPROC_CALLBACK, getnewprog, xdr_int, xdr_void);
    fprintf(stderr, "server going into svc_run\n");
    signal(SIGALRM, docallback);
    alarm(10);
    svc_run();
    fprintf(stderr, "Error: svc_run shouldn't return\n");
}

char *
getnewprog(pnump)
    char *pnump;
{
    pnum = *(int *)pnump;
    return NULL;
}

docallback()
{
    int ans;

    ans = callrpc(hostname, pnum, 1, 1, xdr_void, 0,
        xdr_void, 0);
    if (ans != 0) {
        fprintf(stderr, "server: ");
        clnt_perrno(ans);
        fprintf(stderr, "\n");
    }
}
```

4

External Data Representation: Sun Technical Notes

4

External Data Representation: Sun Technical Notes

This chapter contains technical notes on Sun's implementation of the External Data Representation (XDR) standard, a set of library routines that allow a C programmer to describe arbitrary data structures in a machine-independent fashion. For a formal specification of the XDR standard, see the *External Data Representation Standard: Protocol Specification*. XDR is the backbone of Sun's Remote Procedure Call package, in the sense that data for remote procedure calls is transmitted using the standard. XDR library routines should be used to transmit data that is accessed (read or written) by more than one type of machine.[9]

This chapter contains a short tutorial overview of the XDR library routines, a guide to accessing currently available XDR streams, and information on defining new streams and data types. XDR was designed to work across different languages, operating systems, and machine architectures. Most users (particularly RPC users) will only need the information in the *Number Filters*, *Floating Point Filters*, and *Enumeration Filters* sections. Programmers wishing to implement RPC and XDR on new machines will be interested in the rest of the chapter, as well as the *External Data Representation Standard: Protocol Specification*, which will be their primary reference.

NOTE `rpcgen` *can be used to write XDR routines even in cases where no RPC calls are being made.*

On Sun systems, C programs that want to use XDR routines must include the file `<rpc/rpc.h>`, which contains all the necessary interfaces to the XDR system. Since the C library `libc.a` contains all the XDR routines, compile as normal.

```
example% cc program.c
```

[9] For a compete specification of the system External Data Representation routines, see the `xdr(3N)` manual page.

Justification

Consider the following two programs, `writer`:

```
#include <stdio.h>

main()          /* writer.c */
{
    long i;

    for (i = 0; i < 8; i++) {
        if (fwrite((char *)&i, sizeof(i), 1, stdout) != 1) {
            fprintf(stderr, "failed!\n");
            exit(1);
        }
    }
    exit(0);
}
```

and `reader`:

```
#include <stdio.h>

main()          /* reader.c */
{
    long i, j;

    for (j = 0; j < 8; j++) {
        if (fread((char *)&i, sizeof (i), 1, stdin) != 1) {
            fprintf(stderr, "failed!\n");
            exit(1);
        }
        printf("%ld ", i);
    }
    printf("\n");
    exit(0);
}
```

The two programs appear to be portable, because (a) they pass `lint` checking, and (b) they exhibit the same behavior when executed on two different hardware architectures, a Sun and a VAX.

Piping the output of the `writer` program to the `reader` program gives identical results on a Sun or a VAX.

```
sun% writer | reader
0 1 2 3 4 5 6 7
sun%


vax% writer | reader
0 1 2 3 4 5 6 7
vax%
```

With the advent of local area networks and 4.2BSD came the concept of "network pipes" — a process produces data on one machine, and a second process consumes data on another machine. A network pipe can be constructed with `writer` and `reader`. Here are the results if the first produces data on a Sun, and the second consumes data on a VAX.

```
sun% writer | rsh vax reader
0 16777216 33554432 50331648 67108864 83886080 100663296
117440512
sun%
```

Identical results can be obtained by executing `writer` on the VAX and `reader` on the Sun. These results occur because the byte ordering of long integers differs between the VAX and the Sun, even though word size is the same. Note that 16777216 is 2^{24} — when four bytes are reversed, the 1 winds up in the 24th bit.

Whenever data is shared by two or more machine types, there is a need for portable data. Programs can be made data-portable by replacing the `read()` and `write()` calls with calls to an XDR library routine `xdr_long()`, a filter that knows the standard representation of a long integer in its external form. Here are the revised versions of `writer`:

```
#include <stdio.h>
#include <rpc/rpc.h>      /* xdr is a sub-library of rpc */

main()        /* writer.c */
{
    XDR xdrs;
    long i;

    xdrstdio_create(&xdrs, stdout, XDR_ENCODE);
    for (i = 0; i < 8; i++) {
        if (!xdr_long(&xdrs, &i)) {
            fprintf(stderr, "failed!\n");
            exit(1);
        }
    }
    exit(0);
}
```

and `reader`:

```
#include <stdio.h>
#include <rpc/rpc.h>      /* xdr is a sub-library of rpc */

main()        /* reader.c */
{
    XDR xdrs;
    long i, j;

    xdrstdio_create(&xdrs, stdin, XDR_DECODE);
    for (j = 0; j < 8; j++) {
        if (!xdr_long(&xdrs, &i)) {
            fprintf(stderr, "failed!\n");
            exit(1);
        }
        printf("%ld ", i);
    }
    printf("\n");
    exit(0);
}
```

The new programs were executed on a Sun, on a VAX, and from a Sun to a VAX; the results are shown below.

```
sun% writer | reader
0 1 2 3 4 5 6 7
sun%

vax% writer | reader
0 1 2 3 4 5 6 7
vax%

sun% writer | rsh vax reader
0 1 2 3 4 5 6 7
sun%
```

NOTE *Integers are just the tip of the portable-data iceberg. Arbitrary data structures present portability problems, particularly with respect to alignment and pointers. Alignment on word boundaries may cause the size of a structure to vary from machine to machine. And pointers, which are very convenient to use, have no meaning outside the machine where they are defined.*

A Canonical Standard

XDR's approach to standardizing data representations is *canonical*. That is, XDR defines a single byte order (Big Endian), a single floating-point representation (IEEE), and so on. Any program running on any machine can use XDR to create portable data by translating its local representation to the XDR standard representations; similarly, any program running on any machine can read portable data by translating the XDR standard representaions to its local equivalents. The single standard completely decouples programs that create or send portable data from those that use or receive portable data. The advent of a new machine or a new language has no effect upon the community of existing portable data creators and users. A new machine joins this community by being "taught" how to convert the standard representations and its local representations; the local representations of other machines are irrelevant. Conversely, to existing programs running on other machines, the local representations of the new machine are also irrelevant; such programs can immediately read portable data produced by the new machine because such data conforms to the canonical standards that they already understand.

There are strong precedents for XDR's canonical approach. For example, TCP/IP, UDP/IP, XNS, Ethernet, and, indeed, all protocols below layer five of the ISO model, are canonical protocols. The advantage of any canonical approach is simplicity; in the case of XDR, a single set of conversion routines is written once and is never touched again. The canonical approach has a disadvantage, but it is unimportant in real-world data transfer applications. Suppose two Little-Endian machines are transferring integers according to the XDR standard. The sending machine converts the integers from Little-Endian byte order to XDR (Big-Endian) byte order; the receiving machine performs the reverse conversion. Because both machines observe the same byte order, their conversions are unnecessary. The point, however, is not necessity, but cost as compared to the alternative.

The time spent converting to and from a canonical representation is insignificant, especially in networking applications. Most of the time required to prepare a data structure for transfer is not spent in conversion but in traversing the elements of the data structure. To transmit a tree, for example, each leaf must be visited and each element in a leaf record must be copied to a buffer and aligned there; storage for the leaf may have to be deallocated as well. Similarly, to receive a tree, storage must be allocated for each leaf, data must be moved from the buffer to the leaf and properly aligned, and pointers must be constructed to link the leaves together. Every machine pays the cost of traversing and copying data structures whether or not conversion is required. In networking applications, communications overhead—the time required to move the data down through the sender's protocol layers, across the network and up through the receiver's protocol layers—dwarfs conversion overhead.

The XDR Library

The XDR library not only solves data portability problems, it also allows you to write and read arbitrary C constructs in a consistent, specified, well-documented manner. Thus, it can make sense to use the library even when the data is not shared among machines on a network.

The XDR library has filter routines for strings (null-terminated arrays of bytes), structures, unions, and arrays, to name a few. Using more primitive routines, you can write your own specific XDR routines to describe arbitrary data structures, including elements of arrays, arms of unions, or objects pointed at from other structures. The structures themselves may contain arrays of arbitrary elements, or pointers to other structures.

Let's examine the two programs more closely. There is a family of XDR stream creation routines in which each member treats the stream of bits differently. In our example, data is manipulated using standard I/O routines, so we use `xdrstdio_create()`. The parameters to XDR stream creation routines vary according to their function. In our example, `xdrstdio_create()` takes a pointer to an XDR structure that it initializes, a pointer to a `FILE` that the input or output is performed on, and the operation. The operation may be `XDR_ENCODE` for serializing in the `writer` program, or `XDR_DECODE` for deserializing in the `reader` program.

Note: RPC users never need to create XDR streams; the RPC system itself creates these streams, which are then passed to the users.

The `xdr_long()` primitive is characteristic of most XDR library primitives and all client XDR routines. First, the routine returns `FALSE` (0) if it fails, and `TRUE` (1) if it succeeds. Second, for each data type, `xxx`, there is an associated XDR routine of the form:

```
xdr_xxx(xdrs, xp)
    XDR *xdrs;
    xxx *xp;
{
}
```

In our case, `xxx` is long, and the corresponding XDR routine is a primitive, `xdr_long()`. The client could also define an arbitrary structure `xxx` in which case the client would also supply the routine `xdr_xxx`(), describing each field by calling XDR routines of the appropriate type. In all cases the first parameter, `xdrs` can be treated as an opaque handle, and passed to the primitive routines.

XDR routines are direction independent; that is, the same routines are called to serialize or deserialize data. This feature is critical to software engineering of portable data. The idea is to call the same routine for either operation — this almost guarantees that serialized data can also be deserialized. One routine is used by both producer and consumer of networked data. This is implemented by always passing the address of an object rather than the object itself — only in the case of deserialization is the object modified. This feature is not shown in our trivial example, but its value becomes obvious when nontrivial data structures are passed among machines. If needed, the user can obtain the direction of the XDR operation. See the *XDR Operation Directions* section of this chapter for details.

Let's look at a slightly more complicated example. Assume that a person's gross assets and liabilities are to be exchanged among processes. Also assume that these values are important enough to warrant their own data type:

```
struct gnumbers {
    long g_assets;
    long g_liabilities;
};
```

The corresponding XDR routine describing this structure would be:

```
bool_t            /* TRUE is success, FALSE is failure */
xdr_gnumbers(xdrs, gp)
    XDR *xdrs;
    struct gnumbers *gp;
{
    if (xdr_long(xdrs, &gp->g_assets) &&
        xdr_long(xdrs, &gp->g_liabilities))
        return(TRUE);
    return(FALSE);
}
```

Note that the parameter `xdrs` is never inspected or modified; it is only passed on to the subcomponent routines. It is imperative to inspect the return value of each XDR routine call, and to give up immediately and return `FALSE` if the subroutine fails.

This example also shows that the type `bool_t` is declared as an integer whose only values are `TRUE` (1) and `FALSE` (0). This document uses the following definitions:

```
#define bool_t  int
#define TRUE    1
#define FALSE   0
```

Keeping these conventions in mind, `xdr_gnumbers()` can be rewritten as follows:

```
xdr_gnumbers(xdrs, gp)
    XDR *xdrs;
    struct gnumbers *gp;
{
    return(xdr_long(xdrs, &gp->g_assets) &&
        xdr_long(xdrs, &gp->g_liabilities));
}
```

This document uses both coding styles.

4.1. XDR Library Primitives

This section gives a synopsis of each XDR primitive. It starts with basic data types and moves on to constructed data types. Finally, XDR utilities are discussed. The interface to these primitives and utilities is defined in the include file `<rpc/xdr.h>`, automatically included by `<rpc/rpc.h>`.

Number Filters

The XDR library provides primitives to translate between numbers and their corresponding external representations. Primitives cover the set of numbers in:

```
[signed, unsigned] * [short, int, long]
```

Specifically, the eight primitives are:

```
bool_t xdr_char(xdrs, cp)
    XDR *xdrs;
    char *cp;

bool_t xdr_u_char(xdrs, ucp)
    XDR *xdrs;
    unsigned char *ucp;

bool_t xdr_int(xdrs, ip)
    XDR *xdrs;
    int *ip;

bool_t xdr_u_int(xdrs, up)
    XDR *xdrs;
    unsigned *up;

bool_t xdr_long(xdrs, lip)
    XDR *xdrs;
    long *lip;

bool_t xdr_u_long(xdrs, lup)
    XDR *xdrs;
    u_long *lup;

bool_t xdr_short(xdrs, sip)
    XDR *xdrs;
    short *sip;

bool_t xdr_u_short(xdrs, sup)
    XDR *xdrs;
    u_short *sup;
```

The first parameter, `xdrs`, is an XDR stream handle. The second parameter is the address of the number that provides data to the stream or receives data from it. All routines return `TRUE` if they complete successfully, and `FALSE` otherwise.

Floating Point Filters

The XDR library also provides primitive routines for C's floating point types:

```
bool_t xdr_float(xdrs, fp)
    XDR *xdrs;
    float *fp;

bool_t xdr_double(xdrs, dp)
    XDR *xdrs;
    double *dp;
```

The first parameter, `xdrs` is an XDR stream handle. The second parameter is the address of the floating point number that provides data to the stream or receives data from it. Both routines return `TRUE` if they complete successfully, and `FALSE` otherwise.

Note: Since the numbers are represented in IEEE floating point, routines may fail when decoding a valid IEEE representation into a machine-specific representation, or vice-versa.

Enumeration Filters

The XDR library provides a primitive for generic enumerations. The primitive assumes that a C `enum` has the same representation inside the machine as a C integer. The boolean type is an important instance of the `enum`. The external representation of a boolean is always `TRUE` (1) or `FALSE` (0).

```
#define bool_t  int
#define FALSE   0
#define TRUE    1

#define enum_t int

bool_t xdr_enum(xdrs, ep)
    XDR *xdrs;
    enum_t *ep;

bool_t xdr_bool(xdrs, bp)
    XDR *xdrs;
    bool_t *bp;
```

The second parameters `ep` and `bp` are addresses of the associated type that provides data to, or receives data from, the stream `xdrs`.

No Data

Occasionally, an XDR routine must be supplied to the RPC system, even when no data is passed or required. The library provides such a routine:

```
bool_t xdr_void();   /* always returns TRUE */
```

Constructed Data Type Filters

Constructed or compound data type primitives require more parameters and perform more complicated functions then the primitives discussed above. This section includes primitives for strings, arrays, unions, and pointers to structures.

Constructed data type primitives may use memory management. In many cases, memory is allocated when deserializing data with `XDR_DECODE`. Therefore, the XDR package must provide means to deallocate memory. This is done by an XDR operation, `XDR_FREE`. To review, the three XDR directional operations are `XDR_ENCODE`, `XDR_DECODE`, and `XDR_FREE`.

Strings

In C, a string is defined as a sequence of bytes terminated by a null byte, which is not considered when calculating string length. However, when a string is passed or manipulated, a pointer to it is employed. Therefore, the XDR library defines a string to be a `char *`, and not a sequence of characters. The external representation of a string is drastically different from its internal representation. Externally, strings are represented as sequences of ASCII characters, while internally, they are represented with character pointers. Conversion between the two representations is accomplished with the routine `xdr_string()`:

```
bool_t xdr_string(xdrs, sp, maxlength)
    XDR *xdrs;
    char **sp;
    u_int maxlength;
```

The first parameter `xdrs` is the XDR stream handle. The second parameter `sp` is a pointer to a string (type `char **`). The third parameter `maxlength` specifies the maximum number of bytes allowed during encoding or decoding. its value is usually specified by a protocol. For example, a protocol specification may say that a file name may be no longer than 255 characters.

Keep `maxlength` small. If it is too big you can blow the heap, since `xdr_string()` will call `malloc()` for space.

The routine returns `FALSE` if the number of characters exceeds `maxlength`, and `TRUE` if it doesn't.

The behavior of `xdr_string()` is similar to the behavior of other routines discussed in this section. The direction `XDR_ENCODE` is easiest to understand. The parameter `sp` points to a string of a certain length; if the string does not exceed `maxlength`, the bytes are serialized.

The effect of deserializing a string is subtle. First the length of the incoming string is determined; it must not exceed `maxlength`. Next `sp` is dereferenced; if the the value is `NULL`, then a string of the appropriate length is allocated and `*sp` is set to this string. If the original value of `*sp` is non-null, then the XDR package assumes that a target area has been allocated, which can hold strings no longer than `maxlength`. In either case, the string is decoded into the target area. The routine then appends a null character to the string.

In the `XDR_FREE` operation, the string is obtained by dereferencing `sp`. If the string is not `NULL`, it is freed and `*sp` is set to `NULL`. In this operation, `xdr_string()` ignores the `maxlength` parameter.

Byte Arrays

Often variable-length arrays of bytes are preferable to strings. Byte arrays differ from strings in the following three ways: 1) the length of the array (the byte count) is explicitly located in an unsigned integer, 2) the byte sequence is not terminated by a null character, and 3) the external representation of the bytes is the same as their internal representation. The primitive `xdr_bytes()` converts between the internal and external representations of byte arrays:

```
bool_t xdr_bytes(xdrs, bpp, lp, maxlength)
    XDR *xdrs;
    char **bpp;
    u_int *lp;
    u_int maxlength;
```

The usage of the first, second and fourth parameters are identical to the first, second and third parameters of `xdr_string()`, respectively. The length of the byte area is obtained by dereferencing `lp` when serializing; `*lp` is set to the byte length when deserializing.

Arrays

The XDR library package provides a primitive for handling arrays of arbitrary elements. The `xdr_bytes()` routine treats a subset of generic arrays, in which the size of array elements is known to be 1, and the external description of each element is built-in. The generic array primitive, `xdr_array()` requires parameters identical to those of `xdr_bytes()` plus two more: the size of array elements, and an XDR routine to handle each of the elements. This routine is called to encode or decode each element of the array.

```
bool_t
xdr_array(xdrs, ap, lp, maxlength, elementsiz, xdr_element)
    XDR *xdrs;
    char **ap;
    u_int *lp;
    u_int maxlength;
    u_int elementsiz;
    bool_t (*xdr_element)();
```

The parameter `ap` is the address of the pointer to the array. If `*ap` is `NULL` when the array is being deserialized, XDR allocates an array of the appropriate size and sets `*ap` to that array. The element count of the array is obtained from `*lp` when the array is serialized; `*lp` is set to the array length when the array is deserialized. The parameter `maxlength` is the maximum number of elements that the array is allowed to have; `elementsiz` is the byte size of each element of the array (the C function `sizeof()` can be used to obtain this value). The `xdr_element()` routine is called to serialize, deserialize, or free each element of the array.

Before defining more constructed data types, it is appropriate to present three examples.

Example A:
A user on a networked machine can be identified by (a) the machine name, such as `krypton`: see the `gethostname` man page; (b) the user's UID: see the `geteuid` man page; and (c) the group numbers to which the user belongs: see the `getgroups` man page. A structure with this information and its associated XDR routine could be coded like this:

```
struct netuser {
    char    *nu_machinename;
    int     nu_uid;
    u_int   nu_glen;
    int     *nu_gids;
};
#define NLEN 255      /* machine names < 256 chars */
#define NGRPS 20      /* user can't be in > 20 groups */

bool_t
xdr_netuser(xdrs, nup)
    XDR *xdrs;
    struct netuser *nup;
{
    return(xdr_string(xdrs, &nup->nu_machinename, NLEN) &&
        xdr_int(xdrs, &nup->nu_uid) &&
        xdr_array(xdrs, &nup->nu_gids, &nup->nu_glen,
        NGRPS, sizeof (int), xdr_int));
}
```

Example B:
A party of network users could be implemented as an array of `netuser` structure. The declaration and its associated XDR routines are as follows:

```
struct party {
    u_int p_len;
    struct netuser *p_nusers;
};
#define PLEN 500 /* max number of users in a party */

bool_t
xdr_party(xdrs, pp)
    XDR *xdrs;
    struct party *pp;
{
    return(xdr_array(xdrs, &pp->p_nusers, &pp->p_len, PLEN,
        sizeof (struct netuser), xdr_netuser));
}
```

Example C:
The well-known parameters to `main`, `argc` and `argv` can be combined into a structure. An array of these structures can make up a history of commands. The declarations and XDR routines might look like:

```
struct cmd {
    u_int c_argc;
    char **c_argv;
};
#define ALEN 1000     /* args cannot be > 1000 chars */
#define NARGC 100     /* commands cannot have > 100 args */

struct history {
    u_int h_len;
    struct cmd *h_cmds;
};
#define NCMDS 75   /* history is no more than 75 commands */

bool_t
xdr_wrap_string(xdrs, sp)
    XDR *xdrs;
    char **sp;
{
    return(xdr_string(xdrs, sp, ALEN));
}

bool_t
xdr_cmd(xdrs, cp)
    XDR *xdrs;
    struct cmd *cp;
{
    return(xdr_array(xdrs, &cp->c_argv, &cp->c_argc, NARGC,
        sizeof (char *), xdr_wrap_string));
}

bool_t
xdr_history(xdrs, hp)
    XDR *xdrs;
    struct history *hp;
{
    return(xdr_array(xdrs, &hp->h_cmds, &hp->h_len, NCMDS,
        sizeof (struct cmd), xdr_cmd));
}
```

The most confusing part of this example is that the routine `xdr_wrap_string()` is needed to package the `xdr_string()` routine, because the implementation of `xdr_array()` only passes two parameters to the array element description routine; `xdr_wrap_string()` supplies the third parameter to `xdr_string()`.

By now the recursive nature of the XDR library should be obvious. Let's continue with more constructed data types.

Opaque Data

In some protocols, handles are passed from a server to client. The client passes the handle back to the server at some later time. Handles are never inspected by clients; they are obtained and submitted. That is to say, handles are opaque. The `xdr_opaque()` primitive is used for describing fixed sized, opaque bytes.

```
bool_t xdr_opaque(xdrs, p, len)
    XDR *xdrs;
    char *p;
    u_int len;
```

The parameter `p` is the location of the bytes; `len` is the number of bytes in the opaque object. By definition, the actual data contained in the opaque object are not machine portable.

Fixed Sized Arrays

The XDR library provides a primitive, `xdr_vector()`, for fixed-length arrays.

```
#define NLEN 255      /* machine names must be < 256 chars */
#define NGRPS 20      /* user belongs to exactly 20 groups */

struct netuser {
    char *nu_machinename;
    int nu_uid;
    int nu_gids[NGRPS];
};

bool_t
xdr_netuser(xdrs, nup)
    XDR *xdrs;
    struct netuser *nup;
{
    int i;

    if (!xdr_string(xdrs, &nup->nu_machinename, NLEN))
        return(FALSE);
    if (!xdr_int(xdrs, &nup->nu_uid))
        return(FALSE);
    if (!xdr_vector(xdrs, nup->nu_gids, NGRPS, sizeof(int),
        xdr_int)) {
            return(FALSE);
    }
    return(TRUE);
}
```

Discriminated Unions

The XDR library supports discriminated unions. A discriminated union is a C union and an `enum_t` value that selects an "arm" of the union.

```
struct xdr_discrim {
    enum_t value;
    bool_t (*proc)();
};

bool_t xdr_union(xdrs, dscmp, unp, arms, defaultarm)
    XDR *xdrs;
    enum_t *dscmp;
    char *unp;
    struct xdr_discrim *arms;
    bool_t (*defaultarm)();    /* may equal NULL */
```

First the routine translates the discriminant of the union located at `*dscmp`. The discriminant is always an `enum_t`. Next the union located at `*unp` is translated. The parameter `arms` is a pointer to an array of `xdr_discrim` structures. Each structure contains an ordered pair of `[value,proc]`. If the union's discriminant is equal to the associated `value`, then the `proc` is called to translate the union. The end of the `xdr_discrim` structure array is denoted by a routine of value `NULL` (0). If the discriminant is not found in the `arms` array, then the `defaultarm` procedure is called if it is non-null; otherwise the routine returns `FALSE`.

Example D: Suppose the type of a union may be integer, character pointer (a string), or a `gnumbers` structure. Also, assume the union and its current type are declared in a structure. The declaration is:

```
enum utype { INTEGER=1, STRING=2, GNUMBERS=3 };

struct u_tag {
    enum utype utype;    /* the union's discriminant */
    union {
        int ival;
        char *pval;
        struct gnumbers gn;
    } uval;
};
```

The following constructs and XDR procedure (de)serialize the discriminated union:

```
struct xdr_discrim u_tag_arms[4] = {
    { INTEGER, xdr_int },
    { GNUMBERS, xdr_gnumbers }
    { STRING, xdr_wrap_string },
    { __dontcare__, NULL }
    /* always terminate arms with a NULL xdr_proc */
}

bool_t
xdr_u_tag(xdrs, utp)
    XDR *xdrs;
    struct u_tag *utp;
{
    return(xdr_union(xdrs, &utp->utype, &utp->uval,
        u_tag_arms, NULL));
}
```

The routine `xdr_gnumbers()` was presented above in the *The XDR Library* section. `xdr_wrap_string()` was presented in example C. The default `arm` parameter to `xdr_union()` (the last parameter) is `NULL` in this example. Therefore the value of the union's discriminant may legally take on only values listed in the `u_tag_arms` array. This example also demonstrates that the elements of the arm's array do not need to be sorted.

It is worth pointing out that the values of the discriminant may be sparse, though in this example they are not. It is always good practice to assign explicitly integer values to each element of the discriminant's type. This practice both documents the external representation of the discriminant and guarantees that different C compilers emit identical discriminant values.

Exercise: Implement `xdr_union()` using the other primitives in this section.

Pointers

In C it is often convenient to put pointers to another structure within a structure. The `xdr_reference()` primitive makes it easy to serialize, deserialize, and free these referenced structures.

```
bool_t xdr_reference(xdrs, pp, size, proc)
    XDR *xdrs;
    char **pp;
    u_int ssize;
    bool_t (*proc)();
```

Parameter `pp` is the address of the pointer to the structure; parameter `ssize` is the size in bytes of the structure (use the C function `sizeof()` to obtain this value); and `proc` is the XDR routine that describes the structure. When decoding data, storage is allocated if `*pp` is `NULL`.

There is no need for a primitive `xdr_struct()` to describe structures within structures, because pointers are always sufficient.

Exercise: Implement `xdr_reference()` using `xdr_array()`. Warning: `xdr_reference()` and `xdr_array()` are NOT interchangeable external representations of data.

Example E: Suppose there is a structure containing a person's name and a pointer to a `gnumbers` structure containing the person's gross assets and liabilities. The construct is:

```
struct pgn {
    char *name;
    struct gnumbers *gnp;
};
```

The corresponding XDR routine for this structure is:

```
bool_t
xdr_pgn(xdrs, pp)
    XDR *xdrs;
    struct pgn *pp;
{
    if (xdr_string(xdrs, &pp->name, NLEN) &&
      xdr_reference(xdrs, &pp->gnp,
      sizeof(struct gnumbers), xdr_gnumbers))
        return(TRUE);
    return(FALSE);
}
```

Pointer Semantics and XDR

In many applications, C programmers attach double meaning to the values of a pointer. Typically the value `NULL` (or zero) means data is not needed, yet some application-specific interpretation applies. In essence, the C programmer is encoding a discriminated union efficiently by overloading the interpretation of the value of a pointer. For instance, in example E a `NULL` pointer value for `gnp` could indicate that the person's assets and liabilities are unknown. That is, the pointer value encodes two things: whether or not the data is known; and if it is known, where it is located in memory. Linked lists are an extreme example of the use of application-specific pointer interpretation.

The primitive `xdr_reference()` cannot and does not attach any special meaning to a null-value pointer during serialization. That is, passing an address of a pointer whose value is `NULL` to `xdr_reference()` when serialing data will most likely cause a memory fault and, on the UNIX system, a core dump.

`xdr_pointer()` correctly handles `NULL` pointers. For more information about its use, see *Linked Lists*.

Exercise: After reading the section on *Linked Lists*, return here and extend example E so that it can correctly deal with `NULL` pointer values.

Exercise: Using the `xdr_union()`, `xdr_reference()` and `xdr_void()` primitives, implement a generic pointer handling primitive that implicitly deals with NULL pointers. That is, implement xdr_pointer().

Non-filter Primitives

XDR streams can be manipulated with the primitives discussed in this section.

```
u_int xdr_getpos(xdrs)
    XDR *xdrs;

bool_t xdr_setpos(xdrs, pos)
    XDR *xdrs;
    u_int pos;

xdr_destroy(xdrs)
    XDR *xdrs;
```

The routine xdr_getpos() returns an unsigned integer that describes the current position in the data stream. Warning: In some XDR streams, the returned value of xdr_getpos() is meaningless; the routine returns a –1 in this case (though –1 should be a legitimate value).

The routine xdr_setpos() sets a stream position to pos. Warning: In some XDR streams, setting a position is impossible; in such cases, xdr_setpos() will return FALSE. This routine will also fail if the requested position is out-of-bounds. The definition of bounds varies from stream to stream.

The xdr_destroy() primitive destroys the XDR stream. Usage of the stream after calling this routine is undefined.

XDR Operation Directions

At times you may wish to optimize XDR routines by taking advantage of the direction of the operation — XDR_ENCODE, XDR_DECODE, or XDR_FREE. The value xdrs->x_op always contains the direction of the XDR operation. Programmers are not encouraged to take advantage of this information. Therefore, no example is presented here. However, an example in the *Linked Lists* section, below, demonstrates the usefulness of the xdrs->x_op field.

XDR Stream Access

An XDR stream is obtained by calling the appropriate creation routine. These creation routines take arguments that are tailored to the specific properties of the stream.

Streams currently exist for (de)serialization of data to or from standard I/O FILE streams, TCP/IP connections and UNIX files, and memory.

Standard I/O Streams

XDR streams can be interfaced to standard I/O using the xdrstdio_create() routine as follows:

```
#include <stdio.h>
#include <rpc/rpc.h>     /* xdr streams part of rpc */

void
xdrstdio_create(xdrs, fp, x_op)
    XDR *xdrs;
    FILE *fp;
    enum xdr_op x_op;
```

The routine `xdrstdio_create()` initializes an XDR stream pointed to by `xdrs`. The XDR stream interfaces to the standard I/O library. Parameter `fp` is an open file, and `x_op` is an XDR direction.

Memory Streams

Memory streams allow the streaming of data into or out of a specified area of memory:

```
#include <rpc/rpc.h>

void
xdrmem_create(xdrs, addr, len, x_op)
    XDR *xdrs;
    char *addr;
    u_int len;
    enum xdr_op x_op;
```

The routine `xdrmem_create()` initializes an XDR stream in local memory. The memory is pointed to by parameter `addr`; parameter `len` is the length in bytes of the memory. The parameters `xdrs` and `x_op` are identical to the corresponding parameters of `xdrstdio_create()`. Currently, the UDP/IP implementation of RPC uses `xdrmem_create()`. Complete call or result messages are built in memory before calling the `sendto()` system routine.

Record (TCP/IP) Streams

A record stream is an XDR stream built on top of a record marking standard that is built on top of the UNIX file or 4.2 BSD connection interface.

```
#include <rpc/rpc.h>     /* xdr streams part of rpc */

xdrrec_create(xdrs,
  sendsize, recvsize, iohandle, readproc, writeproc)
    XDR *xdrs;
    u_int sendsize, recvsize;
    char *iohandle;
    int (*readproc)(), (*writeproc)();
```

The routine `xdrrec_create()` provides an XDR stream interface that allows for a bidirectional, arbitrarily long sequence of records. The contents of the records are meant to be data in XDR form. The stream's primary use is for interfacing RPC to TCP connections. However, it can be used to stream data into or out of normal UNIX files.

The parameter `xdrs` is similar to the corresponding parameter described above. The stream does its own data buffering similar to that of standard I/O. The parameters `sendsize` and `recvsize` determine the size in bytes of the output and input buffers, respectively; if their values are zero (0), then predetermined defaults are used. When a buffer needs to be filled or flushed, the routine `readproc()` or `writeproc()` is called, respectively. The usage and behavior of these routines are similar to the UNIX system calls `read()` and `write()`. However, the first parameter to each of these routines is the opaque parameter `iohandle`. The other two parameters (`buf` and `nbytes`) and the results (byte count) are identical to the system routines. If `xxx` is `readproc()` or `writeproc()`, then it has the following form:

```
/*
 * returns the actual number of bytes transferred.
 * -1 is an error
 */
int
xxx(iohandle, buf, len)
    char *iohandle;
    char *buf;
    int nbytes;
```

The XDR stream provides means for delimiting records in the byte stream. The implementation details of delimiting records in a stream are discussed in the *Advanced Topics* section, below. The primitives that are specific to record streams are as follows:

```
bool_t
xdrrec_endofrecord(xdrs, flushnow)
    XDR *xdrs;
    bool_t flushnow;

bool_t
xdrrec_skiprecord(xdrs)
    XDR *xdrs;

bool_t
xdrrec_eof(xdrs)
    XDR *xdrs;
```

The routine `xdrrec_endofrecord()` causes the current outgoing data to be marked as a record. If the parameter `flushnow` is `TRUE`, then the stream's `writeproc` will be called; otherwise, `writeproc` will be called when the output buffer has been filled.

The routine `xdrrec_skiprecord()` causes an input stream's position to be moved past the current record boundary and onto the beginning of the next record in the stream.

If there is no more data in the stream's input buffer, then the routine `xdrrec_eof()` returns `TRUE`. That is not to say that there is no more data in the underlying file descriptor.

XDR Stream Implementation

This section provides the abstract data types needed to implement new instances of XDR streams.

The XDR Object

The following structure defines the interface to an XDR stream:

```
enum xdr_op { XDR_ENCODE=0, XDR_DECODE=1, XDR_FREE=2 };

typedef struct {
    enum xdr_op x_op;      /* operation; fast added param */
    struct xdr_ops {
        bool_t   (*x_getlong)();   /* get long from stream */
        bool_t   (*x_putlong)();   /* put long to stream */
        bool_t   (*x_getbytes)();  /* get bytes from stream */
        bool_t   (*x_putbytes)();  /* put bytes to stream */
        u_int    (*x_getpostn)();  /* return stream offset */
        bool_t   (*x_setpostn)();  /* reposition offset */
        caddr_t  (*x_inline)();    /* ptr to buffered data */
        VOID     (*x_destroy)();   /* free private area */
    } *x_ops;
    caddr_t x_public;      /* users' data */
    caddr_t x_private;     /* pointer to private data */
    caddr_t x_base;        /* private for position info */
    int     x_handy;       /* extra private word */
} XDR;
```

The x_op field is the current operation being performed on the stream. This field is important to the XDR primitives, but should not affect a stream's implementation. That is, a stream's implementation should not depend on this value. The fields x_private, x_base, and x_handy are private to the particular stream's implementation. The field x_public is for the XDR client and should never be used by the XDR stream implementations or the XDR primitives. x_getpostn(), x_setpostn(), and x_destroy(), are macros for accessing operations. The operation x_inline() takes two parameters: an XDR *, and an unsigned integer, which is a byte count. The routine returns a pointer to a piece of the stream's internal buffer. The caller can then use the buffer segment for any purpose. From the stream's point of view, the bytes in the buffer segment have been consumed or put. The routine may return NULL if it cannot return a buffer segment of the requested size. (The x_inline() routine is for cycle squeezers. Use of the resulting buffer is not data-portable. Users are encouraged not to use this feature.)

The operations x_getbytes() and x_putbytes() blindly get and put sequences of bytes from or to the underlying stream; they return TRUE if they are successful, and FALSE otherwise. The routines have identical parameters (replace xxx):

```
bool_t
xxxbytes(xdrs, buf, bytecount)
    XDR *xdrs;
    char *buf;
    u_int bytecount;
```

The operations `x_getlong()` and `x_putlong()` receive and put long numbers from and to the data stream. It is the responsibility of these routines to translate the numbers between the machine representation and the (standard) external representation. The UNIX primitives `htonl()` and `ntohl()` can be helpful in accomplishing this. The higher-level XDR implementation assumes that signed and unsigned long integers contain the same number of bits, and that nonnegative integers have the same bit representations as unsigned integers. The routines return *TRUE* if they succeed, and `FALSE` otherwise. They have identical parameters:

```
bool_t
xxxlong(xdrs, lp)
    XDR *xdrs;
    long *lp;
```

Implementors of new XDR streams must make an XDR structure (with new operation routines) available to clients, using some kind of create routine.

4.2. Advanced Topics

This section describes techniques for passing data structures that are not covered in the preceding sections. Such structures include linked lists (of arbitrary lengths). Unlike the simpler examples covered in the earlier sections, the following examples are written using both the XDR C library routines and the XDR data description language. The *External Data Representation Standard: Protocol Specification* chapter of this *Network Programming* manual describes this language in complete detail.

Linked Lists

The last example in the *Pointers* section presented a C data structure and its associated XDR routines for a individual's gross assets and liabilities. The example is duplicated below:

```
struct gnumbers {
    long g_assets;
    long g_liabilities;
};

bool_t
xdr_gnumbers(xdrs, gp)
    XDR *xdrs;
    struct gnumbers *gp;
{
    if (xdr_long(xdrs, &(gp->g_assets)))
        return(xdr_long(xdrs, &(gp->g_liabilities)));
    return(FALSE);
}
```

Now assume that we wish to implement a linked list of such information. A data structure could be constructed as follows:

```
struct gnumbers_node {
    struct gnumbers gn_numbers;
    struct gnumbers_node *gn_next;
};

typedef struct gnumbers_node *gnumbers_list;
```

The head of the linked list can be thought of as the data object; that is, the head is not merely a convenient shorthand for a structure. Similarly the `gn_next` field is used to indicate whether or not the object has terminated. Unfortunately, if the object continues, the `gn_next` field is also the address of where it continues. The link addresses carry no useful information when the object is serialized.

The XDR data description of this linked list is described by the recursive declaration of `gnumbers_list`:

```
struct gnumbers {
    int g_assets;
    int g_liabilities;
};

struct gnumbers_node {
    gnumbers gn_numbers;
    gnumbers_node *gn_next;
};
```

In this description, the boolean indicates whether there is more data following it. If the boolean is `FALSE`, then it is the last data field of the structure. If it is `TRUE`, then it is followed by a gnumbers structure and (recursively) by a `gnumbers_list`. Note that the C declaration has no boolean explicitly declared in it (though the `gn_next` field implicitly carries the information), while the XDR data description has no pointer explicitly declared in it.

Hints for writing the XDR routines for a `gnumbers_list` follow easily from the XDR description above. Note how the primitive `xdr_pointer()` is used to implement the XDR union above.

```
bool_t
xdr_gnumbers_node(xdrs, gn)
    XDR *xdrs;
    gnumbers_node *gn;
{
    return(xdr_gnumbers(xdrs, &gn->gn_numbers) &&
        xdr_gnumbers_list(xdrs, &gp->gn_next));
}

bool_t
xdr_gnumbers_list(xdrs, gnp)
    XDR *xdrs;
    gnumbers_list *gnp;
{
    return(xdr_pointer(xdrs, gnp,
        sizeof(struct gnumbers_node),
        xdr_gnumbers_node));
}
```

The unfortunate side effect of XDR'ing a list with these routines is that the C stack grows linearly with respect to the number of node in the list. This is due to the recursion. The following routine collapses the above two mutually recursive into a single, non-recursive one.

```
bool_t
xdr_gnumbers_list(xdrs, gnp)
    XDR *xdrs;
    gnumbers_list *gnp;
{
    bool_t more_data;
    gnumbers_list *nextp;

    for (;;) {
        more_data = (*gnp != NULL);
        if (!xdr_bool(xdrs, &more_data)) {
            return(FALSE);
        }
        if (! more_data) {
            break;
        }
        if (xdrs->x_op == XDR_FREE) {
            nextp = &(*gnp)->gn_next;
        }
        if (!xdr_reference(xdrs, gnp,
            sizeof(struct gnumbers_node), xdr_gnumbers)) {

        return(FALSE);
        }
        gnp = (xdrs->x_op == XDR_FREE) ?
            nextp : &(*gnp)->gn_next;
    }
    *gnp = NULL;
    return(TRUE);
}
```

The first task is to find out whether there is more data or not, so that this boolean information can be serialized. Notice that this statement is unnecessary in the `XDR_DECODE` case, since the value of more_data is not known until we deserialize it in the next statement.

The next statement XDR's the more_data field of the XDR union. Then if there is truly no more data, we set this last pointer to `NULL` to indicate the end of the list, and return `TRUE` because we are done. Note that setting the pointer to `NULL` is only important in the `XDR_DECODE` case, since it is already `NULL` in the `XDR_ENCODE` and XDR_FREE cases.

Next, if the direction is `XDR_FREE`, the value of `nextp` is set to indicate the location of the next pointer in the list. We do this now because we need to dereference gnp to find the location of the next item in the list, and after the next statement the storage pointed to by `gnp` will be freed up and no be longer valid. We can't do this for all directions though, because in the `XDR_DECODE` direction the value of `gnp` won't be set until the next statement.

Next, we XDR the data in the node using the primitive `xdr_reference()`. `xdr_reference()` is like `xdr_pointer()` which we used before, but it does not send over the boolean indicating whether there is more data. We use it instead of `xdr_pointer()` because we have already XDR'd this information ourselves. Notice that the xdr routine passed is not the same type as an element in the list. The routine passed is `xdr_gnumbers()`, for XDR'ing gnumbers, but each element in the list is actually of type `gnumbers_node`. We don't pass `xdr_gnumbers_node()` because it is recursive, and instead use `xdr_gnumbers()` which XDR's all of the non-recursive part. Note that this trick will work only if the `gn_numbers` field is the first item in each element, so that their addresses are identical when passed to `xdr_reference()`.

Finally, we update *gnp* to point to the next item in the list. If the direction is `XDR_FREE`, we set it to the previously saved value, otherwise we can dereference *gnp* to get the proper value. Though harder to understand than the recursive version, this non-recursive routine is far less likely to blow the C stack. It will also run more efficiently since a lot of procedure call overhead has been removed. Most lists are small though (in the hundreds of items or less) and the recursive version should be sufficient for them.

PART TWO: Protocol Specifications

5

External Data Representation Standard: Protocol Specification

5

External Data Representation Standard: Protocol Specification

5.1. Status of this Standard

Note: This chapter specifies a protocol that Sun Microsystems, Inc., and others are using. It has been designated RFC1014 by the ARPA Network Information Center.

5.2. Introduction

XDR is a standard for the description and encoding of data. It is useful for transferring data between different computer architectures, and has been used to communicate data between such diverse machines as the Sun Workstation, VAX, IBM-PC, and Cray. XDR fits into the ISO presentation layer, and is roughly analogous in purpose to X.409, ISO Abstract Syntax Notation. The major difference between these two is that XDR uses implicit typing, while X.409 uses explicit typing.

XDR uses a language to describe data formats. The language can only be used only to describe data; it is not a programming language. This language allows one to describe intricate data formats in a concise manner. The alternative of using graphical representations (itself an informal language) quickly becomes incomprehensible when faced with complexity. The XDR language itself is similar to the C language [1], just as Courier [4] is similar to Mesa. Protocols such as Sun RPC (Remote Procedure Call) and the NFS (Network File System) use XDR to describe the format of their data.

The XDR standard makes the following assumption: that bytes (or octets) are portable, where a byte is defined to be 8 bits of data. A given hardware device should encode the bytes onto the various media in such a way that other hardware devices may decode the bytes without loss of meaning. For example, the Ethernet standard suggests that bytes be encoded in "little-endian" style [2], or least significant bit first.

Basic Block Size

The representation of all items requires a multiple of four bytes (or 32 bits) of data. The bytes are numbered 0 through n-1. The bytes are read or written to some byte stream such that byte m always precedes byte m+1. If the n bytes needed to contain the data are not a multiple of four, then the n bytes are followed by enough (0 to 3) residual zero bytes, r, to make the total byte count a multiple of 4.

We include the familiar graphic box notation for illustration and comparison. In most illustrations, each box (delimited by a plus sign at the 4 corners and vertical bars and dashes) depicts a byte. Ellipses (...) between boxes show zero or more additional bytes where required.

A Block

```
+--------+--------+...+--------+--------+...+--------+
| byte 0 | byte 1 |...|byte n-1|    0   |...|    0   |
+--------+--------+...+--------+--------+...+--------+
|<-----------n bytes---------->|<------r bytes------>|
|<-----------n+r (where (n+r) mod 4 = 0)>----------->|
```

5.3. XDR Data Types

Each of the sections that follow describes a data type defined in the XDR standard, shows how it is declared in the language, and includes a graphic illustration of its encoding.

For each data type in the language we show a general paradigm declaration. Note that angle brackets (< and >) denote variable length sequences of data and square brackets ([and]) denote fixed-length sequences of data. "n", "m" and "r" denote integers. For the full language specification and more formal definitions of terms such as "identifier" and "declaration", refer to *The XDR Language Specification*, below.

For some data types, more specific examples are included. A more extensive example of a data description is in *An Example of an XDR Data Description*, below.

Integer

An XDR signed integer is a 32-bit datum that encodes an integer in the range [-2147483648,2147483647]. The integer is represented in two's complement notation. The most and least significant bytes are 0 and 3, respectively. Integers are declared as follows:

Integer

```
(MSB)                   (LSB)
+-------+-------+-------+-------+
|byte 0 |byte 1 |byte 2 |byte 3 |
+-------+-------+-------+-------+
<------------32 bits------------>
```

Unsigned Integer

An XDR unsigned integer is a 32-bit datum that encodes a nonnegative integer in the range [0,4294967295]. It is represented by an unsigned binary number whose most and least significant bytes are 0 and 3, respectively. An unsigned integer is declared as follows:

Unsigned Integer

```
(MSB)                   (LSB)
+-------+-------+-------+-------+
|byte 0 |byte 1 |byte 2 |byte 3 |
+-------+-------+-------+-------+
<------------32 bits------------>
```

Enumeration

Enumerations have the same representation as signed integers. Enumerations are handy for describing subsets of the integers. Enumerated data is declared as follows:

```
enum { name-identifier = constant, ... } identifier;
```

For example, the three colors red, yellow, and blue could be described by an enumerated type:

```
enum { RED = 2, YELLOW = 3, BLUE = 5 } colors;
```

It is an error to encode as an enum any other integer than those that have been given assignments in the enum declaration.

Boolean

Booleans are important enough and occur frequently enough to warrant their own explicit type in the standard. Booleans are declared as follows:

```
bool identifier;
```

This is equivalent to:

```
enum { FALSE = 0, TRUE = 1 } identifier;
```

Hyper Integer and Unsigned Hyper Integer

The standard also defines 64-bit (8-byte) numbers called hyper integer and unsigned hyper integer. Their representations are the obvious extensions of integer and unsigned integer defined above. They are represented in two's complement notation. The most and least significant bytes are 0 and 7, respectively. Their declarations:

Hyper Integer
Unsigned Hyper Integer

```
(MSB)                                                   (LSB)
+-------+-------+-------+-------+-------+-------+-------+-------+
|byte 0 |byte 1 |byte 2 |byte 3 |byte 4 |byte 5 |byte 6 |byte 7 |
+-------+-------+-------+-------+-------+-------+-------+-------+
<----------------------------64 bits---------------------------->
```

Floating-point

The standard defines the floating-point data type "float" (32 bits or 4 bytes). The encoding used is the IEEE standard for normalized single-precision floating-point numbers [3]. The following three fields describe the single-precision floating-point number:

S: The sign of the number. Values 0 and 1 represent positive and negative, respectively. One bit.

E: The exponent of the number, base 2. 8 bits are devoted to this field. The exponent is biased by 127.

F: The fractional part of the number's mantissa, base 2. 23 bits are devoted to this field.

Therefore, the floating-point number is described by:

```
(-1)**S * 2**(E-Bias) * 1.F
```

It is declared as follows:

Single-Precision Floating-Point

```
+-------+-------+-------+-------+
|byte 0 |byte 1 |byte 2 |byte 3 |
S|   E   |          F          |
+-------+-------+-------+-------+
1|<- 8 ->|<-------23 bits------>|
<------------32 bits------------>
```

Just as the most and least significant bytes of a number are 0 and 3, the most and least significant bits of a single-precision floating- point number are 0 and 31. The beginning bit (and most significant bit) offsets of S, E, and F are 0, 1, and 9, respectively. Note that these numbers refer to the mathematical positions of the bits, and NOT to their actual physical locations (which vary from medium to medium).

The IEEE specifications should be consulted concerning the encoding for signed zero, signed infinity (overflow), and denormalized numbers (underflow) [3]. According to IEEE specifications, the "NaN" (not a number) is system dependent and should not be used externally.

Double-precision Floating-point

The standard defines the encoding for the double-precision floating- point data type "double" (64 bits or 8 bytes). The encoding used is the IEEE standard for normalized double-precision floating-point numbers [3]. The standard encodes the following three fields, which describe the double-precision floating-point number:

- **S**: The sign of the number. Values 0 and 1 represent positive and negative, respectively. One bit.
- **E**: The exponent of the number, base 2. 11 bits are devoted to this field. The exponent is biased by 1023.
- **F**: The fractional part of the number's mantissa, base 2. 52 bits are devoted to this field.

Therefore, the floating-point number is described by:

```
(-1)**S * 2**(E-Bias) * 1.F
```

It is declared as follows:

Double-Precision Floating-Point

```
+------+------+------+------+------+------+------+------+
|byte 0|byte 1|byte 2|byte 3|byte 4|byte 5|byte 6|byte 7|
S|    E   |                    F                        |
+------+------+------+------+------+------+------+------+
1|<--11-->|<-----------------52 bits------------------->|
<-----------------------64 bits------------------------->
```

Just as the most and least significant bytes of a number are 0 and 3, the most and least significant bits of a double-precision floating- point number are 0 and 63. The beginning bit (and most significant bit) offsets of S, E , and F are 0, 1, and 12, respectively. Note that these numbers refer to the mathematical positions of the bits, and NOT to their actual physical locations (which vary from medium to medium).

The IEEE specifications should be consulted concerning the encoding for signed zero, signed infinity (overflow), and denormalized numbers (underflow) [3]. According to IEEE specifications, the "NaN" (not a number) is system dependent and should not be used externally.

Fixed-length Opaque Data

At times, fixed-length uninterpreted data needs to be passed among machines. This data is called "opaque" and is declared as follows:

```
opaque identifier[n];
```

where the constant n is the (static) number of bytes necessary to contain the opaque data. If n is not a multiple of four, then the n bytes are followed by enough (0 to 3) residual zero bytes, r, to make the total byte count of the opaque object a multiple of four.

Fixed-Length Opaque

```
0        1     ...
+--------+--------+...+--------+--------+...+--------+
| byte 0 | byte 1 |...|byte n-1|    0   |...|    0   |
+--------+--------+...+--------+--------+...+--------+
|<-----------n bytes---------->|<------r bytes------>|
|<-----------n+r (where (n+r) mod 4 = 0)------------>|
```

Variable-length Opaque Data

The standard also provides for variable-length (counted) opaque data, defined as a sequence of n (numbered 0 through n-1) arbitrary bytes to be the number n encoded as an unsigned integer (as described below), and followed by the n bytes of the sequence.

Byte m of the sequence always precedes byte m+1 of the sequence, and byte 0 of the sequence always follows the sequence's length (count). enough (0 to 3) residual zero bytes, r, to make the total byte count a multiple of four. Variable-length opaque data is declared in the following way:

```
opaque identifier<m>;
```

or

```
opaque identifier<>;
```

The constant m denotes an upper bound of the number of bytes that the sequence may contain. If m is not specified, as in the second declaration, it is assumed to be (2**32) - 1, the maximum length. The constant m would normally be found in a protocol specification. For example, a filing protocol may state that the maximum data transfer size is 8192 bytes, as follows:

```
opaque filedata<8192>;
```

This can be illustrated as follows:

Variable-Length Opaque

```
0     1     2     3     4     5   ...
+-----+-----+-----+-----+-----+-----+...+-----+-----+...+-----+
|        length n       |byte0|byte1|...| n-1 |  0  |...|  0  |
+-----+-----+-----+-----+-----+-----+...+-----+-----+...+-----+
|<-------4 bytes------->|<------n bytes------>|<---r bytes--->|
|<----n+r (where (n+r) mod 4 = 0)---->|
```

It is an error to encode a length greater than the maximum described in the specification.

String

The standard defines a string of n (numbered 0 through n-1) ASCII bytes to be the number n encoded as an unsigned integer (as described above), and followed by the n bytes of the string. Byte m of the string always precedes byte m+1 of the string, and byte 0 of the string always follows the string's length. If n is not a multiple of four, then the n bytes are followed by enough (0 to 3) residual zero bytes, r, to make the total byte count a multiple of four. Counted byte strings are declared as follows:

```
string object<m>;
```

or

```
string object<>;
```

The constant m denotes an upper bound of the number of bytes that a string may contain. If m is not specified, as in the second declaration, it is assumed to be (2**32) - 1, the maximum length. The constant m would normally be found in a protocol specification. For example, a filing protocol may state that a file name can be no longer than 255 bytes, as follows:

```
string filename<255>;
```

Which can be illustrated as:

A String

```
0     1     2     3     4     5   ...
+-----+-----+-----+-----+-----+-----+...+-----+-----+...+-----+
|        length n       |byte0|byte1|...| n-1 |  0  |...|  0  |
+-----+-----+-----+-----+-----+-----+...+-----+-----+...+-----+
|<-------4 bytes------->|<------n bytes------>|<---r bytes--->|
|<----n+r (where (n+r) mod 4 = 0)---->|
```

It is an error to encode a length greater than the maximum described in the specification.

Fixed-length Array

Declarations for fixed-length arrays of homogeneous elements are in the following form:

```
type-name identifier[n];
```

Fixed-length arrays of elements numbered 0 through n-1 are encoded by individually encoding the elements of the array in their natural order, 0 through n-1. Each element's size is a multiple of four bytes. Though all elements are of the same type, the elements may have different sizes. For example, in a fixed-length array of strings, all elements are of type "string", yet each element will vary in its length.

Fixed-Length Array

```
+---+---+---+---+---+---+---+---+...+---+---+---+---+
|   element 0   |   element 1   |...|  element n-1  |
+---+---+---+---+---+---+---+---+...+---+---+---+---+
|<--------------------n elements------------------->|
```

Variable-length Array

Counted arrays provide the ability to encode variable-length arrays of homogeneous elements. The array is encoded as the element count n (an unsigned integer) followed by the encoding of each of the array's elements, starting with element 0 and progressing through element n- 1. The declaration for variable-length arrays follows this form:

```
type-name identifier<m>;
```

or

```
type-name identifier<>;
```

The constant m specifies the maximum acceptable element count of an array; if m is not specified, as in the second declaration, it is assumed to be (2**32) - 1.

Counted Array

```
0  1  2  3
+--+--+--+--+--+--+--+--+--+--+--+--+...+--+--+--+--+
|     n     | element 0 | element 1 |...|element n-1|
+--+--+--+--+--+--+--+--+--+--+--+--+...+--+--+--+--+
|<-4 bytes->|<--------------n elements------------->|
```

It is an error to encode a value of n that is greater than the maximum described in the specification.

Structure

Structures are declared as follows:

```
struct {
    component-declaration-A;
    component-declaration-B;
    ...
} identifier;
```

The components of the structure are encoded in the order of their declaration in the structure. Each component's size is a multiple of four bytes, though the components may be different sizes.

Structure

```
+-------------+-------------+...
| component A | component B |...
+-------------+-------------+...
```

Discriminated Union

A discriminated union is a type composed of a discriminant followed by a type selected from a set of prearranged types according to the value of the discriminant. The type of discriminant is either "int", "unsigned int", or an enumerated type, such as "bool". The component types are called "arms" of the union, and are preceded by the value of the discriminant which implies their encoding. Discriminated unions are declared as follows:

```
union switch (discriminant-declaration) {
    case discriminant-value-A:
    arm-declaration-A;
    case discriminant-value-B:
    arm-declaration-B;
    ...
    default: default-declaration;
} identifier;
```

Each "case" keyword is followed by a legal value of the discriminant. The default arm is optional. If it is not specified, then a valid encoding of the union cannot take on unspecified discriminant values. The size of the implied arm is always a multiple of four bytes.

The discriminated union is encoded as its discriminant followed by the encoding of the implied arm.

Discriminated Union

```
0   1   2   3
+---+---+---+---+---+---+---+---+
|  discriminant |  implied arm  |
+---+---+---+---+---+---+---+---+
|<---4 bytes--->|
```

Void

An XDR void is a 0-byte quantity. Voids are useful for describing operations that take no data as input or no data as output. They are also useful in unions, where some arms may contain data and others do not. The declaration is simply as follows:

```
void;
```

Voids are illustrated as follows:

```
++
||
++
--><-- 0 bytes
```

Constant

The data declaration for a constant follows this form:

```
const name-identifier = n;
```

"const" is used to define a symbolic name for a constant; it does not declare any data. The symbolic constant may be used anywhere a regular constant may be used. For example, the following defines a symbolic constant DOZEN, equal to 12.

```
const DOZEN = 12;
```

Typedef

"typedef" does not declare any data either, but serves to define new identifiers for declaring data. The syntax is:

```
typedef declaration;
```

The new type name is actually the variable name in the declaration part of the typedef. For example, the following defines a new type called "eggbox" using an existing type called "egg":

```
typedef egg eggbox[DOZEN];
```

Variables declared using the new type name have the same type as the new type name would have in the typedef, if it was considered a variable. For example, the following two declarations are equivalent in declaring the variable "fresheggs":

```
eggbox  fresheggs;
egg     fresheggs[DOZEN];
```

When a typedef involves a struct, enum, or union definition, there is another (preferred) syntax that may be used to define the same type. In general, a typedef of the following form:

```
typedef <<struct, union, or enum definition>> identifier;
```

may be converted to the alternative form by removing the "typedef" part and placing the identifier after the "struct", "union", or "enum" keyword, instead of at the end. For example, here are the two ways to define the type "bool":

```
typedef enum {         /* using typedef */
    FALSE = 0,
    TRUE = 1
    } bool;

enum bool {            /* preferred alternative */
    FALSE = 0,
    TRUE = 1
    };
```

The reason this syntax is preferred is one does not have to wait until the end of a declaration to figure out the name of the new type.

Optional-data

Optional-data is one kind of union that occurs so frequently that we give it a special syntax of its own for declaring it. It is declared as follows:

```
type-name *identifier;
```

This is equivalent to the following union:

```
union switch (bool opted) {
    case TRUE:
    type-name element;
    case FALSE:
    void;
} identifier;
```

It is also equivalent to the following variable-length array declaration, since the boolean "opted" can be interpreted as the length of the array:

```
type-name identifier<1>;
```

Optional-data is not so interesting in itself, but it is very useful for describing recursive data-structures such as linked-lists and trees. For example, the following defines a type "stringlist" that encodes lists of arbitrary length strings:

```
struct *stringlist {
    string item<>;
    stringlist next;
};
```

It could have been equivalently declared as the following union:

```
union stringlist switch (bool opted) {
    case TRUE:
        struct {
            string item<>;
            stringlist next;
        } element;
    case FALSE:
        void;
};
```

or as a variable-length array:

```
struct stringlist<1> {
    string item<>;
    stringlist next;
};
```

Both of these declarations obscure the intention of the stringlist type, so the optional-data declaration is preferred over both of them. The optional-data type also has a close correlation to how recursive data structures are represented in high-level languages such as Pascal or C by use of pointers. In fact, the syntax is the same as that of the C language for pointers.

Areas for Future Enhancement

The XDR standard lacks representations for bit fields and bitmaps, since the standard is based on bytes. Also missing are packed (or binary-coded) decimals.

The intent of the XDR standard was not to describe every kind of data that people have ever sent or will ever want to send from machine to machine. Rather, it only describes the most commonly used data-types of high-level languages such as Pascal or C so that applications written in these languages will be able to communicate easily over some medium.

One could imagine extensions to XDR that would let it describe almost any existing protocol, such as TCP. The minimum necessary for this are support for different block sizes and byte-orders. The XDR discussed here could then be considered the 4-byte big-endian member of a larger XDR family.

5.4. Discussion

Why a Language for Describing Data?

There are many advantages in using a data-description language such as XDR versus using diagrams. Languages are more formal than diagrams and lead to less ambiguous descriptions of data. Languages are also easier to understand and allow one to think of other issues instead of the low-level details of bit-encoding. Also, there is a close analogy between the types of XDR and a high-level language such as C or Pascal. This makes the implementation of XDR encoding and decoding modules an easier task. Finally, the language specification itself is an ASCII string that can be passed from machine to machine to perform on-the-fly data interpretation.

Why Only one Byte-Order for an XDR Unit?

Supporting two byte-orderings requires a higher level protocol for determining in which byte-order the data is encoded. Since XDR is not a protocol, this can't be done. The advantage of this, though, is that data in XDR format can be written to a magnetic tape, for example, and any machine will be able to interpret it, since no higher level protocol is necessary for determining the byte-order.

Why does XDR use Big-Endian Byte-Order?

Yes, it is unfair, but having only one byte-order means you have to be unfair to somebody. Many architectures, such as the Motorola 68000 and IBM 370, support the big-endian byte-order.

Why is the XDR Unit Four Bytes Wide?

There is a tradeoff in choosing the XDR unit size. Choosing a small size such as two makes the encoded data small, but causes alignment problems for machines that aren't aligned on these boundaries. A large size such as eight means the data will be aligned on virtually every machine, but causes the encoded data to grow too big. We chose four as a compromise. Four is big enough to support most architectures efficiently, except for rare machines such as the eight-byte aligned Cray. Four is also small enough to keep the encoded data restricted to a reasonable size.

Why must Variable-Length Data be Padded with Zeros?

It is desirable that the same data encode into the same thing on all machines, so that encoded data can be meaningfully compared or checksummed. Forcing the padded bytes to be zero ensures this.

Why is there No Explicit Data-Typing?

Data-typing has a relatively high cost for what small advantages it may have. One cost is the expansion of data due to the inserted type fields. Another is the added cost of interpreting these type fields and acting accordingly. And most protocols already know what type they expect, so data-typing supplies only redundant information. However, one can still get the benefits of data-typing using XDR. One way is to encode two things: first a string which is the XDR data description of the encoded data, and then the encoded data itself. Another way is to assign a value to all the types in XDR, and then define a universal type which takes this value as its discriminant and for each value, describes the corresponding data type.

5.5. The XDR Language Specification

Notational Conventions

This specification uses an extended Backus-Naur Form notation for describing the XDR language. Here is a brief description of the notation:

1. The characters `|`, `(`, `)`, `[`, `]`, `  `, and `*` are special.
2. Terminal symbols are strings of any characters surrounded by double quotes.
3. Non-terminal symbols are strings of non-special characters.
4. Alternative items are separated by a vertical bar `|`). (
5. Optional items are enclosed in brackets.
6. Items are grouped together by enclosing them in parentheses.
7. A `*` following an item means 0 or more occurrences of that item.

For example, consider the following pattern:

```
"a " "very" (", " " very")* [" cold " "and"] " rainy " ("day" | "night")
```

An infinite number of strings match this pattern. A few of them are:

```
"a very rainy day"
"a very, very rainy day"
"a very cold and rainy day"
"a very, very, very cold and rainy night"
```

Lexical Notes

1. Comments begin with '/*' and terminate with '*/'.
2. White space serves to separate items and is otherwise ignored.
3. An identifier is a letter followed by an optional sequence of letters, digits or underbar ('_'). The case of identifiers is not ignored.

4. A constant is a sequence of one or more decimal digits, optionally preceded by a minus-sign ('-').

Syntax Information

```
declaration:
    type-specifier identifier
    | type-specifier identifier "[" value "]"
    | type-specifier identifier "<" [ value ] ">"
    | "opaque" identifier "[" value "]"
    | "opaque" identifier "<" [ value ] ">"
    | "string" identifier "<" [ value ] ">"
    | type-specifier "*" identifier
    | "void"

value:
    constant
    | identifier

type-specifier:
      [ "unsigned" ] "int"
    | [ "unsigned" ] "hyper"
    | "float"
    | "double"
    | "bool"
    | enum-type-spec
    | struct-type-spec
    | union-type-spec
    | identifier

enum-type-spec:
    "enum" enum-body

enum-body:
    "{"
    ( identifier "=" value )
    ( "," identifier "=" value )*
    "}"

struct-type-spec:
    "struct" struct-body

struct-body:
    "{"
    ( declaration ";" )
    ( declaration ";" )*
    "}"

union-type-spec:
    "union" union-body

union-body:
    "switch" "(" declaration ")" "{"
    ( "case" value ":" declaration ";" )
    ( "case" value ":" declaration ";" )*
```

```
    [ "default" ":" declaration ";" ]
    "}"

constant-def:
    "const" identifier "=" constant ";"

type-def:
    "typedef" declaration ";"
    | "enum" identifier enum-body ";"
    | "struct" identifier struct-body ";"
    | "union" identifier union-body ";"

definition:
    type-def
    | constant-def

specification:
    definition *
```

Syntax Notes

1. The following are keywords and cannot be used as identifiers: "bool", "case", "const", "default", "double", "enum", "float", "hyper", "opaque", "string", "struct", "switch", "typedef", "union", "unsigned" and "void".
2. Only unsigned constants may be used as size specifications for arrays. If an identifier is used, it must have been declared previously as an unsigned constant in a "const" definition.
3. Constant and type identifiers within the scope of a specification are in the same name space and must be declared uniquely within this scope.
4. Similarly, variable names must be unique within the scope of struct and union declarations. Nested struct and union declarations create new scopes.
5. The discriminant of a union must be of a type that evaluates to an integer. That is, "int", "unsigned int", "bool", an enumerated type or any typedefed type that evaluates to one of these is legal. Also, the case values must be one of the legal values of the discriminant. Finally, a case value may not be specified more than once within the scope of a union declaration.

5.6. An Example of an XDR Data Description

Here is a short XDR data description of a thing called a "file", which might be used to transfer files from one machine to another.

```
const MAXUSERNAME = 32;       /* max length of a user name */
const MAXFILELEN = 65535;     /* max length of a file     */
const MAXNAMELEN = 255;       /* max length of a file name */

/*
 * Types of files:
 */

enum filekind {
    TEXT = 0,        /* ascii data */
    DATA = 1,        /* raw data   */
    EXEC = 2         /* executable */
};

/*
 * File information, per kind of file:
 */

union filetype switch (filekind kind) {
    case TEXT:
        void;                             /* no extra information */
    case DATA:
        string creator<MAXNAMELEN>;       /* data creator         */
    case EXEC:
        string interpretor<MAXNAMELEN>;   /* program interpretor  */
};

/*
 * A complete file:
 */

struct file {
    string filename<MAXNAMELEN>; /* name of file */
    filetype type;               /* info about file */
    string owner<MAXUSERNAME>;   /* owner of file   */
    opaque data<MAXFILELEN>;     /* file data       */
};
```

Suppose now that there is a user named "john" who wants to store his lisp program "sillyprog" that contains just the data "(quit)". His file would be encoded as follows:

Offset	*Hex Bytes*	*ASCII*	*Description*
0	00 00 00 09	....	Length of filename = 9
4	73 69 6c 6c	sill	Filename characters
8	79 70 72 6f	ypro	... and more characters ...
12	67 00 00 00	g...	... and 3 zero-bytes of fill
16	00 00 00 02	....	Filekind is EXEC = 2
20	00 00 00 04	....	Length of interpretor = 4
24	6c 69 73 70	lisp	Interpretor characters
28	00 00 00 04	....	Length of owner = 4
32	6a 6f 68 6e	john	Owner characters
36	00 00 00 06	....	Length of file data = 6
40	28 71 75 69	(qui	File data bytes ...
44	74 29 00 00	t)..	... and 2 zero-bytes of fill

5.7. References

[1] Brian W. Kernighan & Dennis M. Ritchie, "The C Programming Language", Bell Laboratories, Murray Hill, New Jersey, 1978.

[2] Danny Cohen, "On Holy Wars and a Plea for Peace", IEEE Computer, October 1981.

[3] "IEEE Standard for Binary Floating-Point Arithmetic", ANSI/IEEE Standard 754-1985, Institute of Electrical and Electronics Engineers, August 1985.

[4] "Courier: The Remote Procedure Call Protocol", XEROX Corporation, XSIS 038112, December 1981.

6

Remote Procedure Calls: Protocol Specification

6

Remote Procedure Calls: Protocol Specification

6.1. Status of this Memo

Note: This chapter specifies a protocol that Sun Microsystems, Inc., and others are using. It has been submitted to the ARPA-Internet for consideration as an RFC.

6.2. Introduction

This chapter specifies a message protocol used in implementing Sun's Remote Procedure Call (RPC) package. (The message protocol is specified with the External Data Representation (XDR) language. See the *External Data Representation Standard: Protocol Specification* for the details. Here, we assume that the reader is familiar with XDR and do not attempt to justify it or its uses). The paper by Birrell and Nelson [1] is recommended as an excellent background to and justification of RPC.

Terminology

This chapter discusses servers, services, programs, procedures, clients, and versions. A server is a piece of software where network services are implemented. A network service is a collection of one or more remote programs. A remote program implements one or more remote procedures; the procedures, their parameters, and results are documented in the specific program's protocol specification (see the *Port Mapper Program Protocol*, below, for an example). Network clients are pieces of software that initiate remote procedure calls to services. A server may support more than one version of a remote program in order to be forward compatible with changing protocols.

For example, a network file service may be composed of two programs. One program may deal with high-level applications such as file system access control and locking. The other may deal with low-level file IO and have procedures like "read" and "write". A client machine of the network file service would call the procedures associated with the two programs of the service on behalf of some user on the client machine.

The RPC Model

The remote procedure call model is similar to the local procedure call model. In the local case, the caller places arguments to a procedure in some well-specified location (such as a result register). It then transfers control to the procedure, and eventually gains back control. At that point, the results of the procedure are extracted from the well-specified location, and the caller continues execution.

The remote procedure call is similar, in that one thread of control logically winds through two processes—one is the caller's process, the other is a server's process. That is, the caller process sends a call message to the server process and waits (blocks) for a reply message. The call message contains the procedure's parameters, among other things. The reply message contains the procedure's results, among other things. Once the reply message is received, the results of the procedure are extracted, and caller's execution is resumed.

On the server side, a process is dormant awaiting the arrival of a call message. When one arrives, the server process extracts the procedure's parameters, computes the results, sends a reply message, and then awaits the next call message.

Note that in this model, only one of the two processes is active at any given time. However, this model is only given as an example. The RPC protocol makes no restrictions on the concurrency model implemented, and others are possible. For example, an implementation may choose to have RPC calls be asynchronous, so that the client may do useful work while waiting for the reply from the server. Another possibility is to have the server create a task to process an incoming request, so that the server can be free to receive other requests.

Transports and Semantics

The RPC protocol is independent of transport protocols. That is, RPC does not care how a message is passed from one process to another. The protocol deals only with specification and interpretation of messages.

It is important to point out that RPC does not try to implement any kind of reliability and that the application must be aware of the type of transport protocol underneath RPC. If it knows it is running on top of a reliable transport such as TCP/IP[6], then most of the work is already done for it. On the other hand, if it is running on top of an unreliable transport such as UDP/IP[7], it must implement is own retransmission and time-out policy as the RPC layer does not provide this service.

Because of transport independence, the RPC protocol does not attach specific semantics to the remote procedures or their execution. Semantics can be inferred from (but should be explicitly specified by) the underlying transport protocol. For example, consider RPC running on top of an unreliable transport such as UDP/IP. If an application retransmits RPC messages after short time-outs, the only thing it can infer if it receives no reply is that the procedure was executed zero or more times. If it does receive a reply, then it can infer that the procedure was executed at least once.

A server may wish to remember previously granted requests from a client and not regrant them in order to insure some degree of execute-at-most-once semantics. A server can do this by taking advantage of the transaction ID that is packaged with every RPC request. The main use of this transaction is by the client RPC layer in matching replies to requests. However, a client application may choose to reuse its previous transaction ID when retransmitting a request. The server application, knowing this fact, may choose to remember this ID after granting a request and not regrant requests with the same ID in order to achieve some degree of execute-at-most-once semantics. The server is not allowed to examine this ID in any other way except as a test for equality.

On the other hand, if using a reliable transport such as TCP/IP, the application can infer from a reply message that the procedure was executed exactly once, but if it receives no reply message, it cannot assume the remote procedure was not executed. Note that even if a connection-oriented protocol like TCP is used, an application still needs time-outs and reconnection to handle server crashes.

There are other possibilities for transports besides datagram- or connection-oriented protocols. For example, a request-reply protocol such as VMTP[2] is perhaps the most natural transport for RPC.

NOTE *At Sun, RPC is currently implemented on top of both TCP/IP and UDP/IP transports.*

Binding and Rendezvous Independence

The act of binding a client to a service is NOT part of the remote procedure call specification. This important and necessary function is left up to some higher-level software. (The software may use RPC itself—see the *Port Mapper Program Protocol*, below).

Implementors should think of the RPC protocol as the jump-subroutine instruction ("JSR") of a network; the loader (binder) makes JSR useful, and the loader itself uses JSR to accomplish its task. Likewise, the network makes RPC useful, using RPC to accomplish this task.

Authentication

The RPC protocol provides the fields necessary for a client to identify itself to a service and vice-versa. Security and access control mechanisms can be built on top of the message authentication. Several different authentication protocols can be supported. A field in the RPC header indicates which protocol is being used. More information on specific authentication protocols can be found in the *Authentication Protocols*, below.

6.3. RPC Protocol Requirements

The RPC protocol must provide for the following:

1. Unique specification of a procedure to be called.
2. Provisions for matching response messages to request messages.
3. Provisions for authenticating the caller to service and vice-versa.

Besides these requirements, features that detect the following are worth supporting because of protocol roll-over errors, implementation bugs, user error, and network administration:

1. RPC protocol mismatches.
2. Remote program protocol version mismatches.
3. Protocol errors (such as misspecification of a procedure's parameters).
4. Reasons why remote authentication failed.
5. Any other reasons why the desired procedure was not called.

Programs and Procedures

The RPC call message has three unsigned fields: remote program number, remote program version number, and remote procedure number. The three fields uniquely identify the procedure to be called. Program numbers are administered by some central authority (like Sun). Once an implementor has a program number, he can implement his remote program; the first implementation would most likely have the version number of 1. Because most new protocols evolve into better, stable, and mature protocols, a version field of the call message identifies which version of the protocol the caller is using. Version numbers make speaking old and new protocols through the same server process possible.

The procedure number identifies the procedure to be called. These numbers are documented in the specific program's protocol specification. For example, a file service's protocol specification may state that its procedure number 5 is "read" and procedure number 12 is "write".

Just as remote program protocols may change over several versions, the actual RPC message protocol could also change. Therefore, the call message also has in it the RPC version number, which is always equal to two for the version of RPC described here.

The reply message to a request message has enough information to distinguish the following error conditions:

1. The remote implementation of RPC does speak protocol version 2. The lowest and highest supported RPC version numbers are returned.
2. The remote program is not available on the remote system.
3. The remote program does not support the requested version number. The lowest and highest supported remote program version numbers are returned.
4. The requested procedure number does not exist. (This is usually a caller side protocol or programming error.)
5. The parameters to the remote procedure appear to be garbage from the server's point of view. (Again, this is usually caused by a disagreement about the protocol between client and service.)

Authentication

Provisions for authentication of caller to service and vice-versa are provided as a part of the RPC protocol. The call message has two authentication fields, the credentials and verifier. The reply message has one authentication field, the response verifier. The RPC protocol specification defines all three fields to be the following opaque type:

```
enum auth_flavor {
    AUTH_NULL    = 0,
    AUTH_UNIX    = 1,
    AUTH_SHORT   = 2,
    AUTH_DES     = 3
    /* and more to be defined */
};

struct opaque_auth {
    auth_flavor flavor;
    opaque body<400>;
};
```

In simple English, any `opaque_auth` structure is an `auth_flavor` enumeration followed by bytes which are opaque to the RPC protocol implementation.

The interpretation and semantics of the data contained within the authentication fields is specified by individual, independent authentication protocol specifications. (See *Authentication Protocols*, below, for definitions of the various authentication protocols.)

If authentication parameters were rejected, the response message contains information stating why they were rejected.

Program Number Assignment

Program numbers are given out in groups of `0x20000000` (decimal 536870912) according to the following chart:

Program Numbers	*Description*
`0 - 1fffffff`	*Defined by Sun*
`20000000 - 3fffffff`	*Defined by user*
`40000000 - 5fffffff`	*Transient*
`60000000 - 7fffffff`	*Reserved*
`80000000 - 9fffffff`	*Reserved*
`a0000000 - bfffffff`	*Reserved*
`c0000000 - dfffffff`	*Reserved*
`e0000000 - ffffffff`	*Reserved*

The first group is a range of numbers administered by Sun Microsystems and should be identical for all sites. The second range is for applications peculiar to a particular site. This range is intended primarily for debugging new programs. When a site develops an application that might be of general interest, that application should be given an assigned number in the first range. The third group is for applications that generate program numbers dynamically. The final groups are reserved for future use, and should not be used.

Other Uses of the RPC Protocol

The intended use of this protocol is for calling remote procedures. That is, each call message is matched with a response message. However, the protocol itself is a message-passing protocol with which other (non-RPC) protocols can be implemented. Sun currently uses, or perhaps abuses, the RPC message protocol for the following two (non-RPC) protocols: batching (or pipelining) and broadcast RPC.

These two protocols are discussed but not defined below.

Batching

Batching allows a client to send an arbitrarily large sequence of call messages to a server; batching typically uses reliable byte stream protocols (like TCP/IP) for its transport. In the case of batching, the client never waits for a reply from the server, and the server does not send replies to batch requests. A sequence of batch calls is usually terminated by a legitimate RPC in order to flush the pipeline (with positive acknowledgement).

Broadcast RPC

In broadcast RPC-based protocols, the client sends a broadcast packet to the network and waits for numerous replies. Broadcast RPC uses unreliable, packet-based protocols (like UDP/IP) as its transports. Servers that support broadcast protocols only respond when the request is successfully processed, and are silent in the face of errors. Broadcast RPC uses the Port Mapper RPC service to achieve its semantics. See the *Port Mapper Program Protocol*, below, for more information.

6.4. The RPC Message Protocol

This section defines the RPC message protocol in the XDR data description language. The message is defined in a top-down style.

```
enum msg_type {
    CALL  = 0,
    REPLY = 1
};

/*
 * A reply to a call message can take on two forms:
 * The message was either accepted or rejected.
 */
enum reply_stat {
    MSG_ACCEPTED = 0,
    MSG_DENIED   = 1
};

/*
 * Given that a call message was accepted, the following is the
 * status of an attempt to call a remote procedure.
 */
enum accept_stat {
    SUCCESS       = 0, /* RPC executed successfully     */
    PROG_UNAVAIL  = 1, /* remote hasn't exported program */
    PROG_MISMATCH = 2, /* remote can't support version # */
    PROC_UNAVAIL  = 3, /* program can't support procedure */
    GARBAGE_ARGS  = 4  /* procedure can't decode params  */
};

/*
 * Reasons why a call message was rejected:
 */
enum reject_stat {
    RPC_MISMATCH = 0, /* RPC version number != 2      */
    AUTH_ERROR = 1    /* remote can't authenticate caller */
```

```
};

/*
 * Why authentication failed:
 */
enum auth_stat {
     AUTH_BADCRED        = 1,   /* bad credentials */
     AUTH_REJECTEDCRED = 2,   /* client must begin new session */
     AUTH_BADVERF        = 3,   /* bad verifier */
     AUTH_REJECTEDVERF = 4,   /* verifier expired or replayed */
     AUTH_TOOWEAK        = 5    /* rejected for security reasons */
};

/*
 * The RPC message:
 * All messages start with a transaction identifier, xid,
 * followed by a two-armed discriminated union. The union's
 * discriminant is a msg_type which switches to one of the two
 * types of the message. The xid of a REPLY message always
 * matches that of the initiating CALL message. NB: The xid
 * field is only used for clients matching reply messages with
 * call messages or for servers detecting retransmissions; the
 * service side cannot treat this id as any type of sequence
 * number.
 */
struct rpc_msg {
     unsigned int xid;
     union switch (msg_type mtype) {
          case CALL:
               call_body cbody;
          case REPLY:
               reply_body rbody;
     } body;
};

/*
 * Body of an RPC request call:
 * In version 2 of the RPC protocol specification, rpcvers must
 * be equal to 2. The fields prog, vers, and proc specify the
 * remote program, its version number, and the procedure within
 * the remote program to be called. After these fields are two
 * authentication parameters: cred (authentication credentials)
 * and verf (authentication verifier). The two authentication
 * parameters are followed by the parameters to the remote
 * procedure, which are specified by the specific program
 * protocol.
 */
struct call_body {
     unsigned int rpcvers;   /* must be equal to two (2) */
     unsigned int prog;
     unsigned int vers;
     unsigned int proc;
     opaque_auth cred;
```

```
    opaque_auth verf;
    /* procedure specific parameters start here */
};

/*
* Body of a reply to an RPC request:
* The call message was either accepted or rejected.
*/
union reply_body switch (reply_stat stat) {
    case MSG_ACCEPTED:
        accepted_reply areply;
    case MSG_DENIED:
        rejected_reply rreply;
} reply;

/*
* Reply to an RPC request that was accepted by the server:
* there could be an error even though the request was accepted.
* The first field is an authentication verifier that the server
* generates in order to validate itself to the caller. It is
* followed by a union whose discriminant is an enum
* accept_stat. The SUCCESS arm of the union is protocol
* specific. The PROG_UNAVAIL, PROC_UNAVAIL, and GARBAGE_ARGP
* arms of the union are void. The PROG_MISMATCH arm specifies
* the lowest and highest version numbers of the remote program
* supported by the server.
*/
struct accepted_reply {
    opaque_auth verf;
    union switch (accept_stat stat) {
        case SUCCESS:
            opaque results[0];
            /* procedure-specific results start here */
        case PROG_MISMATCH:
            struct {
                unsigned int low;
                unsigned int high;
            } mismatch_info;
        default:
            /*
            * Void. Cases include PROG_UNAVAIL, PROC_UNAVAIL,
            * and GARBAGE_ARGS.
            */
            void;
    } reply_data;
};

/*
* Reply to an RPC request that was rejected by the server:
* The request can be rejected for two reasons: either the
* server is not running a compatible version of the RPC
* protocol (RPC_MISMATCH), or the server refuses to
* authenticate the caller (AUTH_ERROR). In case of an RPC
```

```
 * version mismatch, the server returns the lowest and highest
 * supported RPC version numbers. In case of refused
 * authentication, failure status is returned.
 */
union rejected_reply switch (reject_stat stat) {
    case RPC_MISMATCH:
        struct {
            unsigned int low;
            unsigned int high;
        } mismatch_info;
    case AUTH_ERROR:
        auth_stat stat;
};
```

6.5. Authentication Protocols

As previously stated, authentication parameters are opaque, but open-ended to the rest of the RPC protocol. This section defines some "flavors" of authentication implemented at (and supported by) Sun. Other sites are free to invent new authentication types, with the same rules of flavor number assignment as there is for program number assignment.

Null Authentication

Often calls must be made where the caller does not know who he is or the server does not care who the caller is. In this case, the flavor value (the discriminant of the `opaque_auth`'s union) of the RPC message's credentials, verifier, and response verifier is `AUTH_NULL`. The bytes of the opaque_auth's body are undefined. It is recommended that the opaque length be zero.

UNIX Authentication

The caller of a remote procedure may wish to identify himself as he is identified on a UNIX system. The value of the credential's discriminant of an RPC call message is `AUTH_UNIX`. The bytes of the credential's opaque body encode the following structure:

```
struct auth_unix {
    unsigned int stamp;
    string machinename<255>;
    unsigned int uid;
    unsigned int gid;
    unsigned int gids<10>;
};
```

The `stamp` is an arbitrary ID which the caller machine may generate. The `machinename` is the name of the caller's machine (like "krypton"). The `uid` is the caller's effective user ID. The `gid` is the caller's effective group ID. The `gids` is a counted array of groups which contain the caller as a member. The verifier accompanying the credentials should be of `AUTH_NULL` (defined above).

The value of the discriminant of the response verifier received in the reply message from the server may be `AUTH_NULL` or `AUTH_SHORT`. In the case of `AUTH_SHORT`, the bytes of the response verifier's string encode an opaque structure. This new opaque structure may now be passed to the server instead of the original `AUTH_UNIX` flavor credentials. The server keeps a cache which maps shorthand opaque structures (passed back by way of an `AUTH_SHORT` style response verifier) to the original credentials of the caller. The caller can save network bandwidth and server cpu cycles by using the new credentials.

The server may flush the shorthand opaque structure at any time. If this happens, the remote procedure call message will be rejected due to an authentication error. The reason for the failure will be `AUTH_REJECTEDCRED`. At this point, the caller may wish to try the original `AUTH_UNIX` style of credentials.

DES Authentication

UNIX authentication suffers from two major problems:

1. The naming is too UNIX-system oriented.
2. There is no verifier, so credentials can easily be faked.

DES authentication attempts to fix these two problems.

Naming

The first problem is handled by addressing the caller by a simple string of characters instead of by an operating system specific integer. This string of characters is known as the "netname" or network name of the caller. The server is not allowed to interpret the contents of the caller's name in any other way except to identify the caller. Thus, netnames should be unique for every caller in the internet.

It is up to each operating system's implementation of DES authentication to generate netnames for its users that insure this uniqueness when they call upon remote servers. Operating systems already know how to distinguish users local to their systems. It is usually a simple matter to extend this mechanism to the network. For example, a UNIX user at Sun with a user ID of 515 might be assigned the following netname: "unix.515@sun.com". This netname contains three items that serve to insure it is unique. Going backwards, there is only one naming domain called "sun.com" in the internet. Within this domain, there is only one UNIX user with user ID 515. However, there may be another user on another operating system, for example VMS, within the same naming domain that, by coincidence, happens to have the same user ID. To insure that these two users can be distinguished we add the operating system name. So one user is "unix.515@sun.com" and the other is "vms.515@sun.com".

The first field is actually a naming method rather than an operating system name. It just happens that today there is almost a one-to-one correspondence between naming methods and operating systems. If the world could agree on a naming standard, the first field could be the name of that standard, instead of an operating system name.

DES Authentication Verifiers

Unlike UNIX authentication, DES authentication does have a verifier so the server can validate the client's credential (and vice-versa). The contents of this verifier is primarily an encrypted timestamp. The server can decrypt this timestamp, and if it is close to what the real time is, then the client must have encrypted it correctly. The only way the client could encrypt it correctly is to know the "conversation key" of the RPC session. And if the client knows the conversation key, then it must be the real client.

The conversation key is a DES [5] key which the client generates and notifies the server of in its first RPC call. The conversation key is encrypted using a public key scheme in this first transaction. The particular public key scheme used in DES authentication is Diffie-Hellman [3] with 192-bit keys. The details of this encryption method are described later.

The client and the server need the same notion of the current time in order for all of this to work. If network time synchronization cannot be guaranteed, then client can synchronize with the server before beginning the conversation, perhaps by consulting the Internet Time Server (TIME[4]).

The way a server determines if a client timestamp is valid is somewhat complicated. For any other transaction but the first, the server just checks for two things:

1. the timestamp is greater than the one previously seen from the same client.

2. the timestamp has not expired.

A timestamp is expired if the server's time is later than the sum of the client's timestamp plus what is known as the client's "window". The "window" is a number the client passes (encrypted) to the server in its first transaction. You can think of it as a lifetime for the credential.

This explains everything but the first transaction. In the first transaction, the server checks only that the timestamp has not expired. If this was all that was done though, then it would be quite easy for the client to send random data in place of the timestamp with a fairly good chance of succeeding. As an added check, the client sends an encrypted item in the first transaction known as the "window verifier" which must be equal to the window minus 1, or the server will reject the credential.

The client too must check the verifier returned from the server to be sure it is legitimate. The server sends back to the client the encrypted timestamp it received from the client, minus one second. If the client gets anything different than this, it will reject it.

Nicknames and Clock Synchronization

After the first transaction, the server's DES authentication subsystem returns in its verifier to the client an integer "nickname" which the client may use in its further transactions instead of passing its netname, encrypted DES key and window every time. The nickname is most likely an index into a table on the server which stores for each client its netname, decrypted DES key and window.

Though they originally were synchronized, the client's and server's clocks can get out of sync again. When this happens the client RPC subsystem most likely will get back `RPC_AUTHERROR` at which point it should resynchronize.

A client may still get the `RPC_AUTHERROR` error even though it is synchronized with the server. The reason is that the server's nickname table is a limited size, and it may flush entries whenever it wants. A client should resend its original credential in this case and the server will give it a new nickname. If a server crashes, the entire nickname table gets flushed, and all clients will have to resend their original credentials.

DES Authentication Protocol (in XDR language)

```
/*
 * There are two kinds of credentials: one in which the client uses
 * its full network name, and one in which it uses its "nickname"
 * (just an unsigned integer) given to it by the server. The
 * client must use its fullname in its first transaction with the
 * server, in which the server will return to the client its
 * nickname. The client may use its nickname in all further
 * transactions with the server. There is no requirement to use the
 * nickname, but it is wise to use it for performance reasons.
 */
enum authdes_namekind {
    ADN_FULLNAME = 0,
    ADN_NICKNAME = 1
};

/*
 * A 64-bit block of encrypted DES data
 */
typedef opaque des_block[8];

/*
 * Maximum length of a network user's name
 */
const MAXNETNAMELEN = 255;

/*
 * A fullname contains the network name of the client, an encrypted
 * conversation key and the window. The window is actually a
 * lifetime for the credential. If the time indicated in the
 * verifier timestamp plus the window has past, then the server
 * should expire the request and not grant it. To insure that
 * requests are not replayed, the server should insist that
 * timestamps are greater than the previous one seen, unless it is
 * the first transaction. In the first transaction, the server
 * checks instead that the window verifier is one less than the
 * window.
 */
struct authdes_fullname {
string name<MAXNETNAMELEN>;   /* name of client */
des_block key;                /* PK encrypted conversation key */
unsigned int window;          /* encrypted window */
};

/*
 * A credential is either a fullname or a nickname
 */
union authdes_cred switch (authdes_namekind adc_namekind) {
    case ADN_FULLNAME:
        authdes_fullname adc_fullname;
    case ADN_NICKNAME:
        unsigned int adc_nickname;
};
```

```
/*
 * A timestamp encodes the time since midnight, January 1, 1970.
 */
struct timestamp {
    unsigned int seconds;     /* seconds */
    unsigned int useconds;    /* and microseconds */
};

/*
 * Verifier: client variety
 * The window verifier is only used in the first transaction. In
 * conjunction with a fullname credential, these items are packed
 * into the following structure before being encrypted:
 *
 * struct {
 *   adv_timestamp;          -- one DES block
 *   adc_fullname.window; -- one half DES block
 *   adv_winverf;        -- one half DES block
 * }
 * This structure is encrypted using CBC mode encryption with an
 * input vector of zero. All other encryptions of timestamps use
 * ECB mode encryption.
 */
struct authdes_verf_clnt {
    timestamp adv_timestamp;     /* encrypted timestamp      */
    unsigned int adv_winverf;    /* encrypted window verifier */
};

/*
 * Verifier: server variety
 * The server returns (encrypted) the same timestamp the client
 * gave it minus one second. It also tells the client its nickname
 * to be used in future transactions (unencrypted).
 */
struct authdes_verf_svr {
timestamp adv_timeverf;      /* encrypted verifier    */
unsigned int adv_nickname;   /* new nickname for client */
};
```

Diffie-Hellman Encryption

In this scheme, there are two constants, `BASE` and `MODULUS`. The particular values Sun has chosen for these for the DES authentication protocol are:

```
const BASE = 3;
const MODULUS = "d4a0ba0250b6fd2ec626e7efd637df76c716e22d0944b
```

The way this scheme works is best explained by an example. Suppose there are two people "A" and "B" who want to send encrypted messages to each other. So, A and B both generate "secret" keys at random which they do not reveal to anyone. Let these keys be represented as SK(A) and SK(B). They also publish in a public directory their "public" keys. These keys are computed as follows:

```
PK(A) = ( BASE ** SK(A) ) mod MODULUS
PK(B) = ( BASE ** SK(B) ) mod MODULUS
```

The "**" notation is used here to represent exponentiation. Now, both A and B can arrive at the "common" key between them, represented here as CK(A, B), without revealing their secret keys.

A computes:

```
CK(A, B) = ( PK(B) ** SK(A)) mod MODULUS
```

while B computes:

```
CK(A, B) = ( PK(A) ** SK(B)) mod MODULUS
```

These two can be shown to be equivalent:

```
(PK(B) ** SK(A)) mod MODULUS = (PK(A) ** SK(B)) mod MODULUS
```

We drop the "mod MODULUS" parts and assume modulo arithmetic to simplify things:

```
PK(B) ** SK(A) = PK(A) ** SK(B)
```

Then, replace PK(B) by what B computed earlier and likewise for PK(A).

```
((BASE ** SK(B)) ** SK(A) = (BASE ** SK(A)) ** SK(B)
```

which leads to:

```
BASE ** (SK(A) * SK(B)) = BASE ** (SK(A) * SK(B))
```

This common key CK(A, B) is not used to encrypt the timestamps used in the protocol. Rather, it is used only to encrypt a conversation key which is then used to encrypt the timestamps. The reason for doing this is to use the common key as little as possible, for fear that it could be broken. Breaking the conversation key is a far less serious offense, since conversations are relatively short-lived.

The conversation key is encrypted using 56-bit DES keys, yet the common key is 192 bits. To reduce the number of bits, 56 bits are selected from the common key as follows. The middle-most 8-bytes are selected from the common key, and then parity is added to the lower order bit of each byte, producing a 56-bit key with 8 bits of parity.

6.6. Record Marking Standard

When RPC messages are passed on top of a byte stream protocol (like TCP/IP), it is necessary, or at least desirable, to delimit one message from another in order to detect and possibly recover from user protocol errors. This is called record marking (RM). Sun uses this RM/TCP/IP transport for passing RPC messages on TCP streams. One RPC message fits into one RM record.

A record is composed of one or more record fragments. A record fragment is a four-byte header followed by 0 to (2**31) - 1 bytes of fragment data. The bytes encode an unsigned binary number; as with XDR integers, the byte order is from highest to lowest. The number encodes two values—a boolean which indicates whether the fragment is the last fragment of the record (bit value 1 implies the fragment is the last fragment) and a 31-bit unsigned binary value which is the length in bytes of the fragment's data. The boolean value is the highest-order bit of the header; the length is the 31 low-order bits. (Note that this record specification is NOT in XDR standard form!)

6.7. The RPC Language

Just as there was a need to describe the XDR data-types in a formal language, there is also need to describe the procedures that operate on these XDR data-types in a formal language as well. We use the RPC Language for this purpose. It is an extension to the XDR language. The following example is used to describe the essence of the language.

An Example Service Described in the RPC Language

Here is an example of the specification of a simple ping program.

```
/*
* Simple ping program
*/
program PING_PROG {
     /* Latest and greatest version */
     version PING_VERS_PINGBACK {
     void
     PINGPROC_NULL(void) = 0;

     /*
     * Ping the caller, return the round-trip time
     * (in microseconds). Returns -1 if the operation
     * timed out.
     */
     int
     PINGPROC_PINGBACK(void) = 1;
} = 2;

/*
* Original version
*/
version PING_VERS_ORIG {
     void
     PINGPROC_NULL(void) = 0;
     } = 1;
} = 1;

const PING_VERS = 2;        /* latest version */
```

The first version described is PING_VERS_PINGBACK with two procedures, PINGPROC_NULL and PINGPROC_PINGBACK. PINGPROC_NULL takes no arguments and returns no results, but it is useful for computing round-trip times from the client to the server and back again. By convention, procedure 0 of any RPC protocol should have the same semantics, and never require any kind of authentication. The second procedure is used for the client to have the server do a reverse ping operation back to the client, and it returns the amount of time (in microseconds) that the operation used. The next version, PING_VERS_ORIG, is the original version of the protocol and it does not contain PINGPROC_PINGBACK procedure. It is useful for compatibility with old client programs, and as this program matures it may be dropped from the protocol entirely.

The RPC Language Specification

The RPC language is identical to the XDR language, except for the added definition of a `program-def` described below.

```
program-def:
    "program" identifier "{"
        version-def
        version-def *
    "}" "=" constant ";"

version-def:
    "version" identifier "{"
        procedure-def
        procedure-def *
    "}" "=" constant ";"

procedure-def:
    type-specifier identifier "(" type-specifier ")"
    "=" constant ";"
```

Syntax Notes

1. The following keywords are added and cannot be used as identifiers: "program" and "version";
2. A version name cannot occur more than once within the scope of a program definition. Nor can a version number occur more than once within the scope of a program definition.
3. A procedure name cannot occur more than once within the scope of a version definition. Nor can a procedure number occur more than once within the scope of version definition.
4. Program identifiers are in the same name space as constant and type identifiers.
5. Only unsigned constants can be assigned to programs, versions and procedures.

6.8. Port Mapper Program Protocol

The port mapper program maps RPC program and version numbers to transport-specific port numbers. This program makes dynamic binding of remote programs possible.

This is desirable because the range of reserved port numbers is very small and the number of potential remote programs is very large. By running only the port mapper on a reserved port, the port numbers of other remote programs can be ascertained by querying the port mapper.

The port mapper also aids in broadcast RPC. A given RPC program will usually have different port number bindings on different machines, so there is no way to directly broadcast to all of these programs. The port mapper, however, does have a fixed port number. So, to broadcast to a given program, the client actually sends its message to the port mapper located at the broadcast address. Each port mapper that picks up the broadcast then calls the local service specified by the client. When the port mapper gets the reply from the local service, it sends the reply on back to the client.

Port Mapper Protocol Specification (in RPC Language)

```
const PMAP_PORT = 111;          /* portmapper port number */

/*
 * A mapping of (program, version, protocol) to port number
 */
struct mapping {
    unsigned int prog;
    unsigned int vers;
    unsigned int prot;
    unsigned int port;
};

/*
 * Supported values for the "prot" field
 */
const IPPROTO_TCP = 6;          /* protocol number for TCP/IP */
const IPPROTO_UDP = 17;         /* protocol number for UDP/IP */

/*
 * A list of mappings
 */
struct *pmaplist {
    mapping map;
    pmaplist next;
};

/*
 * Arguments to callit
 */
struct call_args {
    unsigned int prog;
    unsigned int vers;
    unsigned int proc;
    opaque args<>;
};

/*
 * Results of callit
 */
struct call_result {
    unsigned int port;
    opaque res<>;
};

/*
 * Port mapper procedures
 */
program PMAP_PROG {
    version PMAP_VERS {
        void
        PMAPPROC_NULL(void)         = 0;

        bool
```

```
            PMAPPROC_SET(mapping)         = 1;

            bool
            PMAPPROC_UNSET(mapping)       = 2;

            unsigned int
            PMAPPROC_GETPORT(mapping)     = 3;

            pmaplist
            PMAPPROC_DUMP(void)           = 4;

            call_result
            PMAPPROC_CALLIT(call_args)    = 5;
        } = 2;
    } = 100000;
```

Port Mapper Operation

The portmapper program currently supports two protocols (UDP/IP and TCP/IP). The portmapper is contacted by talking to it on assigned port number 111 (SUNRPC [8]) on either of these protocols. The following is a description of each of the portmapper procedures:

PMAPPROC_NULL:
This procedure does no work. By convention, procedure zero of any protocol takes no parameters and returns no results.

PMAPPROC_SET:
When a program first becomes available on a machine, it registers itself with the port mapper program on the same machine. The program passes its program number "prog", version number "vers", transport protocol number "prot", and the port "port" on which it awaits service request. The procedure returns a boolean response whose value is `TRUE` if the procedure successfully established the mapping and `FALSE` otherwise. The procedure refuses to establish a mapping if one already exists for the tuple "(prog, vers, prot)".

PMAPPROC_UNSET:
When a program becomes unavailable, it should unregister itself with the port mapper program on the same machine. The parameters and results have meanings identical to those of `PMAPPROC_SET`. The protocol and port number fields of the argument are ignored.

PMAPPROC_GETPORT:
Given a program number "prog", version number "vers", and transport protocol number "prot", this procedure returns the port number on which the program is awaiting call requests. A port value of zeros means the program has not been registered. The "port" field of the argument is ignored.

PMAPPROC_DUMP:
This procedure enumerates all entries in the port mapper's database. The procedure takes no parameters and returns a list of program, version, protocol, and port values.

PMAPPROC_CALLIT:
This procedure allows a caller to call another remote procedure on the same

machine without knowing the remote procedure's port number. It is intended for supporting broadcasts to arbitrary remote programs via the well-known port mapper's port. The parameters "prog", "vers", "proc", and the bytes of "args" are the program number, version number, procedure number, and parameters of the remote procedure. Note:

1. This procedure only sends a response if the procedure was successfully executed and is silent (no response) otherwise.

2. The port mapper communicates with the remote program using UDP/IP only.

The procedure returns the remote program's port number, and the bytes of results are the results of the remote procedure.

6.9. References

[1] Birrell, Andrew D. & Nelson, Bruce Jay; "Implementing Remote Procedure Calls"; XEROX CSL-83-7, October 1983.

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[3] Diffie & Hellman; "Net Directions in Cryptography"; IEEE Transactions on Information Theory IT-22, November 1976.

[4] Harrenstien, K.; "Time Server", RFC 738; Information Sciences Institute, October 1977.

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[6] Postel, J.; "Transmission Control Protocol - DARPA Internet Program Protocol Specification", RFC 793; Information Sciences Institute, September 1981.

[7] Postel, J.; "User Datagram Protocol", RFC 768; Information Sciences Institute, August 1980.

[8] Reynolds, J. & Postel, J.; "Assigned Numbers", RFC 923; Information Sciences Institute, October 1984.

7

Network File System: Version 2 Protocol Specification

7

Network File System: Version 2 Protocol Specification

7.1. Status of this Standard

Note: This chapter specifies a protocol that Sun Microsystems, Inc., and others are using. It specifies it in standard ARPA RFC form.

7.2. Introduction

The Sun Network Filesystem (NFS) protocol provides transparent remote access to shared filesystems over local area networks. The NFS protocol is designed to be machine, operating system, network architecture, and transport protocol independent. This independence is achieved through the use of Remote Procedure Call (RPC) primitives built on top of an External Data Representation (XDR). Implementations exist for a variety of machines, from personal computers to supercomputers.

The supporting mount protocol allows the server to hand out remote access privileges to a restricted set of clients. It performs the operating system-specific functions that allow, for example, to attach remote directory trees to some local file system.

Remote Procedure Call

Sun's remote procedure call specification provides a procedure- oriented interface to remote services. Each server supplies a program that is a set of procedures. NFS is one such "program". The combination of host address, program number, and procedure number specifies one remote service procedure. RPC does not depend on services provided by specific protocols, so it can be used with any underlying transport protocol. See the *Remote Procedure Calls: Protocol Specification* chapter of this manual.

External Data Representation

The External Data Representation (XDR) standard provides a common way of representing a set of data types over a network. The NFS Protocol Specification is written using the RPC data description language. For more information, see the *External Data Representation Standard: Protocol Specification* chapter of this manual. Sun provides implementations of XDR and RPC, but NFS does not require their use. Any software that provides equivalent functionality can be used, and if the encoding is exactly the same it can interoperate with other implementations of NFS.

Stateless Servers

The NFS protocol is stateless. That is, a server does not need to maintain any extra state information about any of its clients in order to function correctly. Stateless servers have a distinct advantage over stateful servers in the event of a failure. With stateless servers, a client need only retry a request until the server responds; it does not even need to know that the server has crashed, or the network temporarily went down. The client of a stateful server, on the other hand, needs to either detect a server crash and rebuild the server's state when it comes back up, or cause client operations to fail.

This may not sound like an important issue, but it affects the protocol in some unexpected ways. We feel that it is worth a bit of extra complexity in the protocol to be able to write very simple servers that do not require fancy crash recovery.

On the other hand, NFS deals with objects such as files and directories that inherently have state -- what good would a file be if it did not keep its contents intact? The goal is to not introduce any extra state in the protocol itself. Another way to simplify recovery is by making operations "idempotent" whenever possible (so that they can potentially be repeated).

7.3. NFS Protocol Definition

Servers have been known to change over time, and so can the protocol that they use. So RPC provides a version number with each RPC request. This RFC describes version two of the NFS protocol. Even in the second version, there are various obsolete procedures and parameters, which will be removed in later versions. An RFC for version three of the NFS protocol is currently under preparation.

File System Model

NFS assumes a file system that is hierarchical, with directories as all but the bottom-level files. Each entry in a directory (file, directory, device, etc.) has a string name. Different operating systems may have restrictions on the depth of the tree or the names used, as well as using different syntax to represent the "pathname", which is the concatenation of all the "components" (directory and file names) in the name. A "file system" is a tree on a single server (usually a single disk or physical partition) with a specified "root". Some operating systems provide a "mount" operation to make all file systems appear as a single tree, while others maintain a "forest" of file systems. Files are unstructured streams of uninterpreted bytes. Version 3 of NFS uses a slightly more general file system model.

NFS looks up one component of a pathname at a time. It may not be obvious why it does not just take the whole pathname, traipse down the directories, and return a file handle when it is done. There are several good reasons not to do this. First, pathnames need separators between the directory components, and different operating systems use different separators. We could define a Network Standard Pathname Representation, but then every pathname would have to be parsed and converted at each end. Other issues are discussed in *NFS Implementation Issues* below.

Although files and directories are similar objects in many ways, different procedures are used to read directories and files. This provides a network standard format for representing directories. The same argument as above could have been used to justify a procedure that returns only one directory entry per call. The problem is efficiency. Directories can contain many entries, and a remote call to return each would be just too slow.

RPC Information

Authentication

The NFS service uses `AUTH_UNIX`, `AUTH_DES`, or `AUTH_SHORT` style authentication, except in the NULL procedure where `AUTH_NONE` is also allowed.

Transport Protocols

NFS currently is supported on UDP/IP only.

Port Number

The NFS protocol currently uses the UDP port number 2049. This is not an officially assigned port, so later versions of the protocol use the "Portmapping" facility of RPC.

Sizes of XDR Structures

These are the sizes, given in decimal bytes, of various XDR structures used in the protocol:

```
/* The maximum number of bytes of data in a READ or WRITE request */
const MAXDATA = 8192;

/* The maximum number of bytes in a pathname argument */
const MAXPATHLEN = 1024;

/* The maximum number of bytes in a file name argument */
const MAXNAMLEN = 255;

/* The size in bytes of the opaque "cookie" passed by READDIR */
const COOKIESIZE = 4;

/* The size in bytes of the opaque file handle */
const FHSIZE = 32;
```

Basic Data Types

The following XDR definitions are basic structures and types used in other structures described further on.

stat

```
enum stat {
    NFS_OK = 0,
    NFSERR_PERM=1,
    NFSERR_NOENT=2,
    NFSERR_IO=5,
    NFSERR_NXIO=6,
    NFSERR_ACCES=13,
    NFSERR_EXIST=17,
    NFSERR_NODEV=19,
    NFSERR_NOTDIR=20,
    NFSERR_ISDIR=21,
    NFSERR_FBIG=27,
    NFSERR_NOSPC=28,
    NFSERR_ROFS=30,
    NFSERR_NAMETOOLONG=63,
    NFSERR_NOTEMPTY=66,
    NFSERR_DQUOT=69,
    NFSERR_STALE=70,
    NFSERR_WFLUSH=99
};
```

The `stat()` type is returned with every procedure's results. A value of `NFS_OK` indicates that the call completed successfully and the results are valid. The other values indicate some kind of error occurred on the server side during the servicing of the procedure. The error values are derived from UNIX error numbers.

NFSERR_PERM:
: Not owner. The caller does not have correct ownership to perform the requested operation.

NFSERR_NOENT:
: No such file or directory. The file or directory specified does not exist.

NFSERR_IO:
: Some sort of hard error occurred when the operation was in progress. This could be a disk error, for example.

NFSERR_NXIO:
: No such device or address.

NFSERR_ACCES:
: Permission denied. The caller does not have the correct permission to perform the requested operation.

NFSERR_EXIST:
: File exists. The file specified already exists.

NFSERR_NODEV:
: No such device.

NFSERR_NOTDIR:
: Not a directory. The caller specified a non-directory in a directory operation.

NFSERR_ISDIR:
Is a directory. The caller specified a directory in a non- directory operation.

NFSERR_FBIG:
File too large. The operation caused a file to grow beyond the server's limit.

NFSERR_NOSPC:
No space left on device. The operation caused the server's filesystem to reach its limit.

NFSERR_ROFS:
Read-only filesystem. Write attempted on a read-only filesystem.

NFSERR_NAMETOOLONG:
File name too long. The file name in an operation was too long.

NFSERR_NOTEMPTY:
Directory not empty. Attempted to remove a directory that was not empty.

NFSERR_DQUOT:
Disk quota exceeded. The client's disk quota on the server has been exceeded.

NFSERR_STALE:
The "fhandle" given in the arguments was invalid. That is, the file referred to by that file handle no longer exists, or access to it has been revoked.

NFSERR_WFLUSH:
The server's write cache used in the `WRITECACHE` call got flushed to disk.

`ftype`

```
enum ftype {
    NFNON = 0,
    NFREG = 1,
    NFDIR = 2,
    NFBLK = 3,
    NFCHR = 4,
    NFLNK = 5
};
```

The enumeration `ftype` gives the type of a file. The type `NFNON` indicates a non-file, `NFREG` is a regular file, `NFDIR` is a directory, `NFBLK` is a block-special device, `NFCHR` is a character-special device, and `NFLNK` is a symbolic link.

`fhandle`

```
typedef opaque fhandle[FHSIZE];
```

The `fhandle` is the file handle passed between the server and the client. All file operations are done using file handles to refer to a file or directory. The file handle can contain whatever information the server needs to distinguish an individual file.

timeval

```
struct timeval {
    unsigned int seconds;
    unsigned int useconds;
};
```

The timeval structure is the number of seconds and microseconds since midnight January 1, 1970, Greenwich Mean Time. It is used to pass time and date information.

fattr

```
struct fattr {
    ftype        type;
    unsigned int mode;
    unsigned int nlink;
    unsigned int uid;
    unsigned int gid;
    unsigned int size;
    unsigned int blocksize;
    unsigned int rdev;
    unsigned int blocks;
    unsigned int fsid;
    unsigned int fileid;
    timeval      atime;
    timeval      mtime;
    timeval      ctime;
};
```

The fattr structure contains the attributes of a file; "type" is the type of the file; "nlink" is the number of hard links to the file (the number of different names for the same file); "uid" is the user identification number of the owner of the file; "gid" is the group identification number of the group of the file; "size" is the size in bytes of the file; "blocksize" is the size in bytes of a block of the file; "rdev" is the device number of the file if it is type NFCHR or NFBLK; "blocks" is the number of blocks the file takes up on disk; "fsid" is the file system identifier for the filesystem containing the file; "fileid" is a number that uniquely identifies the file within its filesystem; "atime" is the time when the file was last accessed for either read or write; "mtime" is the time when the file data was last modified (written); and "ctime" is the time when the status of the file was last changed. Writing to the file also changes "ctime" if the size of the file changes.

"mode" is the access mode encoded as a set of bits. Notice that the file type is specified both in the mode bits and in the file type. This is really a bug in the protocol and will be fixed in future versions. The descriptions given below specify the bit positions using octal numbers.

Bit	*Description*
0040000	This is a directory; "type" field should be NFDIR.
0020000	This is a character special file; "type" field should be NFCHR.
0060000	This is a block special file; "type" field should be NFBLK.
0100000	This is a regular file; "type" field should be NFREG.
0120000	This is a symbolic link file; "type" field should be NFLNK.
0140000	This is a named socket; "type" field should be NFNON.
0004000	Set user id on execution.
0002000	Set group id on execution.
0001000	Save swapped text even after use.
0000400	Read permission for owner.
0000200	Write permission for owner.
0000100	Execute and search permission for owner.
0000040	Read permission for group.
0000020	Write permission for group.
0000010	Execute and search permission for group.
0000004	Read permission for others.
0000002	Write permission for others.
0000001	Execute and search permission for others.

Notes:

The bits are the same as the mode bits returned by the `stat(2)` system call in the UNIX system. The file type is specified both in the mode bits and in the file type. This is fixed in future versions.

The "rdev" field in the attributes structure is an operating system specific device specifier. It will be removed and generalized in the next revision of the protocol.

`sattr`

```
struct sattr {
    unsigned int mode;
    unsigned int uid;
    unsigned int gid;
    unsigned int size;
    timeval      atime;
    timeval      mtime;
};
```

The `sattr` structure contains the file attributes which can be set from the client. The fields are the same as for `fattr` above. A "size" of zero means the file should be truncated. A value of -1 indicates a field that should be ignored.

`filename`

```
typedef string filename<MAXNAMLEN>;
```

The type `filename` is used for passing file names or pathname components.

`path`

```
typedef string path<MAXPATHLEN>;
```

The type `path` is a pathname. The server considers it as a string with no internal structure, but to the client it is the name of a node in a filesystem tree.

attrstat

```
union attrstat switch (stat status) {
    case NFS_OK:
        fattr attributes;
    default:
        void;
};
```

The `attrstat` structure is a common procedure result. It contains a "status" and, if the call succeeded, it also contains the attributes of the file on which the operation was done.

diropargs

```
struct diropargs {
    fhandle  dir;
    filename name;
};
```

The `diropargs` structure is used in directory operations. The "fhandle" "dir" is the directory in which to find the file "name". A directory operation is one in which the directory is affected.

diropres

```
union diropres switch (stat status) {
    case NFS_OK:
        struct {
            fhandle file;
            fattr   attributes;
        } diropok;
    default:
        void;
};
```

The results of a directory operation are returned in a `diropres` structure. If the call succeeded, a new file handle "file" and the "attributes" associated with that file are returned along with the "status".

Server Procedures

The protocol definition is given as a set of procedures with arguments and results defined using the RPC language. A brief description of the function of each procedure should provide enough information to allow implementation.

All of the procedures in the NFS protocol are assumed to be synchronous. When a procedure returns to the client, the client can assume that the operation has completed and any data associated with the request is now on stable storage. For example, a client `WRITE` request may cause the server to update data blocks, filesystem information blocks (such as indirect blocks), and file attribute information (size and modify times). When the `WRITE` returns to the client, it can assume that the write is safe, even in case of a server crash, and it can discard the data written. This is a very important part of the statelessness of the server. If the server waited to flush data from remote requests, the client would have to save those requests so that it could resend them in case of a server crash.

```
/*
* Remote file service routines
*/
program NFS_PROGRAM {
    version NFS_VERSION {
        void NFSPROC_NULL(void) = 0;
        attrstat NFSPROC_GETATTR(fhandle)= 1;
        attrstat NFSPROC_SETATTR(sattrargs) = 2;
        void NFSPROC_ROOT(void) = 3;
        diropres NFSPROC_LOOKUP(diropargs)  = 4;
        readlinkres NFSPROC_READLINK(fhandle) = 5;
        readres NFSPROC_READ(readargs) = 6;
        void NFSPROC_WRITECACHE(void) = 7;
        attrstat NFSPROC_WRITE(writeargs) = 8;
        diropres NFSPROC_CREATE(createargs) = 9;
        stat NFSPROC_REMOVE(diropargs) = 10;
        stat NFSPROC_RENAME(renameargs) = 11;
        stat NFSPROC_LINK(linkargs) = 12;
        stat NFSPROC_SYMLINK(symlinkargs) = 13;
        diropres NFSPROC_MKDIR(createargs)  = 14;
        stat NFSPROC_RMDIR(diropargs)   = 15;
        readdirres NFSPROC_READDIR(readdirargs) = 16;
        statfsres NFSPROC_STATFS(fhandle) = 17;
    } = 2;
} = 100003;
```

Do Nothing

```
void
NFSPROC_NULL(void) = 0;
```

This procedure does no work. It is made available in all RPC services to allow server response testing and timing.

Get File Attributes

```
attrstat
NFSPROC_GETATTR (fhandle) = 1;
```

If the reply status is `NFS_OK`, then the reply attributes contains the attributes for the file given by the input fhandle.

Set File Attributes

```
struct sattrargs {
    fhandle file;
    sattr attributes;
    };

attrstat
NFSPROC_SETATTR (sattrargs) = 2;
```

The "attributes" argument contains fields which are either -1 or are the new value for the attributes of "file". If the reply status is `NFS_OK`, then the reply attributes have the attributes of the file after the "SETATTR" operation has completed.

Note: The use of -1 to indicate an unused field in "attributes" is changed in the next version of the protocol.

Get Filesystem Root

```
void
NFSPROC_ROOT(void) = 3;
```

Obsolete. This procedure is no longer used because finding the root file handle of a filesystem requires moving pathnames between client and server. To do this right we would have to define a network standard representation of pathnames. Instead, the function of looking up the root file handle is done by the `MNTPROC_MNT()` procedure. (See the *Mount Protocol Definition* below for details).

Look Up File Name

```
diropres
NFSPROC_LOOKUP(diropargs) = 4;
```

If the reply "status" is `NFS_OK`, then the reply "file" and reply "attributes" are the file handle and attributes for the file "name" in the directory given by "dir" in the argument.

Read From Symbolic Link

```
union readlinkres switch (stat status) {
    case NFS_OK:
        path data;
    default:
        void;
};

readlinkres
NFSPROC_READLINK(fhandle) = 5;
```

If "status" has the value `NFS_OK`, then the reply "data" is the data in the symbolic link given by the file referred to by the fhandle argument.

Note: since NFS always parses pathnames on the client, the pathname in a symbolic link may mean something different (or be meaningless) on a different client or on the server if a different pathname syntax is used.

Read From File

```
struct readargs {
    fhandle file;
    unsigned offset;
    unsigned count;
    unsigned totalcount;
};

union readres switch (stat status) {
    case NFS_OK:
        fattr attributes;
        opaque data<NFS_MAXDATA>;
    default:
        void;
};

readres
NFSPROC_READ(readargs) = 6;
```

Returns up to "count" bytes of "data" from the file given by "file", starting at "offset" bytes from the beginning of the file. The first byte of the file is at offset zero. The file attributes after the read takes place are returned in "attributes".

Note: The argument "totalcount" is unused, and is removed in the next protocol revision.

Write to Cache

```
void
NFSPROC_WRITECACHE(void) = 7;
```

To be used in the next protocol revision.

Write to File

```
struct writeargs {
    fhandle file;
    unsigned beginoffset;
    unsigned offset;
    unsigned totalcount;
    opaque data<NFS_MAXDATA>;
};

attrstat
NFSPROC_WRITE(writeargs) = 8;
```

Writes "data" beginning "offset" bytes from the beginning of "file". The first byte of the file is at offset zero. If the reply "status" is NFS_OK, then the reply "attributes" contains the attributes of the file after the write has completed. The write operation is atomic. Data from this call to `WRITE` will not be mixed with data from another client's calls.

Note: The arguments "beginoffset" and "totalcount" are ignored and are removed in the next protocol revision.

Create File

```
struct createargs {
    diropargs where;
    sattr attributes;
};

diropres
NFSPROC_CREATE(createargs) = 9;
```

The file "name" is created in the directory given by "dir". The initial attributes of the new file are given by "attributes". A reply "status" of NFS_OK indicates that the file was created, and reply "file" and reply "attributes" are its file handle and attributes. Any other reply "status" means that the operation failed and no file was created.

Note: This routine should pass an exclusive create flag, meaning "create the file only if it is not already there".

Remove File

```
stat
NFSPROC_REMOVE(diropargs) = 10;
```

The file "name" is removed from the directory given by "dir". A reply of NFS_OK means the directory entry was removed.

Note: possibly non-idempotent operation.

Rename File

```
struct renameargs {
    diropargs from;
    diropargs to;
};

stat
NFSPROC_RENAME(renameargs) = 11;
```

The existing file "from.name" in the directory given by "from.dir" is renamed to "to.name" in the directory given by "to.dir". If the reply is NFS_OK, the file was renamed. The RENAME operation is atomic on the server; it cannot be interrupted in the middle.

Note: possibly non-idempotent operation.

Create Link to File

```
struct linkargs {
    fhandle from;
    diropargs to;
};

stat
NFSPROC_LINK(linkargs) = 12;
```

Creates the file "to.name" in the directory given by "to.dir", which is a hard link to the existing file given by "from". If the return value is NFS_OK, a link was created. Any other return value indicates an error, and the link was not created.

A hard link should have the property that changes to either of the linked files are reflected in both files. When a hard link is made to a file, the attributes for the file should have a value for "nlink" that is one greater than the value before the link.

Note: possibly non-idempotent operation.

Create Symbolic Link

```
struct symlinkargs {
    diropargs from;
    path to;
    sattr attributes;
};

stat
NFSPROC_SYMLINK(symlinkargs) = 13;
```

Creates the file "from.name" with ftype NFLNK in the directory given by "from.dir". The new file contains the pathname "to" and has initial attributes given by "attributes". If the return value is NFS_OK, a link was created. Any other return value indicates an error, and the link was not created.

A symbolic link is a pointer to another file. The name given in "to" is not interpreted by the server, only stored in the newly created file. When the client references a file that is a symbolic link, the contents of the symbolic link are normally transparently reinterpreted as a pathname to substitute. A READLINK operation returns the data to the client for interpretation.

Note: On UNIX servers the attributes are never used, since symbolic links always have mode 0777.

Create Directory

```
diropres
NFSPROC_MKDIR (createargs) = 14;
```

The new directory "where.name" is created in the directory given by "where.dir". The initial attributes of the new directory are given by "attributes". A reply "status" of NFS_OK indicates that the new directory was created, and reply "file" and reply "attributes" are its file handle and attributes. Any other reply "status" means that the operation failed and no directory was created.

Note: possibly non-idempotent operation.

Remove Directory

```
stat
NFSPROC_RMDIR(diropargs) = 15;
```

The existing empty directory "name" in the directory given by "dir" is removed. If the reply is NFS_OK, the directory was removed.

Note: possibly non-idempotent operation.

Read From Directory

```
struct readdirargs {
    fhandle dir;
    nfscookie cookie;
    unsigned count;
};

struct entry {
    unsigned fileid;
    filename name;
    nfscookie cookie;
    entry *nextentry;
};

union readdirres switch (stat status) {
    case NFS_OK:
        struct {
            entry *entries;
            bool eof;
        } readdirok;
    default:
        void;
};

readdirres
NFSPROC_READDIR (readdirargs) = 16;
```

Returns a variable number of directory entries, with a total size of up to "count" bytes, from the directory given by "dir". If the returned value of "status" is NFS_OK, then it is followed by a variable number of "entry"s. Each "entry" contains a "fileid" which consists of a unique number to identify the file within a filesystem, the "name" of the file, and a "cookie" which is an opaque pointer to the next entry in the directory. The cookie is used in the next READDIR call to get more entries starting at a given point in the directory. The special cookie zero (all bits zero) can be used to get the entries starting at the beginning of the directory. The "fileid" field should be the same number as the "fileid" in the the attributes of the file. (See the *Basic Data Types* section.) The "eof" flag has a value of TRUE if there are no more entries in the directory.

Get Filesystem Attributes

```
union statfsres (stat status) {
    case NFS_OK:
        struct {
            unsigned tsize;
            unsigned bsize;
            unsigned blocks;
            unsigned bfree;
            unsigned bavail;
        } info;
    default:
        void;
};

statfsres
NFSPROC_STATFS(fhandle) = 17;
```

If the reply "status" is NFS_OK, then the reply "info" gives the attributes for the filesystem that contains file referred to by the input fhandle. The attribute fields contain the following values:

tsize:
: The optimum transfer size of the server in bytes. This is the number of bytes the server would like to have in the data part of READ and WRITE requests.

bsize:
: The block size in bytes of the filesystem.

blocks:
: The total number of "bsize" blocks on the filesystem.

bfree:
: The number of free "bsize" blocks on the filesystem.

bavail:
: The number of "bsize" blocks available to non-privileged users.

Note: This call does not work well if a filesystem has variable size blocks.

7.4. NFS Implementation Issues

The NFS protocol is designed to be operating system independent, but since this version was designed in a UNIX environment, many operations have semantics similar to the operations of the UNIX file system. This section discusses some of the implementation-specific semantic issues.

Server/Client Relationship

The NFS protocol is designed to allow servers to be as simple and general as possible. Sometimes the simplicity of the server can be a problem, if the client wants to implement complicated filesystem semantics.

For example, some operating systems allow removal of open files. A process can open a file and, while it is open, remove it from the directory. The file can be read and written as long as the process keeps it open, even though the file has no name in the filesystem. It is impossible for a stateless server to implement these semantics. The client can do some tricks such as renaming the file on remove, and only removing it on close. We believe that the server provides enough functionality to implement most file system semantics on the client.

Every NFS client can also potentially be a server, and remote and local mounted filesystems can be freely intermixed. This leads to some interesting problems when a client travels down the directory tree of a remote filesystem and reaches the mount point on the server for another remote filesystem. Allowing the server to follow the second remote mount would require loop detection, server lookup, and user revalidation. Instead, we decided not to let clients cross a server's mount point. When a client does a LOOKUP on a directory on which the server has mounted a filesystem, the client sees the underlying directory instead of the mounted directory. A client can do remote mounts that match the server's mount points to maintain the server's view.

Pathname Interpretation

There are a few complications to the rule that pathnames are always parsed on the client. For example, symbolic links could have different interpretations on different clients. Another common problem for non-UNIX implementations is the special interpretation of the pathname ".." to mean the parent of a given directory. The next revision of the protocol uses an explicit flag to indicate the parent instead.

Permission Issues

The NFS protocol, strictly speaking, does not define the permission checking used by servers. However, it is expected that a server will do normal operating system permission checking using `AUTH_UNIX` style authentication as the basis of its protection mechanism. The server gets the client's effective "uid", effective "gid", and groups on each call and uses them to check permission. There are various problems with this method that can been resolved in interesting ways.

Using "uid" and "gid" implies that the client and server share the same "uid" list. Every server and client pair must have the same mapping from user to "uid" and from group to "gid". Since every client can also be a server, this tends to imply that the whole network shares the same "uid/gid" space. `AUTH_DES` (and the next revision of the NFS protocol) uses string names instead of numbers, but there are still complex problems to be solved.

Another problem arises due to the usually stateful open operation. Most operating systems check permission at open time, and then check that the file is open on each read and write request. With stateless servers, the server has no idea that the file is open and must do permission checking on each read and write call. On a local filesystem, a user can open a file and then change the permissions so that no one is allowed to touch it, but will still be able to write to the file because it is open. On a remote filesystem, by contrast, the write would fail. To get around this problem, the server's permission checking algorithm should allow the owner of a file to access it regardless of the permission setting.

A similar problem has to do with paging in from a file over the network. The operating system usually checks for execute permission before opening a file for demand paging, and then reads blocks from the open file. The file may not have read permission, but after it is opened it doesn't matter. An NFS server can not tell the difference between a normal file read and a demand page-in read. To make this work, the server allows reading of files if the "uid" given in the call has execute or read permission on the file.

In most operating systems, a particular user (on the user ID zero) has access to all files no matter what permission and ownership they have. This "super-user" permission may not be allowed on the server, since anyone who can become super-user on their workstation could gain access to all remote files. The UNIX server by default maps user id 0 to -2 before doing its access checking. This works except for NFS root filesystems, where super-user access cannot be avoided.

Setting RPC Parameters

Various file system parameters and options should be set at mount time. The mount protocol is described in the appendix below. For example, "Soft" mounts as well as "Hard" mounts are usually both provided. Soft mounted file systems return errors when RPC operations fail (after a given number of optional retransmissions), while hard mounted file systems continue to retransmit forever. Clients and servers may need to keep caches of recent operations to help avoid problems with non-idempotent operations.

7.5. Mount Protocol Definition

Introduction

The mount protocol is separate from, but related to, the NFS protocol. It provides operating system specific services to get the NFS off the ground -- looking up server path names, validating user identity, and checking access permissions. Clients use the mount protocol to get the first file handle, which allows them entry into a remote filesystem.

The mount protocol is kept separate from the NFS protocol to make it easy to plug in new access checking and validation methods without changing the NFS server protocol.

Notice that the protocol definition implies stateful servers because the server maintains a list of client's mount requests. The mount list information is not critical for the correct functioning of either the client or the server. It is intended for advisory use only, for example, to warn possible clients when a server is going down.

Version one of the mount protocol is used with version two of the NFS protocol. The only connecting point is the `fhandle` structure, which is the same for both protocols.

RPC Information

Authentication

The mount service uses AUTH_UNIX and AUTH_DES style authentication only.

Transport Protocols

The mount service is currently supported on UDP/IP only.

Port Number

Consult the server's portmapper, described in the *Remote Procedure Calls: Protocol Specification*, to find the port number on which the mount service is registered.

Sizes of XDR Structures

These are the sizes, given in decimal bytes, of various XDR structures used in the protocol:

```
/* The maximum number of bytes in a pathname argument */
const MNTPATHLEN = 1024;

/* The maximum number of bytes in a name argument */
const MNTNAMLEN = 255;

/* The size in bytes of the opaque file handle */
const FHSIZE = 32;
```

Basic Data Types

This section presents the data types used by the mount protocol. In many cases they are similar to the types used in NFS.

fhandle

```
typedef opaque fhandle[FHSIZE];
```

The type fhandle is the file handle that the server passes to the client. All file operations are done using file handles to refer to a file or directory. The file handle can contain whatever information the server needs to distinguish an individual file.

This is the same as the "fhandle" XDR definition in version 2 of the NFS protocol; see *Basic Data Types* in the definition of the NFS protocol, above.

fhstatus

```
union fhstatus switch (unsigned status) {
    case 0:
        fhandle directory;
    default:
        void;
};
```

The type fhstatus is a union. If a "status" of zero is returned, the call completed successfully, and a file handle for the "directory" follows. A non-zero status indicates some sort of error. In this case the status is a UNIX error number.

dirpath

```
typedef string dirpath<MNTPATHLEN>;
```

The type dirpath is a server pathname of a directory.

`name`

```
typedef string name<MNTNAMLEN>;
```

The type `name` is an arbitrary string used for various names.

Server Procedures

The following sections define the RPC procedures supplied by a mount server.

```
/*
* Protocol description for the mount program
*/

program MOUNTPROG {
/*
* Version 1 of the mount protocol used with
* version 2 of the NFS protocol.
*/
    version MOUNTVERS {
        void MOUNTPROC_NULL(void) = 0;
        fhstatus MOUNTPROC_MNT(dirpath) = 1;
        mountlist MOUNTPROC_DUMP(void) = 2;
        void MOUNTPROC_UMNT(dirpath) = 3;
        void MOUNTPROC_UMNTALL(void) = 4;
        exportlist MOUNTPROC_EXPORT(void) = 5;
    } = 1;
} = 100005;
```

Do Nothing

```
void
MNTPROC_NULL(void) = 0;
```

This procedure does no work. It is made available in all RPC services to allow server response testing and timing.

Add Mount Entry

```
fhstatus
MNTPROC_MNT(dirpath) = 1;
```

If the reply "status" is 0, then the reply "directory" contains the file handle for the directory "dirname". This file handle may be used in the NFS protocol. This procedure also adds a new entry to the mount list for this client mounting "dirname".

Return Mount Entries

```
struct *mountlist {
    name      hostname;
    dirpath   directory;
    mountlist nextentry;
};

mountlist
MNTPROC_DUMP(void) = 2;
```

Returns the list of remote mounted filesystems. The "mountlist" contains one entry for each "hostname" and "directory" pair.

Remove Mount Entry

```
void
MNTPROC_UMNT(dirpath) = 3;
```

Removes the mount list entry for the input "dirpath".

Remove All Mount Entries

```
void
MNTPROC_UMNTALL(void) = 4;
```

Removes all of the mount list entries for this client.

Return Export List

```
struct *groups {
    name grname;
    groups grnext;
};

struct *exportlist {
    dirpath filesys;
    groups groups;
    exportlist next;
};

exportlist
MNTPROC_EXPORT(void) = 5;
```

Returns a variable number of export list entries. Each entry contains a filesystem name and a list of groups that are allowed to import it. The filesystem name is in "filesys", and the group name is in the list "groups".

Note: The exportlist should contain more information about the status of the filesystem, such as a read-only flag.

PART THREE: Socket-Based IPC

8

A Socket-Based Interprocess Communications Tutorial

8

A Socket-Based Interprocess Communications Tutorial

This tutorial is intended as the first introduction to the socket-based interprocess communication (IPC) mechanisms. SunOS provides all these IPC mechanisms, as well as the STREAMS and remote procedure call (RPC) mechanisms. STREAMS — not to be confused with the sorts of "streams" (sockets-based data streams) discussed here — are introduced in the *Introduction to STREAMS* section of the *Writing Device Drivers*. Information about RPC — now the preferred foundation for Sun network applications — can be found in the *Remote Procedure Call Programming Guide* section of this manual.

Various approaches are possible within the socket paradigm; this manual discusses them, and then illustrates them by way a series of example programs. These programs demonstrate in a simple way the use of pipes, socketpairs, and the use of datagram socket and stream socket communication.

NOTE *Unlike RPC-based networking (which presumes XDR) socket-based IPC does not contain a mechanism for ensuring architecture independent code. Socket-based programs must make judicious use of the host-to-network byte-order conversion macros described in* `byteorder(3N)` *if they are to be portable.*

The intent of this chapter is to present a few simple example programs, not to describe the socket-based networking facilities in full. For more information, see the next chapter, *An Advanced Socket-Based Interprocess Communications Tutorial.*

8.1. Goals

Facilities for interprocess communication (IPC) and networking were a major addition to the UNIX system — first introduced in 4.2BSD and available in all versions of SunOS. These facilities required major additions and some changes to the system interface. The basic idea of this interface is to make IPC similar to file I/O. In the UNIX system a process has a set of I/O descriptors, from which one reads and to which one writes. Descriptors may refer to normal files, to devices (including terminals), or to communication channels. The use of a descriptor has three phases: creation, use for reading and writing, and destruction. By using descriptors to write files, rather than simply naming the target file in the write call, one gains a surprising amount of flexibility. Often, the program that creates a descriptor will be different from the program that uses the descriptor. For example the shell can create a descriptor for the output of the `ls` command that will cause the listing to appear in a file rather than on a terminal. Pipes are another form of descriptor that have been used in the UNIX system for some time. Pipes allow one-way data transmission from one process to another; the two processes and the pipe must be set up by a common ancestor.[10]

The use of descriptors is not the only communication interface provided by the UNIX system. The signal mechanism sends a tiny amount of information from one process to another. The signaled process receives only the signal type, not the identity of the sender, and the number of possible signals is small. The signal semantics limit the flexibility of the signaling mechanism as a means of interprocess communication.

The identification of IPC with I/O is quite longstanding in the UNIX system and has proved quite successful. At first, however, IPC was limited to processes communicating within a single machine. With 4.2BSD (and consequently with SunOS) this expanded to include IPC between machines. This expansion has necessitated some change in the way that descriptors are created. Additionally, new possibilities for the meaning of read and write have been admitted. Originally the meanings, or semantics, of these terms were fairly simple. When you wrote something it was delivered. When you read something, you were blocked until the data arrived. Other possibilities exist, however. One can write without full assurance of delivery if one can check later to catch occasional failures. Messages can be kept as discrete units or merged into a stream. One can ask to read, but insist on not waiting if nothing is immediately available. These new possibilities have been implemented in 4.3BSD and incorporated in SunOS.

Socket-based IPC offers several choices. This chapter presents simple examples that illustrate some of them. The reader is presumed to be familiar with the C programming language, but not necessarily with UNIX system calls or processes and interprocess communication. The chapter reviews the notion of a process and the types of communication that are supported by the socket abstraction. A series of examples are presented that create processes that communicate with one another. The programs show different ways of establishing channels of communication. Finally, the calls that actually transfer data are reviewed. To clearly present how communication can take place, the example programs have been cleared of anything that might be construed as useful work. They can serve as models for the programmer trying to construct programs that are composed of cooperating processes.

8.2. Processes

A *process* can be thought of as a single line of control in a program. Programs can have a point where control splits into two independent lines, an action called *forking*. In the UNIX system these lines can never join again. A call to the system routine `fork()` causes a process to split in this way. The result of this call is that two independent processes will be running, executing exactly the same code. Memory values will be the same for all values set before the fork, but, subsequently, each version will be able to change only the value of its own copy of each variable. Initially, the only difference between the two will be the value returned by `fork()`. The parent will receive a process id for the child, the child will receive a zero. Calls to `fork()` typically precede, or are included in, an if-

[10] This common-ancestry restriction has been relaxed in *named pipes* (FIFOs), which come from the AT&T line of UNIX-system development.

statement.

A process views the rest of the system through a private table of descriptors. The descriptors can represent open files or sockets (sockets are the endpoints of communications channels, as discussed below). Descriptors are referred to by their index numbers in the table. The first three descriptors are often known by special names, *stdin*, *stdout*, and *stderr*. These are the standard input, output, and error. When a process forks, its descriptor table is copied to the child. Thus, if the parent's standard input is being taken from a terminal (devices are also treated as files in the UNIX system), the child's input will be taken from the same terminal. Whoever reads first will get the input. If, before forking, the parent changes its standard input so that it is reading from a new file, the child will take its input from the new file. It is also possible to take input from a socket, rather than from a file.

8.3. Pipes

Most users of the UNIX system know that they can pipe the output of a program `prog1`, to the input of another, `prog2`, by typing the command

```
example# prog1 | prog2
```

This is called "piping" the output of one program to another because the mechanism used to transfer the output is called a pipe. When the user types a command, the command is read by the shell, which decides how to execute it. If the command is simple, for example,

```
example# prog1
```

the shell forks a process, which executes the program, `prog1`, and then dies. The shell waits for this termination and then prompts for the next command. If the command is a compound command,

```
example# prog1 | prog2
```

the shell creates two processes connected by a pipe. One process runs the program, `prog1`, the other runs `prog2`, The pipe is an I/O mechanism with two ends. Data that is written into one end can be read from the other.

Since a program specifies its input and output only by the descriptor table indices, the input source and output destination can be changed without changing the text of the program. It is in this way that the shell is able to set up pipes. Before executing `prog1`, the process can close whatever is at *stdout* and replace it with one end of a pipe. Similarly, the process that will execute `prog2` can substitute the opposite end of the pipe for *stdin*.

Now let's examine a program that creates a pipe for communication between its child and itself. A pipe is created by a parent process, which then forks. When a process forks, the parent's descriptor table is copied into the child's.

Figure 8-1 *Use of a Pipe*

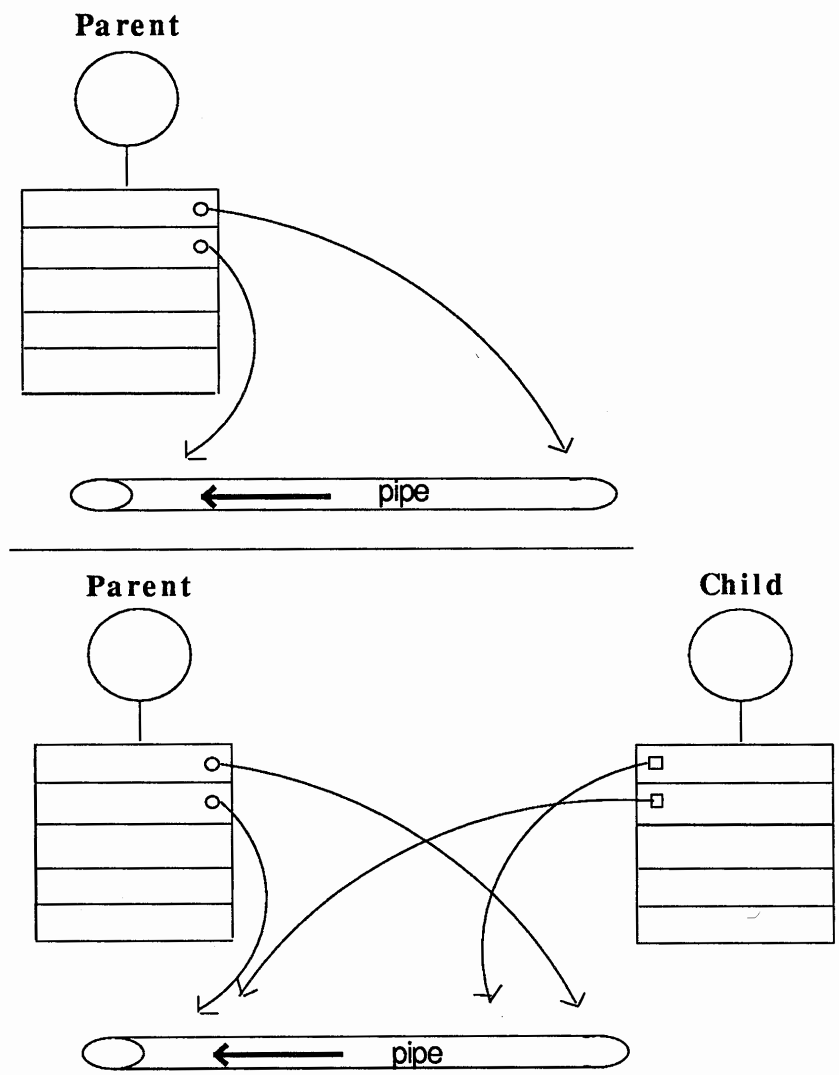
```
#include <stdio.h>

#define DATA "Bright star, would I . . ."
```

```
/*
 * This program creates a pipe, then forks. The child communicates to the
 * parent over the pipe. Notice that a pipe is a one-way communications
 * device. I can write to the output socket (sockets[1], the second
 * socket of the array returned by pipe) and read from the input
 * socket (sockets[0]), but not vice versa.
 */

main()
{
    int sockets[2], child;

    /* Create a pipe */
    if (pipe(sockets) < 0) {
        perror("opening stream socket pair");
        exit(10);
    }

    if ((child = fork()) == -1)
        perror("fork");
    else if (child) {
        char buf[1024];

        /* This is still the parent. It reads the child's message. */
        close(sockets[1]);
        if (read(sockets[0], buf, 1024) < 0)
            perror("reading message");
        printf("-->%s\n", buf);
        close(sockets[0]);
    } else {
        /* This is the child. It writes a message to its parent. */
        close(sockets[0]);
        if (write(sockets[1], DATA, sizeof(DATA)) < 0)
            perror("writing message");
        close(sockets[1]);
    }
    exit(0);
}
```

Here the parent process makes a call to the system routine `pipe()`. This routine creates a pipe and places descriptors for the sockets for the two ends of the pipe in the process's descriptor table. `pipe()`. is passed an array into which it places the index numbers of the sockets it creates. The two ends are not equivalent. The socket whose index is returned in the first word of the array is opened for reading only, while the socket in the second word is opened only for writing. This corresponds to the fact that the standard input is the first descriptor of a process's descriptor table and the standard output is the second. After creating the pipe, the parent creates the child with which it will share the pipe by calling `fork()`.

The following figure illustrates the effect of such a call to `fork()`. The parent process's descriptor table points to both ends of the pipe. After the fork, both parent's and child's descriptor tables point to the pipe. The child can then use the pipe to send a message to the parent.

Figure 8-2 *Sharing a Pipe between Parent and Child*



Just what is a pipe? It is a one-way communication mechanism, with one end opened for reading and the other end for writing. Therefore, parent and child need to agree on which way to turn the pipe, from parent to child or the other way around. Using the same pipe for communication both from parent to child and from child to parent would be possible (since both processes have references to both ends), but very complicated. If the parent and child are to have a two-way conversation, the parent creates two pipes, one for use in each direction. (In accordance with their plans, both parent and child in the example above close the socket that they will not use. It is not required that unused descriptors be closed, but it is good practice.) A pipe is also a *stream* communication mechanism; that is, all messages sent through the pipe are placed in order and reliably delivered. When the reader asks for a certain number of bytes from this stream, it is given as many bytes as are available, up to the amount of the request. Note that these bytes may have come from the same call to `write()` or from several calls to `write()` that were concatenated.

8.4. Socketpairs

SunOS provides a slight generalization of pipes. A pipe is now a pair of connected sockets for one-way stream communication. One may obtain a pair of connected sockets for two-way stream communication by calling the routine `socketpair()`. The program in figure *8-3*, below, calls `socketpair()` to create such a connection. The program uses the link for communication in both directions. Since socketpairs are an extension of pipes, their use resembles that of pipes. Figure *8-4* illustrates the result of a fork following a call to `socketpair()`.

`socketpair()` takes as arguments a specification of a communication domain, a style of communication, and a protocol. These are the parameters shown in the example. Domains and protocols will be discussed in the next section. Briefly, a domain specifies a socket name space and implies a set of conventions for manipulating socket names. Currently, socketpairs have only been implemented for the UNIX domain. The UNIX domain uses UNIX path names for naming sockets. It only allows communication between sockets on the same machine.

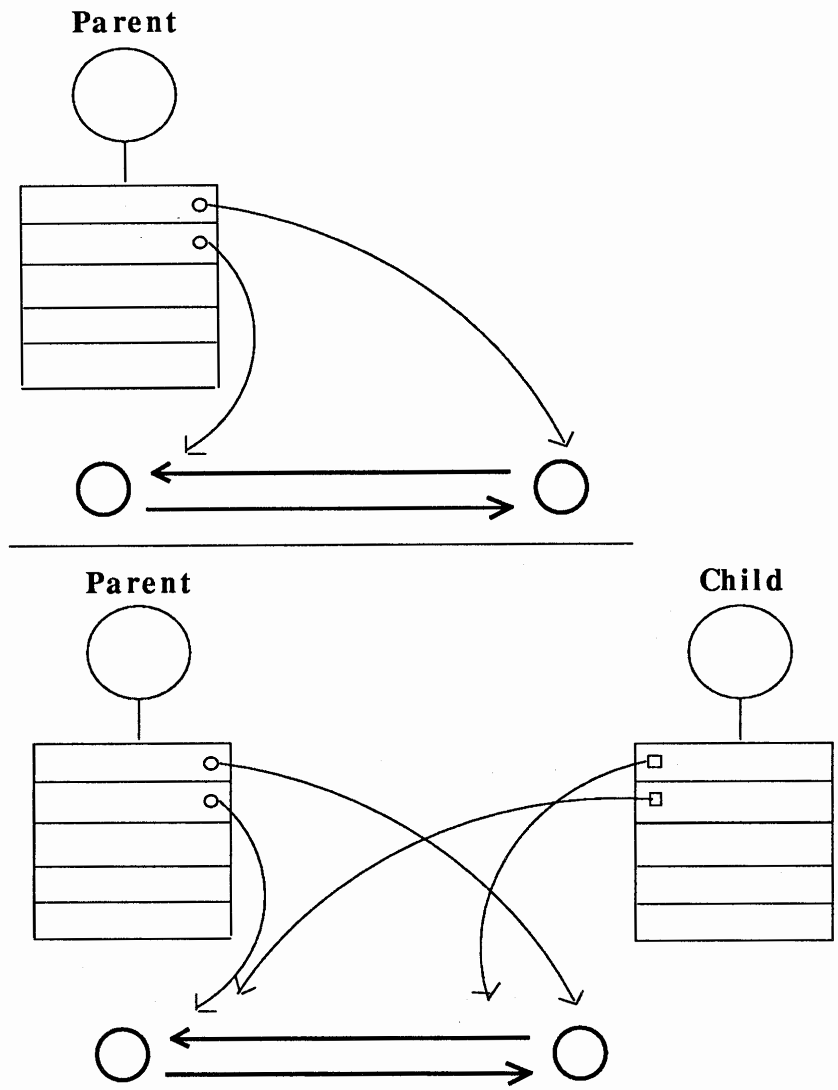
Note that the header files `<sys/socket.h>` and `<sys/types.h>`. are required in this program. The constants `AF_UNIX` and `SOCK_STREAM` are defined in `<sys/socket.h>`, which in turn requires the file `<sys/types.h>` for some of its definitions.

Figure 8-3 *Use of a Socketpair*

```
#include <sys/types.h>
#include <sys/socket.h>
#include <stdio.h>

#define DATA1 "In Xanadu, did Kublai Khan . . ."
#define DATA2 "A stately pleasure dome decree . . ."

/*
 * This program creates a pair of connected sockets then forks and
 * communicates over them. This is very similar to communication with pipes,
 * however, socketpairs are two-way communications objects. Therefore I can
 * send messages in both directions.
 */

main()
{
    int sockets[2], child;
    char buf[1024];

    if (socketpair(AF_UNIX, SOCK_STREAM, 0, sockets) < 0) {
```

```
        perror("opening stream socket pair");
        exit(1);
    }

    if ((child = fork()) == -1)
        perror("fork");
    else if (child) {    /* This is the parent */
        close(sockets[0]);
        if (read(sockets[1], buf, 1024, 0) < 0)
            perror("reading stream message");
        printf("-->%s\n", buf);
        if (write(sockets[1], DATA2, sizeof(DATA2)) < 0)
            perror("writing stream message");
        close(sockets[1]);
    } else {            /* This is the child */
        close(sockets[1]);
        if (write(sockets[0], DATA1, sizeof(DATA1)) < 0)
            perror("writing stream message");
        if (read(sockets[0], buf, 1024, 0) < 0)
            perror("reading stream message");
        printf("-->%s\n", buf);
        close(sockets[0]);
    }
    exit(0);
}
```

Figure 8-4 *Sharing a Socketpair between Parent and Child*



8.5. Domains and Protocols

Pipes and socketpairs are a simple solution for communicating between a parent and child or between child processes. What if we wanted to communicate between processes that have no common ancestor. Neither standard UNIX pipes nor socketpairs are the answer here, since both mechanisms require a common ancestor to set up the communication. We would like to have two processes separately create sockets and then have messages sent between them. This is often the case when providing or using a service in the system. This is also the case when the communicating processes are on separate machines.

Sockets created by different programs use names to refer to one another; names generally must be translated into addresses for use. The space from which an address is specified by a *domain*. There are several such domains for sockets. Two that will be used in the examples here are the UNIX domain (or `AF_UNIX`, for Address Format UNIX) and the Internet domain (or `AF_INET`). In the UNIX domain, a socket is given a path name within the file system name space. A file system node is created for the socket and other processes may then refer to it by giving its pathname. UNIX domain names, thus, allow communication between any two processes that reside on the same machine and that are able to access the socket pathnames. The Internet domain is the UNIX implementation of the DARPA Internet standard protocols `IP/TCP/UDP`. Addresses in the Internet domain consist of a machine network address and an identifying number, called a port. Internet domain names allow communication between separate machines.

Communication follows some particular "style." Currently, communication is either through a *stream* socket or by *datagram*. Stream communication implies a connection. The communication is reliable, error-free, and, as in pipes, no message boundaries are kept. Reading from a stream may result in reading the data sent from one or several calls to `write()` or only part of the data from a single call, if there is not enough room for the entire message, or if not all the data from a large message has been transferred. The protocol implementing such a style will retransmit messages received with errors. It will also return error messages if one tries to send a message after the connection has been broken. Datagram communication does not use connections. Each message is addressed individually. If the address is correct, it will generally be received, although this is not guaranteed. Often datagrams are used for requests that require a response from the recipient. If no response arrives in a reasonable amount of time, the request is repeated. The individual datagrams will be kept separate when they are read, that is, message boundaries are preserved.

The difference in performance between the two styles of communication is generally less important than the difference in semantics. The performance gain that one might find in using datagrams must be weighed against the increased complexity of the program, which must now concern itself with lost or out of order messages. If lost messages may simply be ignored, the quantity of traffic may be a consideration. The expense of setting up a connection is best justified by frequent use of the connection. Since the performance of a protocol changes as it is tuned for different situations, it is best to seek the most up-to-date information when making choices for a program in which performance is crucial.

A protocol is a set of rules, data formats, and conventions that regulate the transfer of data between participants in the communication. In general, there is one protocol for each socket type (stream, datagram, etc.) within each domain. The code that implements a protocol keeps track of the names that are bound to sockets, sets up connections, and transfers data between sockets, perhaps sending the data across a network. This code also keeps track of the names that are bound to sockets. It is possible for several protocols, differing only in low level details, to implement the same style of communication within a particular domain. Although it is possible to select which protocol should be used, for nearly all uses it is sufficient to request the default protocol. This has been done in all of the example programs.

One specifies the domain, style and protocol of a socket when it is created. For example, in figure *8-6* the call to `socket()` causes the creation of a datagram socket with the default protocol in the UNIX domain.

8.6. Datagrams in the UNIX Domain

Let us now look at two programs that create sockets separately. The programs in Figures *8-5* and *8-6* use datagram communication rather than a stream. The structure used to name UNIX domain sockets is defined in the file `<sys/un.h>`. The definition has also been included in the example for clarity.

Each program creates a socket with a call to `socket()`. These sockets are in the UNIX domain. Once a name has been decided upon it is attached to a socket by the system call `bind()`. The program in Figure *8-5* uses the name "socket", which it binds to its socket. This name will appear in the working directory of the program. The routines in Figure *8-6*, use the socket only for sending messages. They do not create a name for the socket because no other process has to refer to it.

Figure 8-5 *Reading UNIX Domain Datagrams*

```
#include <sys/types.h>
#include <sys/socket.h>
#include <sys/un.h>
#include <stdio.h>

/*
 * The include file <sys/un.h> defines sockaddr_un as follows:
 * struct sockaddr_un {
 *   short    sun_family;
 *   char     sun_path[108];
 * };
 */

#define NAME "socket"

/*
 * This program creates a UNIX domain datagram socket, binds a name to it,
 * then reads from the socket.
 */
main()
{
    int sock, length;
    struct sockaddr_un name;
    char buf[1024];

    /* Create socket from which to read. */
    sock = socket(AF_UNIX, SOCK_DGRAM, 0);
    if (sock < 0) {
        perror("opening datagram socket");
        exit(1);
    }
    /* Create name. */
    name.sun_family = AF_UNIX;
    strcpy(name.sun_path, NAME);
    if (bind(sock, (struct sockaddr *)&name,
      sizeof(struct sockaddr_un)) < 0) {
        perror("binding name to datagram socket");
```

```
        exit(1);
    }
    printf("socket -->%s\n", NAME);
    /* Read from the socket. */
    if (read(sock, buf, 1024) < 0)
        perror("receiving datagram packet");
    printf("-->%s\n", buf);
    close(sock);
    unlink(NAME);
    exit(0);
}
```

Note that, in the call to `bind()` above, the *&name* parameter is cast to a `(struct sockaddr *)`. In writing networking code, one invariably has to cast such address arguments to network-related system calls, since the system-call routines must be able to handle a variety of address formats, yet each individual call will use a specialization of the general format. It is poor programming style to omit these casts, a fact which `lint` will be only to glad to remind you of.

Figure 8-6 *Sending a UNIX Domain Datagrams*

```
#include <sys/types.h>
#include <sys/socket.h>
#include <sys/un.h>
#include <stdio.h>

#define DATA "The sea is calm, the tide is full . . ."

/*
 * Here I send a datagram to a receiver whose name I get from the command
 * line arguments. The form of the command line is udgramsend pathname.
 */

main(argc, argv)
    int argc;
    char *argv[];
{
    int sock;
    struct sockaddr_un name;

    /* Create socket on which to send. */
    sock = socket(AF_UNIX, SOCK_DGRAM, 0);
    if (sock < 0) {
        perror("opening datagram socket");
        exit(1);
    }
    /* Construct name of socket to send to. */
    name.sun_family = AF_UNIX;
    strcpy(name.sun_path, argv[1]);
    /* Send message. */
```

```
    if (sendto(sock, DATA, sizeof(DATA), 0,
      (struct sockaddr *)&name,
      sizeof(struct sockaddr_un)) < 0) {
        perror("sending datagram message");
    }
    close(sock);
    exit(0);
}
```

Names in the UNIX domain are path names. Like file path names they may be either absolute (e.g. "/dev/imaginary") or relative (e.g. "socket"). Because these names are used to allow processes to rendezvous, relative path names can pose difficulties and should be used with care. When a name is bound into the name space, a file (vnode) is allocated in the file system. If the vnode is not deallocated, the name will continue to exist even after the bound socket is closed. This can cause subsequent runs of a program to find that a name is unavailable, and can cause directories to fill up with these objects. The names are removed by calling `unlink()` or using the `rm(1)` command. Names in the UNIX domain are only used for rendezvous. They are not used for message delivery once a connection is established. Therefore, in contrast with the Internet domain, unbound sockets need not be (and are not) automatically given addresses when they are connected.

There is no established means of communicating names to interested parties. In the example, the program in Figure *8-6* gets the name of the socket to which it will send its message through its command line arguments. Once a line of communication has been created, one can send the names of additional, perhaps new, sockets over the link.

8.7. Datagrams in the Internet Domain

Figure 8-7 *Reading Internet Domain Datagrams*

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <stdio.h>

/*
 * The include file <netinet/in.h> defines sockaddr_in as follows:
 * struct sockaddr_in {
 *   short   sin_family;
 *   u_short sin_port;
 *   struct in_addr sin_addr;
 *   char    sin_zero[8];
 * };
 *
 * This program creates a datagram socket, binds a name to it, then reads
 * from the socket.
 */
main()
{
    int sock, length;
    struct sockaddr_in name;
    char buf[1024];

    /* Create socket from which to read. */
    sock = socket(AF_INET, SOCK_DGRAM, 0);
    if (sock < 0) {
        perror("opening datagram socket");
        exit(1);
    }
    /* Create name with wildcards. */
    name.sin_family = AF_INET;
    name.sin_addr.s_addr = INADDR_ANY;
    name.sin_port = 0;
    if (bind(sock, (struct sockaddr *)&name,
      sizeof name ) < 0) {
        perror("binding datagram socket");
        exit(1);
    }
    /* Find assigned port value and print it out. */
    length = sizeof(name);
    if (getsockname(sock, (struct sockaddr *)&name,
      &length) < 0) {
        perror("getting socket name");
        exit(1);
    }
    printf("Socket port #%d\n", ntohs(name.sin_port));
    /* Read from the socket. */
```

```
    if (read(sock, buf, 1024) < 0)
        perror("receiving datagram packet");
    printf("-->%s\n", buf);
    close(sock);
    exit(0);
}
```

The examples in Figure *8-7* and *8-8* are very close to the previous examples except that the socket is in the Internet domain. The structure of Internet domain addresses is defined in the file `<netinet/in.h>`. Internet addresses specify a host address (a 32-bit number) and a delivery slot, or port, on that machine. These ports are managed by the system routines that implement a particular protocol. Unlike UNIX domain names, Internet socket names are not entered into the file system and, therefore, they do not have to be unlinked after the socket has been closed. When a message must be sent between machines it is sent to the protocol routine on the destination machine, which interprets the address to determine to which socket the message should be delivered. Several different protocols may be active on the same machine, but, in general, they will not communicate with one another. As a result, different protocols are allowed to use the same port numbers. Thus, implicitly, an Internet address is a triple including a protocol as well as the port and machine address. An *association* is a temporary or permanent specification of a pair of communicating sockets. An association is thus identified by the tuple *<protocol, local machine address, local port, remote machine address, remote port>*. An association may be transient when using datagram sockets; the association actually exists during a `send()` operation.

Figure 8-8 *Sending an Internet Domain Datagram*

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#include <stdio.h>

#define DATA "The sea is calm, the tide is full . . ."

/*
 * Here I send a datagram to a receiver whose name I get from the command
 * line arguments. The form of the command line is:
 * dgramsend hostname portnumber
 */

main(argc, argv)
    int argc;
    char *argv[];
{
    int sock;
    struct sockaddr_in name;
    struct hostent *hp, *gethostbyname();
```

```
    /* Create socket on which to send. */
    sock = socket(AF_INET, SOCK_DGRAM, 0);
    if (sock < 0) {
        perror("opening datagram socket");
        exit(1);
    }
    /*
     * Construct name, with no wildcards, of the socket to send to.
     * gethostbyname returns a structure including the network address
     * of the specified host. The port number is taken from the command
     * line.
     */
    hp = gethostbyname(argv[1]);
    if (hp == 0) {
        fprintf(stderr, "%s: unknown host0, argv[1]);
        exit(2);
    }
    bcopy((char *)hp->h_addr, (char *)&name.sin_addr,
      hp->h_length);
    name.sin_family = AF_INET;
    name.sin_port = htons(atoi(argv[2]));
    /* Send message. */
    if (sendto(sock, DATA, sizeof DATA , 0,
      (struct sockaddr *)&name, sizeof name) < 0)
        perror("sending datagram message");
    close(sock);
    exit(0);
}
```

The protocol for a socket is chosen when the socket is created. The local machine address for a socket can be any valid network address of the machine, if it has more than one, or it can be the wildcard value `INADDR_ANY`. The wildcard value is used in the program in Figure *8-7*. If a machine has several network addresses, it is likely that messages sent to any of the addresses should be deliverable to a socket. This will be the case if the wildcard value has been chosen. Note that even if the wildcard value is chosen, a program sending messages to the named socket must specify a valid network address. One can be willing to receive from "anywhere," but one cannot send a message "anywhere." The program in Figure *8-8* is given the destination host name as a command line argument. To determine a network address to which it can send the message, it looks up the host address by the call to `gethostbyname()`. The returned structure includes the host's network address, which is copied into the structure specifying the destination of the message.

The port number can be thought of as the number of a mailbox, into which the protocol places one's messages. Certain daemons, offering certain advertised services, have reserved or "well-known" port numbers. These fall in the range from 1 to 1023. Higher numbers are available to general users. Only servers need to ask for a particular number. The system will assign an unused port number when an address is bound to a socket. This may happen when an explicit `bind()` call is made with a port number of 0, or when a `connect()` or send() is performed on an unbound socket. Note that port numbers are not automatically reported back to the user. After calling bind(), asking for port 0, one may call getsockname() to discover what port was actually assigned. The routine getsockname() will not work for names in the UNIX domain.

The format of the socket address is specified in part by standards within the Internet domain. The specification includes the order of the bytes in the address. Because machines differ in the internal representation they ordinarily use to represent integers, printing out the port number as returned by getsockname may result in a misinterpretation. To print out the number, it is necessary to use the routine ntohs() (for *network to host: short*) to convert the number from the network representation to the host's representation. On some machines, such as 68000-based machines, this is a null operation. On others, such as VAXes, this results in a swapping of bytes. Another routine exists to convert a short integer from the host format to the network format, called htons(); similar routines exist for long integers. For further information, see byteorder(3).

8.8. Connections

To send data between stream sockets (having communication style SOCK_STREAM), the sockets must be connected. Figures *8-9* and *8-10* show two programs that create such a connection. The program in *8-9* is relatively simple. To initiate a connection, this program simply creates a stream socket, then calls connect(), specifying the address of the socket to which it wishes its socket connected. Provided that the target socket exists and is prepared to handle a connection, connection will be complete, and the program can begin to send messages. Messages will be delivered in order without message boundaries, as with pipes. The connection is destroyed when either socket is closed (or soon thereafter). If a process persists in sending messages after the connection is closed, a SIGPIPE signal is sent to the process by the operating system. Unless explicit action is taken to handle the signal (see the signal(3) or sigvec(3) man pages) the process will terminate.

Figure 8-9 *Initiating an Internet Domain Stream Connection*

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#include <stdio.h>

#define DATA "Half a league, half a league . . ."

/*
 * This program creates a socket and initiates a connection with the socket
 * given in the command line. One message is sent over the connection and
 * then the socket is closed, ending the connection. The form of the command
 * line is: streamwrite hostname portnumber
 */

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

```
{
    int sock;
    struct sockaddr_in server;
    struct hostent *hp, *gethostbyname();
    char buf[1024];

    /* Create socket. */
    sock = socket(AF_INET, SOCK_STREAM, 0);
    if (sock < 0) {
        perror("opening stream socket");
        exit(1);
    }
    /* Connect socket using name specified by command line. */
    server.sin_family = AF_INET;
    hp = gethostbyname(argv[1]);
    if (hp == 0) {
        fprintf(stderr, "%s: unknown host0, argv[1]);
        exit(2);
    }
    bcopy((char *)hp->h_addr, (char *)&server.sin_addr,
      hp->h_length);
    server.sin_port = htons(atoi(argv[2]));

    if (connect(sock,
      (struct sockaddr *)&server, sizeof server ) < 0) {
        perror("connecting stream socket");
        exit(1);
    }
    if (write(sock, DATA, sizeof DATA ) < 0)
        perror("writing on stream socket");
    close(sock);
    exit(0);
}
```

Forming a connection is asymmetrical; one process, such as the program in Figure *8-9* requests a connection with a particular socket, the other process accepts connection requests. Before a connection can be accepted a socket must be created and an address bound to it. This situation is illustrated in the top half of Figure *8-12*. Process 2 has created a socket and bound a port number to it. Process 1 has created an unnamed socket. The address bound to process 2's socket is then made known to process 1 and, perhaps to several other potential communicants as well. If there are several possible communicants, this one socket might receive several requests for connections. As a result, a new socket is created for each connection. This new socket is the endpoint for communication within this process for this connection. A connection may be destroyed by closing the corresponding socket.

The program in Figure *8-10* is a rather trivial example of a server. It creates a socket to which it binds a name, which it then advertises. (In this case it prints out the socket number.) The program then calls `listen()` for this socket. Since several clients may attempt to connect more or less simultaneously, a queue of pending connections is maintained in the system address space. `listen()` marks the socket as willing to accept connections and initializes the queue. When a connection is requested, it is listed in the queue. If the queue is full, an error status may be returned to the requester. The maximum length of this queue is specified by the second argument of `listen()`; the maximum length is limited by the system. Once the listen call has been completed, the program enters an infinite loop. On each pass through the loop, a new connection is accepted and removed from the queue, and, hence, a new socket for the connection is created. The bottom half of Figure *8-12* shows the result of Process 1 connecting with the named socket of Process 2, and Process 2 accepting the connection. After the connection is created, the service, in this case printing out the messages, is performed and the connection socket closed. The `accept()` call will take a pending connection request from the queue if one is available, or block waiting for a request. Messages are read from the connection socket. Reads from an active connection will normally block until data is available. The number of bytes read is returned. When a connection is destroyed, the read call returns immediately. The number of bytes returned will be zero.

The program in Figure *8-11* is a slight variation on the server in Figure *8-10*. It avoids blocking when there are no pending connection requests by calling `select()` to check for pending requests before calling `accept()`. This strategy is useful when connections may be received on more than one socket, or when data may arrive on other connected sockets before another connection request.

The programs in Figures *8-13* and *8-14* show a program using stream socket communication in the UNIX domain. Streams in the UNIX domain can be used for this sort of program in exactly the same way as Internet domain streams, except for the form of the names and the restriction of the connections to a machine. There are some differences, however, in the functionality of streams in the two domains, notably in the handling of *out-of-band* data (discussed briefly below). These differences are beyond the scope of this chapter.

Figure 8-10 *Accepting an Internet Domain Stream Connection*

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#include <stdio.h>
#define TRUE 1

/*
 * This program creates a socket and then begins an infinite loop. Each time
 * through the loop it accepts a connection and prints out messages from it.
 * When the connection breaks, or a termination message comes through, the
 * program accepts a new connection.
 */

main()
{
```

```
    int sock, length;
    struct sockaddr_in server;
    int msgsock;
    char buf[1024];
    int rval;
    int i;

    /* Create socket. */
    sock = socket(AF_INET, SOCK_STREAM, 0);
    if (sock < 0) {
        perror("opening stream socket");
        exit(1);
    }
    /* Name socket using wildcards. */
    server.sin_family = AF_INET;
    server.sin_addr.s_addr = INADDR_ANY;
    server.sin_port = 0;
    if (bind(sock, (struct sockaddr *)&server,
      sizeof server ) < 0) {
        perror("binding stream socket");
        exit(1);
    }
    /* Find out assigned port number and print it out. */
    length = sizeof server;
    if (getsockname(sock, (struct sockaddr *)&server,
      &length) < 0) {
        perror("getting socket name");
        exit(1);
    }
    printf("Socket port #%d\n", ntohs(server.sin_port));

    /* Start accepting connections. */
    listen(sock, 5);
    do {
        msgsock = accept(sock,
             (struct sockaddr *)0, (int *)0);
        if (msgsock == -1)
            perror("accept");
        else do {
            bzero(buf, sizeof buf );
            if ((rval = read(msgsock, buf, 1024)) < 0)
                perror("reading stream message");
            i = 0;
            if (rval == 0)
                printf("Ending connection\n");
            else
                printf("-->%s\n", buf);
        } while (rval != 0);
        close(msgsock);
    } while (TRUE);
    /*
     * Since this program has an infinite loop, the socket "sock" is
     * never explicitly closed. However, all sockets will be closed
```

```
         * automatically when a process is killed or terminates normally.
         */
         exit(0);
}
```

Figure 8-11 *Using* `select()` *to Check for Pending Connections*

```
#include <sys/types.h>
#include <sys/socket.h>
#include <sys/time.h>
#include <netinet/in.h>
#include <netdb.h>
#include <stdio.h>
#define TRUE 1

/*
 * This program uses select to check that someone is trying to connect
 * before calling accept.
 */

main()
{
    int sock, length;
    struct sockaddr_in server;
    int msgsock;
    char buf[1024];
    int rval;
    fd_set ready;
    struct timeval to;

    /* Create socket. */
    sock = socket(AF_INET, SOCK_STREAM, 0);
    if (sock < 0) {
        perror("opening stream socket");
        exit(1);
    }
    /* Name socket using wildcards. */
    server.sin_family = AF_INET;
    server.sin_addr.s_addr = INADDR_ANY;
    server.sin_port = 0;
    if (bind(sock, (struct sockaddr *)&server,
      sizeof server) < 0) {
        perror("binding stream socket");
        exit(1);
    }
    /* Find out assigned port number and print it out. */
    length = sizeof server;
    if (getsockname(sock, (struct sockaddr *)&server,
      &length) < 0) {
        perror("getting socket name");
        exit(1);
```

```
    }
    printf("Socket port #%d\n", ntohs(server.sin_port));

    /* Start accepting connections. */
    listen(sock, 5);
    do {
        FD_ZERO(&ready);
        FD_SET(sock, &ready);
        to.tv_sec = 5;
        if (select(sock + 1, &ready, (fd_set *)0,
          (fd_set *)0, &to) < 0) {
            perror("select");
            continue;
        }
        if (FD_ISSET(sock, &ready)) {
            msgsock = accept(sock, (struct sockaddr *)0,
              (int *)0);
            if (msgsock == -1)
                perror("accept");
            else do {
                bzero(buf, sizeof buf);
                if ((rval = read(msgsock, buf, 1024)) < 0)
                    perror("reading stream message");
                else if (rval == 0)
                    printf("Ending connection\n");
                else
                    printf("-->%s\n", buf);
            } while (rval > 0);
            close(msgsock);
        } else
            printf("Do something else\n");
    } while (TRUE);
    exit(0);
}
```

Figure 8-12 *Establishing a Stream Connection*

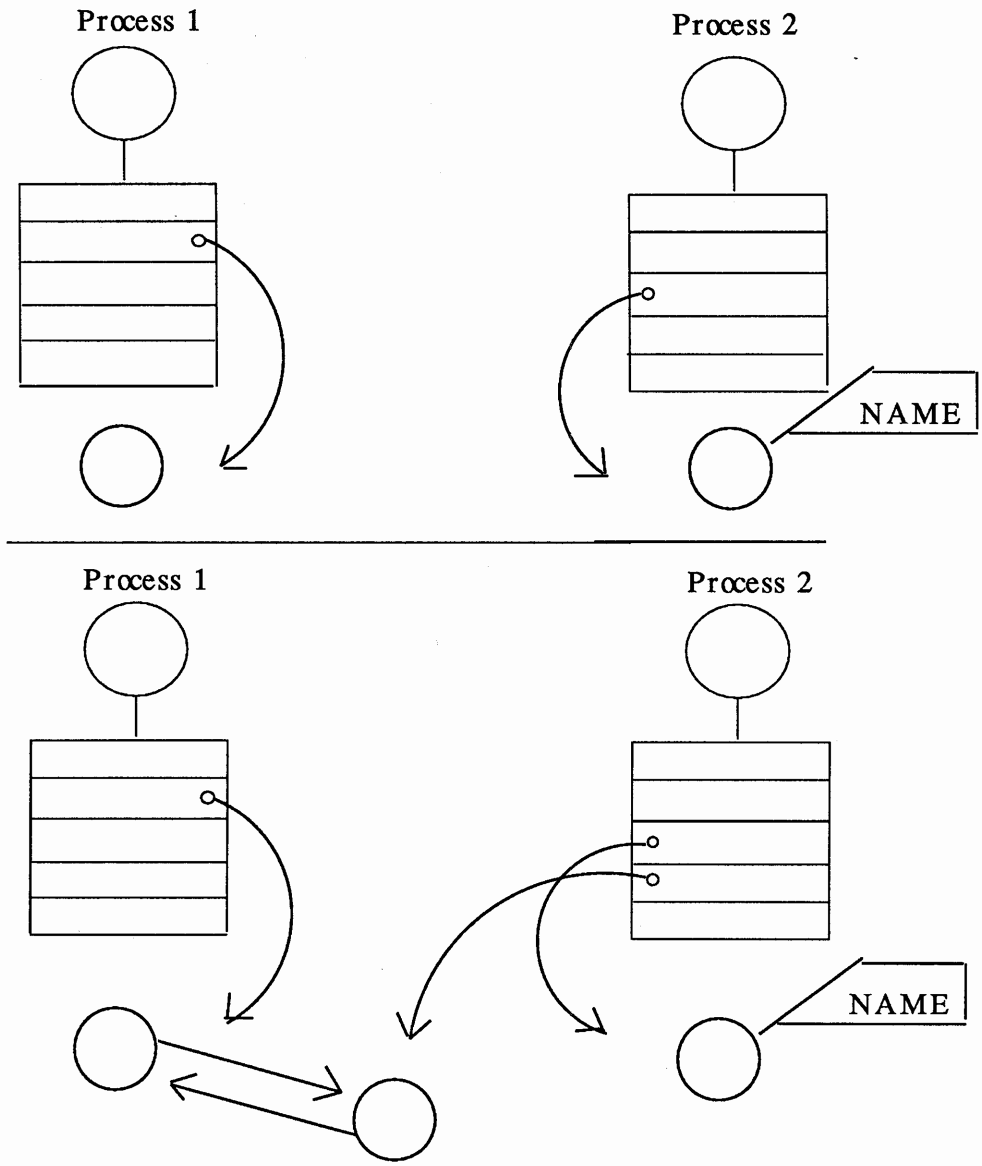


Figure 8-13 *Initiating a UNIX Domain Stream Connection*

```
#include <sys/types.h>
#include <sys/socket.h>
#include <sys/un.h>
#include <stdio.h>

#define DATA "Half a league, half a league . . ."

/*
 * This program connects to the socket named in the command line and sends a
 * one line message to that socket. The form of the command line is:
 * ustreamwrite pathname
 */
main(argc, argv)
```

```
    int argc;
    char *argv[];
{
    int sock;
    struct sockaddr_un server;
    char buf[1024];

    /* Create socket. */
    sock = socket(AF_UNIX, SOCK_STREAM, 0);
    if (sock < 0) {
        perror("opening stream socket");
        exit(1);
    }
    /* Connect socket using name specified by command line. */
    server.sun_family = AF_UNIX;
    strcpy(server.sun_path, argv[1]);

    if (connect(sock, (struct sockaddr *)&server,
      sizeof(struct sockaddr_un)) < 0) {
        close(sock);
        perror("connecting stream socket");
        exit(1);
    }
    if (write(sock, DATA, sizeof(DATA)) < 0)
        perror("writing on stream socket");
    exit(0);
}
```

Figure 8-14 *Accepting a UNIX Domain Stream Connection*

```
#include <sys/types.h>
#include <sys/socket.h>
#include <sys/un.h>
#include <stdio.h>

#define NAME "socket"

/*
 * This program creates a socket in the UNIX domain and binds a name to it.
 * After printing the socket's name it begins a loop. Each time through the
 * loop it accepts a connection and prints out messages from it. When the
 * connection breaks, or a termination message comes through, the program
 * accepts a new connection.
 */
main()
{
    int sock, msgsock, rval;
    struct sockaddr_un server;
    char buf[1024];

    /* Create socket. */
```

```
    sock = socket(AF_UNIX, SOCK_STREAM, 0);
    if (sock < 0) {
        perror("opening stream socket");
        exit(1);
    }
    /* Name socket using file system name. */
    server.sun_family = AF_UNIX;
    strcpy(server.sun_path, NAME);
    if (bind(sock, (struct sockaddr *)&server,
      sizeof(struct sockaddr_un)) < 0) {
        perror("binding stream socket");
        exit(1);
    }
    printf("Socket has name %s\n", server.sun_path);
    /* Start accepting connections. */
    listen(sock, 5);
    for (;;) {
        msgsock = accept(sock, (struct sockaddr *)0,
          (int *)0);
        if (msgsock == -1)
            perror("accept");
        else do {
            bzero(buf, sizeof buf);
            if ((rval = read(msgsock, buf, 1024)) < 0)
                perror("reading stream message");
            else if (rval == 0)
                printf("Ending connection\n");
            else
                printf("-->%s\n", buf);
        } while (rval > 0);
        close(msgsock);
    }
    /*
     * The following statements are not executed, because they follow an
     * infinite loop. However, most ordinary programs will not run
     * forever. In the UNIX domain it is necessary to tell the file
     * system that one is through using NAME. In most programs one uses
     * the call unlink as below. Since the user will have to kill this
     * program, it will be necessary to remove the name by a command from
     * the shell.
     */
    close(sock);
    unlink(NAME);
    exit(0);
}
```

8.9. Reads, Writes, Recvs, etc.

SunOS has several system calls for reading and writing information. The simplest calls are `read()` and `write()`. `write()` takes as arguments the index of a descriptor, a pointer to a buffer containing the data, and the size of the data. The descriptor may indicate either a file or a connected socket. "Connected" can mean either a connected stream socket (as described in the *Connections* section below, or a datagram socket for which a `connect`(3) call has provided a default destination. `read()` also takes a descriptor that indicates either a file or a socket. `write()` requires a connected socket since no destination is specified in the parameters of the system call. `read()` can be used for either a connected or an unconnected socket. These calls are, therefore, quite flexible and may be used to write applications that make no assumptions about the source of their input or the destination of their output. There are variations on `read()` and `write()` that allow the source and destination of the input and output to use several separate buffers, while retaining the flexibility to handle both files and sockets. These are `readv()` and `writev`(), for read and write *vector*.

It is sometimes necessary to send high priority data over a connection that may have unread low priority data at the other end. For example, a user interface process may be interpreting commands and sending them on to another process through a stream socket connection. The user interface may have filled the stream with as yet unprocessed requests when the user types a command to cancel all outstanding requests. Rather than have the high priority data wait to be processed after the low priority data, it is possible to send it as *out-of-band* (OOB) data. The notification of pending OOB data results in the generation of a `SIGURG` signal, if this signal has been enabled (see the `signal(3)` and `sigvec(3)` man pages). See *An Advanced Socket-Based Interprocess Communications Tutorial* for a more complete description of the OOB mechanism.

There are a pair of calls similar to `read()` and `write()` that allow options, including sending and receiving OOB information; these are `send()` and `recv`(). These calls are used only with sockets; specifying a descriptor for a file will result in the return of an error status. These calls also allow *peeking* at data in a stream. That is, they allow a process to read data without removing the data from the stream. One use of this facility is to read ahead in a stream to determine the size of the next item to be read. When not using these options, these calls have the same functions as `read()` and `write`().

To send datagrams, one must be allowed to specify the destination. The call `sendto()` takes a destination address as an argument and is therefore used for sending datagrams. The call `recvfrom()` is often used to read datagrams, since this call returns the address of the sender, if it is available, along with the data. If the identity of the sender does not matter, one may use `read()` or `recv()`.

Finally, there are a pair of calls that allow the sending and receiving of messages from multiple buffers, when the address of the recipient must be specified. These are `sendmsg()` and `recvmsg()`. These calls are actually quite general and have other uses, including, in the UNIX domain, the transmission of a file descriptor from one process to another.

The various options for reading and writing, together with their parameters, are shown in Figure *8-15* below. The parameters for each system call reflect the differences in function of the different calls. In the examples given in this chapter, the calls `read()` and `write()` have been used whenever possible.

Figure 8-15 *Varieties of Read and Write Commands*

```
/*
 * The variable descriptor may be the descriptor of either a file
 * or of a socket.
 */
cc = read(descriptor, buf, nbytes)
int cc, descriptor; char *buf; int nbytes;

/*
 * An iovec can include several source buffers.
 */
cc = readv(descriptor, iov, iovcnt)
int cc, descriptor; struct iovec *iov; int iovcnt;

cc = write(descriptor, buf, nbytes)
int cc, descriptor; char *buf; int nbytes;

cc = writev(descriptor, iovec, ioveclen)
int cc, descriptor; struct iovec *iovec; int ioveclen;

/*
 * The variable "sock" must be the descriptor of a socket.
 * Flags may include MSG_OOB and MSG_PEEK.
 */
cc = send(sock, msg, len, flags)
int cc, sock; char *msg; int len, flags;

cc = sendto(sock, msg, len, flags, to, tolen)
int cc, sock; char *msg; int len, flags;
struct sockaddr *to; int tolen;

cc = sendmsg(sock, msg, flags)
int cc, sock; struct msghdr msg[]; int flags;

cc = recv(sock, buf, len, flags)
int cc, sock; char *buf; int len, flags;

cc = recvfrom(sock, buf, len, flags, from, fromlen)
int cc, sock; char *buf; int len, flags;
struct sockaddr *from; int *fromlen;

cc = recvmsg(sock, msg, flags)
int cc, socket; struct msghdr msg[]; int flags;
```

Note that the meaning assigned to the `msg_accrights` and `msg_accrightslen` fields of the `msghdr` structure used in the `recvmsg()` and `sendmsg()` system calls is protocol-dependent. See the *Scatter/Gather and Exchanging Access Rights* section of the *System Services Overview* for details about the msghdr structure.

8.10. Choices

This chapter has presented examples of some of the forms of communication supported by SunOS. These have been presented in an order chosen for ease of presentation. It is useful to review these options emphasizing the factors that make each attractive.

Pipes have the advantage of portability, in that they are supported in all UNIX systems. They also are relatively simple to use. Socketpairs share this simplicity and have the additional advantage of allowing bidirectional communication. The major shortcoming of these mechanisms is that they require communicating processes to be descendants of a common process. They do not allow inter-machine communication.

The two communication domains, the UNIX domain and the Internet domain, allow processes with no common ancestor to communicate. Of the two, only the Internet domain allows communication between machines. This makes the Internet domain a necessary choice for processes running on separate machines.

The choice between datagrams and socket stream communication is best made by carefully considering the semantic and performance requirements of the application. Streams can be both advantageous and disadvantageous. One disadvantage is that, since a process is only allowed a limited number of open file descriptors (normally 64) there is a limit on the number of streams that a process can have open at any given time. This can cause problems if a single server must talk with a large number of clients. Another is that for delivering a short message the stream setup and teardown time can be unnecessarily long. Weighed against this are the reliability built into the streams. This will often be the deciding factor in favor of streams.

8.11. What to do Next

Many of the examples presented here can serve as models for multiprocess programs and for programs distributed across several machines. In developing a new multiprocess program, it is often easiest to first write the code to create the processes and communication paths. After this code is debugged, the code specific to the application can be added.

Further documentation of the socket-based IPC mechanisms can be found in *An Advanced Socket-Based Interprocess Communications Tutorial*. More detailed information about particular calls and protocols is provided in the *SunOS Reference Manual.*

9

An Advanced Socket-Based Interprocess Communications Tutorial

9

An Advanced Socket-Based Interprocess Communications Tutorial

SunOS provides all of the socket-based interprocess communications mechanisms available in the Berkeley UNIX system. This chapter is intended to help programmers understand the fine points by supplementing the more introductory information given in *A Socket-Based Interprocess Communications Tutorial.* It does *not* discuss SunOS's remote procedure call (RPC) mechanism, which is the preferred foundation for Sun network applications. For information about RPC, see the *Remote Procedure Call Programming Guide* section of this manual.

This chapter continues the discussion of socket-based IPC primitives that the Berkeley developers added to the system. The majority of the chapter considers the use of these primitives in developing network applications. The reader is expected to be familiar with the C programming language.

Socket-based interprocess communication was first introduced in 4.2BSD and subsequently incorporated into SunOS. The design of these facilities was the result of more than two years of discussion and research, and they incorporated many ideas from then-current research, while maintaining the UNIX philosophy of simplicity and conciseness. The current release of SunOS includes the extensions of the socket-based IPC facilities that were introduced in 4.3BSD.

Prior to the 4.2BSD IPC facilities, the only standard mechanism that allowed two processes to communicate were pipes (the mpx files that were in Version 7 were experimental). Unfortunately, pipes are very restrictive in that the two communicating processes must be related through a common ancestor. Further, the semantics of pipes makes them almost impossible to maintain in a distributed environment.

Earlier attempts at extending the IPC facilities of the UNIX system have met with mixed reaction. The majority of the problems have been related to the fact that these facilities have been tied to the UNIX file system, either through naming or implementation. Consequently, the 4.3BSD IPC facilities were designed as a totally independent subsystem. They allow processes to rendezvous in many ways. Processes may rendezvous through a UNIX file system-like name space (a space where all names are path names) as well as through a network name space. In fact, new name spaces may be added at a future time with only minor changes visible to users. Further, the communication facilities have been extended to include more than the simple byte stream provided by a pipe.

This chapter provides a high-level description of the socket-based IPC facilities and their use. It is designed to complement the manual pages for the IPC primitives with examples of their use. After this initial description, come four more sections. The *Basics* section introduces the IPC-related system calls and the basic model of communication. The *Library Routines* section describes some of the supporting library routines that users may find useful in constructing distributed applications. The *Client/Server Model* section is concerned with the client/server model used in developing applications and includes examples of the two major types of servers. The *Advanced Topics* section delves into advanced topics that sophisticated users are likely to encounter when using the these IPC facilities.

9.1. Basics

The basic building block for communication is the `socket()`. A socket is an endpoint of communication to which a name may be *bound*. Each socket in use has a *type* and one or more associated processes. Sockets exist within *communications domains*. Domains are abstractions which imply both an addressing structure (address family) and a set of protocols which implement various socket types within the domain (protocol family). Communications domains are introduced to bundle common properties of processes communicating through sockets. One such property is the scheme used to name sockets. For example, in the UNIX domain sockets are named with UNIX path names; e.g. a socket may be named `/dev/foo`. Sockets normally exchange data only with sockets in the same domain (it may be possible to cross between communications domains, but only if some translation process is performed). The 4.3BSD, and thus the socket-based SunOS IPC facilities support several separate communications domains: notably the UNIX domain, for on-system communication, and the Internet domain, which is used by processes that communicate using the the DARPA standard communication protocols. The underlying communication facilities provided by these domains have a significant influence on the internal system implementation as well as the interface to socket facilities available to a user. An example of the latter is that a socket operating in the UNIX domain sees a subset of the error conditions that are possible when operating in the Internet, DECNET, X.25, or OSI domains.

Socket Types

Sockets are typed according to the communication properties visible to a user. Processes are presumed to communicate only between sockets of the same type, although there is nothing that prevents communication between sockets of different types should the underlying communication protocols support this.

There are several types of sockets currently available:

- A *stream* socket provides for the bidirectional, reliable, sequenced, and unduplicated flow of data without record boundaries. Aside from the bidirectionality of data flow, a pair of connected stream sockets provides an interface nearly identical to that of pipes[11].

[11] In the UNIX domain, in fact, the semantics are identical and, as one might expect, pipes have been implemented internally as simply a pair of connected stream sockets.

- A *datagram* socket supports bidirectional flow of data that is not promised to be sequenced, reliable, or unduplicated. That is, a process receiving messages on a datagram socket may find messages duplicated, and, possibly, in an order different from the order in which they were sent. An important characteristic of a datagram socket is that record boundaries in data are preserved. Datagram sockets closely model the facilities found in many contemporary packet switched networks such as the Ethernet.

- A *raw* socket provides users access to the underlying communication protocols which support socket abstractions. These sockets are normally datagram oriented, though their exact characteristics are dependent on the interface provided by the protocol. Raw sockets are not intended for the general user; they have been provided mainly for those interested in developing new communication protocols, or for gaining access to some of the more esoteric facilities of an existing protocol. The use of raw sockets is considered in the *Advanced Topics* section below.

Another potential socket type with interesting properties is the *sequenced packet* socket. Such a socket would have properties similar to those of a stream socket, except that it would preserve record boundaries. There is currently no support for this type of socket.

Another potential socket type which has interesting properties is the *reliably delivered message* socket. The reliably delivered message socket has similar properties to a datagram socket, but with reliable delivery. There is currently no support for this type of socket.

Socket Creation

To create a socket, the `socket()` system call is used:

```
s = socket(domain, type, protocol);
```

This call requests that the system create a socket in the specified *domain* and of the specified *type*. A particular protocol may also be requested. If the protocol is left unspecified (a value of 0), the system will select an appropriate protocol from those that comprise the domain and that may be used to support the requested socket type. The user is returned a descriptor (a small integer number) that may be used in later system calls that operate on sockets. The domain is specified as one of the manifest constants defined in the file `<sys/socket.h>`. For the UNIX domain the constant is

`AF_UNIX`; for the Internet domain, it is `AF_INET`[12]. The socket types are also defined in this file and one of `SOCK_STREAM`, `SOCK_DGRAM`, or `SOCK_RAW` must be specified. To create a stream socket in the Internet domain the following call might be used:

```
s = socket(AF_INET, SOCK_STREAM, 0);
```

This call would result in a stream socket being created with the TCP protocol

[12] The manifest constants are named AF_whatever as they indicate the "address format" to use in interpreting names.

providing the underlying communication support. To create a datagram socket for on-machine use the call might be:

```
s = socket(AF_UNIX, SOCK_DGRAM, 0);
```

The default protocol (used when the *protocol* argument to the `socket()` call is 0) should be correct for most every situation. However, it is possible to specify a protocol other than the default; this will be covered in the *Advanced Topics* section below.

There are several reasons a socket call may fail. Aside from the rare occurrence of lack of memory (ENOBUFS), a socket request may fail due to a request for an unknown protocol (EPROTONOSUPPORT), or a request for a type of socket for which there is no supporting protocol (EPROTOTYPE).

Binding Local Names

A socket is created without a name. Until a name is bound to a socket, processes have no way to reference it and, consequently, no messages may be received on it. Communicating processes are bound by an *association*. In the Internet domain, an association is composed of local and foreign addresses, and local and foreign ports, while in the UNIX domain, an association is composed of local and foreign path names (the phrase "foreign pathname" means a pathname created by a foreign process, not a pathname on a foreign system). In most domains, associations must be unique. In the Internet domain there may never be duplicate

<protocol, local address, local port, foreign address, foreign port>

tuples. UNIX domain sockets need not always be bound to a name, but when bound there may never be duplicate

<protocol, local pathname, foreign pathname>

tuples. Currently, the pathnames may not refer to files already existing on the system, though this may change in future releases.

The `bind()` system call allows a process to specify half of an association,

<local address, local port> (or <local pathname>)

while the `connect()` and `accept()` primitives are used to complete a socket's association.

In the Internet domain, binding names to sockets can be fairly complex. Fortunately, it is usually not necessary to specifically bind an address and port number to a socket, because the `connect()` and `send()` calls will automatically bind an appropriate address if they are used with an unbound socket.

The `bind()` system call is used as follows:

```
bind(s, name, namelen);
```

The bound name is a variable length byte string that is interpreted by the supporting protocol(s). Its interpretation may vary between communication domains (this is one of the properties that comprise a domain). As mentioned, Internet domain names contain an Internet address and port number. In the UNIX domain, names contain a path name and a family, which is always AF_UNIX. If one wanted to bind the name /tmp/foo to a UNIX domain socket, the following code would be used:[13]

```
#include <sys/un.h>
 ...
struct sockaddr_un addr;
 ...
strcpy(addr.sun_path, "/tmp/foo");
addr.sun_family = AF_UNIX;
bind(s, (struct sockaddr *) &addr, strlen(addr.sun_path) +
    sizeof (addr.sun_family));
```

Note that in determining the size of a UNIX domain address null bytes are not counted, which is why `strlen()` is used. In the current implementation of UNIX domain IPC, the file name referred to in `addr.sun_path` is created as a socket in the system file space. The caller must, therefore, have write permission in the directory where `addr.sun_path` is to reside, and this file should be deleted by the caller when it is no longer needed. Future versions may not create this file.

In binding an Internet address things become more complicated. The actual call is similar,

```
#include <sys/types.h>
#include <netinet/in.h>
 ...
struct sockaddr_in sin;
 ...
bind(s, (struct sockaddr *) &sin, sizeof sin);
```

but the selection of what to place in the address *sin* requires some discussion. We will come back to the problem of formulating Internet addresses in the *Library Routines* section when the library routines used in name resolution are discussed.

Connection Establishment

Connection establishment is usually asymmetric, with one process a *client* and the other a *server*. The server, when willing to offer its advertised services, binds a socket to a well-known address associated with the service and then passively *listens* on its socket. It is then possible for an unrelated process to rendezvous with the server. The client requests services from the server by initiating a *connection* to the server's socket. On the client side the `connect()` call is used to initiate a connection. Using the UNIX domain, this might appear as,

[13] Beware of the tendency to call the "addr" structure "sun", which collides with a symbol predefined by the C preprocessor.

```
struct sockaddr_un server;
 ...
connect(s, (struct sockaddr *)&server,
    strlen(server.sun_path) + sizeof (server.sun_family));
```

while in the Internet domain,

```
struct sockaddr_in server;
 ...
connect(s, (struct sockaddr *)&server, sizeof server);
```

where *server* in the example above would contain either the UNIX pathname, or the Internet address and port number of the server to which the client process wishes to speak. If the client process's socket is unbound at the time of the connect call, the system will automatically select and bind a name to the socket if necessary. See the *Signals and Process Groups* section below. This is the usual way that local addresses are bound to a socket.

An error is returned if the connection was unsuccessful (however, any name automatically bound by the system remains). Otherwise, the socket is associated with the server and data transfer may begin. Some of the more common errors returned when a connection attempt fails are:

ETIMEDOUT
: After failing to establish a connection for a period of time, the system decided there was no point in retrying the connection attempt any more. This usually occurs because the destination host is down, or because problems in the network resulted in transmissions being lost.

ECONNREFUSED
: The host refused service for some reason. This is usually due to a server process not being present at the requested name.

ENETDOWN or EHOSTDOWN
: These operational errors are returned based on status information delivered to the client host by the underlying communication services.

ENETUNREACH or EHOSTUNREACH
: These operational errors can occur either because the network or host is unknown (no route to the network or host is present), or because of status information returned by intermediate gateways or switching nodes. Many times the status returned is not sufficient to distinguish a network being down from a host being down, in which case the system indicates the entire network is unreachable.

For the server to receive a client's connection it must perform two steps after binding its socket. The first is to indicate a willingness to listen for incoming connection requests:

```
listen(s, 5);
```

The second parameter to the `listen()` call specifies the maximum number of outstanding connections that may be queued awaiting acceptance by the server process; this number may be limited by the system. Should a connection be requested while the queue is full, the connection will not be refused, but rather the individual messages that comprise the request will be ignored. This gives a harried server time to make room in its pending connection queue while the client retries the connection request. Had the connection been returned with the `ECONNREFUSED` error, the client would be unable to tell if the server was up or not. As it is now it is still possible to get the `ETIMEDOUT` error back, though this is unlikely. The backlog figure supplied with the listen call is currently limited by the system to a maximum of 5 pending connections on any one queue. This avoids the problem of processes hogging system resources by setting an infinite backlog, then ignoring all connection requests.

With a socket marked as listening, a server may `accept()` a connection:

```
struct sockaddr_in from;
 ...
fromlen = sizeof from;
newsock = accept(s, (struct sockaddr *)&from, &fromlen);
```

(For the UNIX domain, *from* would be declared as a `struct sockaddr_un`, but nothing different would need to be done as far as *fromlen* is concerned. In the examples that follow, only Internet routines will be discussed.) A new descriptor is returned on receipt of a connection (along with a new socket). If the server wishes to find out who its client is, it may supply a buffer for the client socket's name. The value-result parameter *fromlen* is initialized by the server to indicate how much space is associated with *from*, then modified on return to reflect the true size of the name. If the client's name is not of interest, the second parameter may be a null pointer.

`accept()` normally blocks. That is, `accept()` will not return until a connection is available or the system call is interrupted by a signal to the process. Further, there is no way for a process to indicate it will accept connections from only a specific individual, or individuals. It is up to the user process to consider who the connection is from and close down the connection if it does not wish to speak to the process. If the server process wants to accept connections on more than one socket, or wants to avoid blocking on the accept call, there are alternatives; they will be considered in the *Advanced Topics* section below.

Data Transfer

With a connection established, data may begin to flow. To send and receive data there are a number of possible calls. With the peer entity at each end of a connection anchored, a user can send or receive a message without specifying the peer. As one might expect, in this case, then the normal `read()` and `write()` system calls are usable,

```
write(s, buf, sizeof buf);
read(s, buf, sizeof buf);
```

In addition to `read()` and `write()`, the calls `send()` and `recv()` may be used:

```
send(s, buf, sizeof buf, flags);
recv(s, buf, sizeof buf, flags);
```

While send() and recv() are virtually identical to read() and write(), the extra *flags* argument is important. The flags, defined in <sys/socket.h>, may be specified as a non-zero value if one or more of the following is required:

MSG_OOB	send/receive out of band data
MSG_PEEK	look at data without reading
MSG_DONTROUTE	send data without routing packets (internal only)

Out of band data is a notion specific to stream sockets, and one that we will not immediately consider. The option to have data sent without routing applied to the outgoing packets is currently used only by the routing table management process, and is unlikely to be of interest to the casual user. However, the ability to preview data is of interest. When MSG_PEEK is specified with a recv() call, any data present is returned to the user, but treated as still "unread". That is, the next read() or recv() call applied to the socket will return the data previously previewed.

Discarding Sockets

Once a socket is no longer of interest, it may be discarded by applying a close() to the descriptor,

```
close(s);
```

If data is associated with a socket that promises reliable delivery (e.g. a stream socket) when a close takes place, the system will continue to attempt to transfer the data. However, after a fairly long period of time, if the data is still undelivered, it will be discarded. Should a user have no use for any pending data, it may perform a shutdown() on the socket prior to closing it. This call is of the form:

```
shutdown(s, how);
```

where *how* is 0 if the user is no longer interested in reading data, 1 if no more data will be sent, or 2 if no data is to be sent or received.

Connectionless Sockets

To this point we have been concerned mostly with sockets that follow a connection oriented model. However, there is also support for connectionless interactions typical of the datagram facilities found in contemporary packet switched networks. A datagram socket provides a symmetric interface to data exchange. While processes are still likely to be client and server, there is no requirement for connection establishment. Instead, each message includes the destination address.

Datagram sockets are created as before. If a particular local address is needed, the bind() operation must precede the first data transmission. Otherwise, the system will set the local address and/or port when data is first sent. To send data, the sendto() primitive is used,

```
sendto(s, buf, buflen, flags, (struct sockaddr *)&to, tolen);
```

The *s*, *buf*, *buflen*, and *flags* parameters are used as before. The *to* and *tolen* values are used to indicate the address of the intended recipient of the message.

When using an unreliable datagram interface, it is unlikely that any errors will be reported to the sender. When information is present locally to recognize a message that can not be delivered (for instance when a network is unreachable), the call will return –1 and the global value `errno` will contain an error number.

To receive messages on an unconnected datagram socket, the `recvfrom()` primitive is provided:

```
recvfrom(s, buf, buflen, flags, (struct sockaddr *)&from,
     &fromlen);
```

Once again, the *fromlen* parameter is handled in a value-result fashion, initially containing the size of the `from` buffer, and modified on return to indicate the actual size of the address from which the datagram was received.

In addition to the two calls mentioned above, datagram sockets may also use the `connect()` call to associate a socket with a specific destination address. In this case, any data sent on the socket will automatically be addressed to the connected peer, and only data received from that peer will be delivered to the user. Only one connected address is permitted for each socket at one time; a second connect will change the destination address, and a connect to a null address (domain `AF_UNSPEC`) will disconnect. Connect requests on datagram sockets return immediately, as this simply results in the system recording the peer's address (as compared to a stream socket, where a connect request initiates establishment of an end to end connection). `accept()` and `listen()` are not used with datagram sockets.

While a datagram socket socket is connected, errors from recent `send()` calls may be returned asynchronously. These errors may be reported on subsequent operations on the socket, or a special socket option used with `getsockopt`, `SO_ERROR`, may be used to interrogate the error status. A `select()` for reading or writing will return true when an error indication has been received. The next operation will return the error, and the error status is cleared. Other of the less important details of datagram sockets are described in the *Advanced Topics* section below.

Input/Output Multiplexing

One last facility often used in developing applications is the ability to multiplex i/o requests among multiple sockets and/or files. This is done using the `select()` call:

```
#include <sys/time.h>
#include <sys/types.h>
 ...

fd_set readmask, writemask, exceptmask;
struct timeval timeout;
 ...
select(nfds, &readmask, &writemask, &exceptmask, &timeout);
```

`select()` takes as arguments pointers to three sets, one for the set of file descriptors on which the caller wishes to be able to read data, one for those descriptors to which data is to be written, and one for which exceptional conditions are pending; out-of-band data is the only exceptional condition currently implemented by the socket abstraction. If the user is not interested in certain conditions (i.e., read, write, or exceptions), the corresponding argument to the `select()` should be a properly cast null pointer.

Each set is actually a structure containing an array of long integer bit masks; the size of the array is set by the definition `FD_SETSIZE`. The array is long enough to hold one bit for each of `FD_SETSIZE` file descriptors.

The macros `FD_SET(`*fd, &mask*`)` and `FD_CLR(`*fd, &mask*`)` have been provided for adding and removing file descriptor *fd* in the set *mask*. The set should be zeroed before use, and the macro `FD_ZERO(`*&mask*`)` has been provided to clear the set *mask*. The parameter *nfds* in the `select()` call specifies the range of file descriptors (i.e. one plus the value of the largest descriptor) to be examined in a set.

A timeout value may be specified if the selection is not to last more than a predetermined period of time. If the fields in *timeout* are set to 0, the selection takes the form of a *poll*, returning immediately. If the last parameter is a null pointer, the selection will block indefinitely[14]. `select()` normally returns the number of file descriptors selected; if the `select()` call returns due to the timeout expiring, then the value 0 is returned. If the `select()` terminates because of an error or interruption, a –1 is returned with the error number in `errno`, and with the file descriptor masks unchanged.

Assuming a successful return, the three sets will indicate which file descriptors are ready to be read from, written to, or have exceptional conditions pending. The status of a file descriptor in a select mask may be tested with the `FD_ISSET(`*fd, &mask*`)` macro, which returns a non-zero value if *fd* is a member of the set *mask*, and 0 if it is not.

---

[14] To be more specific, a return takes place only when a descriptor is selectable, or when a signal is received by the caller, interrupting the system call.

To determine if there are connections waiting on a socket to be used with an `accept()` call, `select()` can be used, followed by a `FD_ISSET(`*fd, &mask*`)` macro to check for read readiness on the appropriate socket. If `FD_ISSET` returns a non-zero value, indicating permission to read, then a connection is pending on the socket.

As an example, to read data from two sockets, *s1* and *s2* as it is available from each and with a one-second timeout, the following code might be used:

```
#include <sys/time.h>
#include <sys/types.h>
 ...
fd_set read_template;
struct timeval wait;
 ...
for (;;) {
     wait.tv_sec = 1;     /* one second */
     wait.tv_usec = 0;

     FD_ZERO(&read_template);

     FD_SET(s1, &read_template);
     FD_SET(s2, &read_template);

     nb = select(FD_SETSIZE, &read_template, (fd_set *) 0,
          (fd_set *) 0, &wait);
     if (nb <= 0) {
    /*
         * An error occurred during the select, or
     * the select timed out.
     */
     }

     if (FD_ISSET(s1, &read_template)) {
          /* Socket #1 is ready to be read from. */
     }

     if (FD_ISSET(s2, &read_template)) {
          /* Socket #2 is ready to be read from. */
     }
}
```

In previous versions of `select()`, its arguments were pointers to integers instead of pointers to *fd_sets*. This type of call will still work as long as the number of file descriptors being examined is less than the number of bits in an integer; however, the methods illustrated above should be used in all current programs.

`select()` provides a synchronous multiplexing scheme. Asynchronous notification of output completion, input availability, and exceptional conditions is possible through use of the SIGIO and SIGURG signals described in the

Advanced Topics section below.

9.2. Library Routines

The discussion in the *Basics* section above indicated the possible need to locate and construct network addresses when using the interprocess communication facilities in a distributed environment. To aid in this task a number of routines have been added to the standard C run-time library. In this section we will consider the new routines provided to manipulate network addresses.

Locating a service on a remote host requires many levels of mapping before client and server may communicate. A service is assigned a name that is intended for human consumption; e.g. the *login server* on host monet. This name, and the name of the peer host, must then be translated into network *addresses* that are not necessarily suitable for human consumption. Finally, the address must then used in locating a physical *location* and *route* to the service. The specifics of these three mappings are likely to vary between network architectures. For instance, it is desirable for a network to not require hosts to be named in such a way that their physical location is known by the client host. Instead, underlying services in the network may discover the actual location of the host at the time a client host wishes to communicate. This ability to have hosts named in a location independent manner may induce overhead in connection establishment, as a discovery process must take place, but allows a host to be physically mobile without requiring it to notify its clientele of its current location.

Standard routines are provided for mapping host names to network addresses, network names to network numbers, protocol names to protocol numbers, and service names to port numbers and the appropriate protocol to use in communicating with the server process. The file `<netdb.h>` must be included when using any of these routines.

Host Names

An Internet host name to address mapping is represented by the `hostent` structure:

```
struct hostent {
     char *h_name;            /* official name of host */
     char **h_aliases;        /* alias list */
     int  h_addrtype;         /* host address type (e.g., AF_INET) */
     int  h_length;           /* length of address */
     char **h_addr_list;      /* list of addresses, null terminated */
};
#define h_addr h_addr_list[0]   /* first address, network byte order */
```

The routine `gethostbyname`(3N) takes an Internet host name and returns a `hostent` structure, while the routine `gethostbyaddr`(3N) maps Internet host addresses into a *hostent* structure. The routine `inet_ntoa`(3N) maps an Internet host address into an ASCII string for printing by log and error messages.

The official name of the host and its public aliases are returned by these routines, along with the address type (domain) and a null terminated list of variable length addresses. This list of addresses is required because it is possible for a host to have many addresses, all having the same name. The `h_addr` definition is provided for backward compatibility, and is defined to be the first address in the list of addresses in the *hostent* structure.

The database for these calls is provided either by the *Yellow Pages* name lookup service (the preferred alternative), from the `/etc/hosts` file (see `hosts`(5)), or by use of the `resolver(5)` nameserver. Because of the differences in these databases and their access protocols, the information returned may differ. When using the Yellow Pages on the host table version of `gethostbyname`(), only one address will be returned, but all listed aliases will be included. The nameserver version may return alternate addresses, but will not provide any aliases other than one given as argument.

Network Names

As for host names, routines for mapping network names to numbers, and back, are provided. These routines return a `netent` structure:

```
/*
 * Assumption here is that a network number
 * fits in 32 bits -- probably a poor one.
 */
struct netent {
     char *n_name;            /* official name of net */
     char **n_aliases;        /* alias list */
     int  n_addrtype;         /* net address type */
     int  n_net;              /* network number, host byte order */
};
```

The routines `getnetbyname(3N)`, `getnetbynumber(3N)`, and `getnetent(3N)` are the network counterparts to the host routines described above. The routines extract their information from the Yellow Pages maps hosts.byname and hosts.byaddr or from /etc/networks.

Protocol Names

For protocols (which are defined in the Yellow-Pages protocols.byname map and /etc/protocols) the protoent structure defines the protocol-name mapping used with the routines getprotobyname(3N), getprotobynumber(3N), and getprotoent(3N):

```
struct protoent {
     char *p_name;            /* official protocol name */
     char **p_aliases;        /* alias list */
     int  p_proto;            /* protocol number */
};
```

Service Names

Information regarding services is a bit more complicated. A service is expected to reside at a specific *port* and employ a particular communication protocol. This view is consistent with the Internet domain, but inconsistent with other network architectures. Further, a service may reside on multiple ports. If this occurs, the higher level library routines will have to be bypassed or extended. Services available are contained in the Yellow Pages services.byname map and the file /etc/services. (Actually, the name services.byname is a misnomer, since the map actually orders Internet ports by number and protocol).[15] A service mapping is described by the servent structure:

```
struct servent {
     char *s_name;            /* official service name */
     char **s_aliases;        /* alias list */
     int  s_port;             /* port number, network byte order */
     char *s_proto;           /* protocol to use */
};
```

The routine getservbyname(3N) maps service names to a servent structure by specifying a service name and, optionally, a qualifying protocol. Thus the call

```
sp = getservbyname("telnet", (char *) 0);
```

returns the service specification for a telnet server using any protocol, while the call

```
sp = getservbyname("telnet", "tcp");
```

returns only that telnet server which uses the TCP protocol. The routines getservbyport(3N) and getservent(3N) are also provided. The getservbyport() routine has an interface similar to that provided by getservbyname(); an optional protocol name may be specified to qualify lookups.

[15] For details about the association of RPC services with ports, see the *Port Mapper Program Protocol* section of the *Network Services* chapter.

Miscellaneous

With the support routines described above, an Internet application program should rarely have to deal directly with addresses. This allows services to be developed as much as possible in a network independent fashion. It is clear, however, that purging all network dependencies is very difficult. So long as the user is required to supply network addresses when naming services and sockets there will always some network dependency in a program. For example, the normal code included in client programs, such as the remote login program, is of the form shown in Figure *9-1*. (This example will be considered in more detail in the *Client/Server Model* section below.)

Aside from the address-related data base routines, there are several other routines available in the run-time library that are of interest to users. These are intended mostly to simplify manipulation of names and addresses. Table *9-1* summarizes the routines for manipulating variable length byte strings and handling byte swapping of network addresses and values.

Table 9-1 *C Run-time Routines*

Call	*Synopsis*
`bcmp(s1, s2, n)`	Compare byte-strings; 0 if same, not 0 otherwise
`bcopy(s1, s2, n)`	Copy n bytes from s1 to s2
`bzero(base, n)`	Zero-fill n bytes starting at base
`htonl(val)`	32-bit quantity from host into network byte order
`htons(val)`	16-bit quantity from host into network byte order
`ntohl(val)`	32-bit quantity from network into host byte order
`ntohs(val)`	16-bit quantity from network into host byte order

The byte swapping routines are provided because the operating system expects addresses to be supplied in network order. On some architectures, such as the VAX, host byte ordering is different than network byte ordering. Consequently, programs are sometimes required to byte swap quantities. The library routines that return network addresses provide them in network order so that they may simply be copied into the structures provided to the system. This implies users should encounter the byte swapping problem only when *interpreting* network addresses. For example, if an Internet port is to be printed out the following code would be required:

```
printf("port number %d\n", ntohs(sp->s_port));
```

On machines such as the Sun-3 and Sun-4, where these routines are unneeded, they are defined as null macros.[16]

[16] Sun-4 (SPARC) machines do have alignment restrictions which network programmers need to be aware of. See *Porting Software to SPARC Systems.*

Figure 9-1 *Remote Login Client Code*

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <stdio.h>
#include <netdb.h>
    ...
main(argc, argv)
    int argc;
    char *argv[];
{
    struct sockaddr_in server;
    struct servent *sp;
    struct hostent *hp;
    int s;
    ...
    sp = getservbyname("login", "tcp");
    if (sp == NULL) {
        fprintf(stderr,
            "rlogin: tcp/login: unknown service\n");
        exit(1);
    }
    hp = gethostbyname(argv[1]);
    if (hp == NULL) {
        fprintf(stderr,
            "rlogin: %s: unknown host\n", argv[1]);
        exit(2);
    }
    bzero((char *)&server, sizeof server);
    bcopy(hp->h_addr, (char *)&server.sin_addr,
        hp->h_length);
    server.sin_family = hp->h_addrtype;
    server.sin_port = sp->s_port;
    s = socket(AF_INET, SOCK_STREAM, 0);
    if (s < 0) {
        perror("rlogin: socket");
        exit(3);
    }
    ...
    /* Connect does the bind for us */

    if (connect(s, (struct sockaddr *)&server,
     sizeof server) < 0) {
        perror("rlogin: connect");
        exit(5);
    }
    ...
    exit(0);
}
```

9.3. Client/Server Model

The most commonly used paradigm in constructing distributed applications is the client/server model. In this scheme client applications request services from a server process. This implies an asymmetry in establishing communication between the client and server that has been examined in the *Basics* section above. In this section we will look more closely at the interactions between client and server, and consider some of the problems in developing client and server applications.

The client and server require a well known set of conventions before service may be rendered (and accepted). This set of conventions comprises a protocol that must be implemented at both ends of a connection. Depending on the situation, the protocol may be symmetric or asymmetric. In a symmetric protocol, either side may play the master or slave roles. In an asymmetric protocol, one side is immutably recognized as the master, with the other as the slave. An example of a symmetric protocol is the TELNET protocol used in the Internet for remote terminal emulation. An example of an asymmetric protocol is the Internet file transfer protocol, FTP. No matter whether the specific protocol used in obtaining a service is symmetric or asymmetric, when accessing a service there is a *client process* and a *server process*. We will first consider the properties of server processes, then client processes.

A server process normally listens at a well known address for service requests. That is, the server process remains dormant until a connection is requested by a client's connection to the server's address. At such a time the server process "wakes up" and services the client, performing whatever appropriate actions the client requests of it.

Alternative schemes that use a service server may be used to eliminate a flock of server processes clogging the system while remaining dormant most of the time. For Internet servers, this scheme has been implemented via `inetd`, the so called "internet super-server." `inetd` listens at a variety of ports, determined at start-up by reading a configuration file. When a connection is requested to a port on which `inetd` is listening, `inetd` executes the appropriate server program to handle the client. With this method, clients are unaware that an intermediary such as `inetd` has played any part in the connection. `inetd` will be described in more detail in the *Advanced Topics* section below.

Servers

In SunOS most servers are accessed at well known Internet addresses or UNIX domain names. The form of their main loop is illustrated by the following code form the remote-login server:

Figure 9-2 *Remote Login Server*

```
main(argc, argv)
     int argc;
     char *argv[];
{
     int f;
     struct sockaddr_in from;
     struct sockaddr_in sin;
     struct servent *sp;
```

```
    sp = getservbyname("login", "tcp");
    if (sp == NULL) {
        fprintf(stderr,
            "rlogind: tcp/login: unknown service\n");
        exit(1);
    }
    ...
#ifndef DEBUG
    /* Disassociate server from controlling terminal. */
    ...
#endif

    sin.sin_port = sp->s_port;   /* Restricted port */
    sin.sin_addr = INADDR_ANY;
    ...
    f = socket(AF_INET, SOCK_STREAM, 0);
    ...
    if (bind(f, (struct sockaddr *)&sin, sizeof sin) < 0) {
        ...
    }
    ...
    listen(f, 5);
    for (;;) {
        int g, len = sizeof from;

        g = accept(f, (struct sockaddr *) &from, &len);
        if (g < 0) {
            if (errno != EINTR)
                syslog(LOG_ERR, "rlogind: accept: %m");
            continue;
        }
        if (fork() == 0) {
            close(f);
            doit(g, &from);
        }
        close(g);
    }
    exit(0);
}
```

The first step taken by the server is look up its service definition:

```
sp = getservbyname("login", "tcp");
if (sp == NULL) {
    fprintf(stderr,
        "rlogind: tcp/login: unknown service\n");
    exit(1);
}
```

The result of the `getservbyname()` call is used in later portions of the code to define the Internet port at which it listens for service requests (indicated by a connection). Some standard port numbers are given in the file /usr/include/netinet/in.h for backward compatibility purposes.

Step two is to disassociate the server from the controlling terminal of its invoker:

```
for (i = getdtablesize()-1; i >= 0; --i)
    close(i);

open("/dev/null", O_RDONLY);
dup2(0, 1);
dup2(0, 2);

i = open("/dev/tty", O_RDWR);
if (i >= 0) {
    ioctl(i, TIOCNOTTY, 0);
    close(i);
}
```

This step is important as the server will likely not want to receive signals delivered to the process group of the controlling terminal. Note, however, that once a server has disassociated itself it can no longer send reports of errors to a terminal, and must log errors via syslog().

Once a server has established a pristine environment, it creates a socket and begins accepting service requests. The bind() call is required to insure the server listens at its expected location. It should be noted that the remote login server listens at a restricted port number, and must therefore be run with a user-id of root. This concept of a "restricted port number" is covered in the *Advanced Topics* section below.

The main body of the loop is fairly simple:

```
for (;;) {
    int g, len = sizeof from;

    g = accept(f, (struct sockaddr *)&from, &len);
    if (g < 0) {
        if (errno != EINTR)
            syslog(LOG_ERR, "rlogind: accept: %m");
        continue;
    }
    if (fork() == 0) {   /* Child */
        close(f);
        doit(g, &from);
    }
    close(g);          /* Parent */
}
```

An accept() call blocks the server until a client requests service. This call could return a failure status if the call is interrupted by a signal such as SIGCHLD (to be discussed in the *Advanced Topics* section below.) Therefore, the return value from accept() is checked to insure a connection has actually been established, and an error report is logged via `syslog()` if an error has occurred.

With a connection in hand, the server then forks a child process and invokes the main body of the remote login protocol processing. Note how the socket used by the parent for queuing connection requests is closed in the child, while the socket created as a result of the `accept()` is closed in the parent. The address of the client is also handed the `doit()` routine because it requires it in authenticating clients.

Clients

The client side of the remote login service was shown earlier in Figure *9-1*. One can see the separate, asymmetric roles of the client and server clearly in the code. The server is a passive entity, listening for client connections, while the client process is an active entity, initiating a connection when invoked.

Let us consider more closely the steps taken by the client remote login process. As in the server process, the first step is to locate the service definition for a remote login:

```
sp = getservbyname("login", "tcp");
if (sp == NULL) {
    fprintf(stderr,
        "rlogin: tcp/login: unknown service\n");
    exit(1);
}
```

Next the destination host is looked up with a `gethostbyname()` call:

```
hp = gethostbyname(argv[1]);
if (hp == NULL) {
    fprintf(stderr, "rlogin: %s: unknown host\n", argv[1]);
    exit(2);
}
```

With this accomplished, all that is required is to establish a connection to the server at the requested host and start up the remote login protocol. The address buffer is cleared, then filled in with the Internet address of the foreign host and the port number at which the login process resides on the foreign host:

```
bzero((char *)&server, sizeof server);
bcopy(hp->h_addr, (char *) &server.sin_addr, hp->h_length);
server.sin_family = hp->h_addrtype;
server.sin_port = sp->s_port;
```

A socket is created, and a connection initiated. Note that `connect()` implicitly performs a `bind()` call, since `s` is unbound.

```
s = socket(hp->h_addrtype, SOCK_STREAM, 0);
if (s < 0) {
    perror("rlogin: socket");
    exit(3);
}
 ...
if (connect(s, (struct sockaddr *)&server,
 sizeof server) < 0) {
    perror("rlogin: connect");
    exit(4);
}
```

The details of the remote login protocol will not be considered here.

Connectionless Servers

While connection-based services are the norm, some services are based on the use of datagram sockets. One, in particular, is the `rwho` service which provides users with status information for hosts connected to a local area network. This service, while predicated on the ability to *broadcast* information to all hosts connected to a particular network, is of interest as an example usage of datagram sockets.

A user on any machine running the rwho server may find out the current status of a machine with the `ruptime` program. The output generated is illustrated in Figure 9-2.

Table 9-2 `ruptime` *Output*

arpa	up	9:45,	5 users, load	1.15,	1.39,	1.31
cad	up	2+12:04,	8 users, load	4.67,	5.13,	4.59
calder	up	10:10,	0 users, load	0.27,	0.15,	0.14
dali	up	2+06:28,	9 users, load	1.04,	1.20,	1.65
degas	up	25+09:48,	0 users, load	1.49,	1.43,	1.41
ear	up	5+00:05,	0 users, load	1.51,	1.54,	1.56
ernie	down	0:24				
esvax	down	17:04				
oz	down	16:09				
statvax	up	2+15:57,	3 users, load	1.52,	1.81,	1.86

Status information for each host is periodically broadcast by rwho server processes on each machine. The same server process also receives the status information and uses it to update a database. This database is then interpreted to generate the status information for each host. Servers operate autonomously, coupled only by the local network and its broadcast capabilities.

Note that the use of broadcast for such a task is fairly inefficient, as all hosts must process each message, whether or not using an rwho server. Unless such a service is sufficiently universal and is frequently used, the expense of periodic broadcasts outweighs the simplicity.

The `rwho` server, in a simplified form, is pictured below. It preforms two separate tasks. The first is to act as a receiver of status information broadcast by other hosts on the network. This job is carried out in the main loop of the program. Packets received at the rwho port are interrogated to insure they've been sent by another rwho server process, then are time stamped with their arrival time and used to update a file indicating the status of the host. When a host has not been heard from for an extended period of time, the database interpretation routines assume the host is down and indicate such on the status reports. This algorithm is prone to error, as a server may be down while a host is actually up.

Figure 9-3 `rwho` *Server*

```
main()
{
    ...
    sp = getservbyname("who", "udp");
    net = getnetbyname("localnet");
    sin.sin_addr = inet_makeaddr(INADDR_ANY, net);
    sin.sin_port = sp->s_port;
    ...
    s = socket(AF_INET, SOCK_DGRAM, 0);
    ...
    on = 1;
    if (setsockopt(s, SOL_SOCKET, SO_BROADCAST, &on,
     sizeof on) < 0) {
        syslog(LOG_ERR, "setsockopt SO_BROADCAST: %m");
        exit(1);
    }
    bind(s, (struct sockaddr *) &sin, sizeof sin);
    ...
    signal(SIGALRM, onalrm);
    onalrm();
    for (;;) {
        struct whod wd;
        int cc, whod, len = sizeof from;

        cc = recvfrom(s, (char *)&wd, sizeof (struct whod),
            0, (struct sockaddr *)&from, &len);
        if (cc <= 0) {
            if (cc < 0 && errno != EINTR)
                syslog(LOG_ERR, "rwhod: recv: %m");
            continue;
        }
        if (from.sin_port != sp->s_port) {
            syslog(LOG_ERR, "rwhod: %d: bad from port",
                ntohs(from.sin_port));
            continue;
        }
        ...
        if (!verify(wd.wd_hostname)) {
            syslog(LOG_ERR, "rwhod: bad host name from %x",
                ntohl(from.sin_addr.s_addr));
```

```
                continue;
            }
            (void) sprintf(path, "%s/whod.%s", RWHODIR,
                wd.wd_hostname);
            whod = open(path, O_WRONLY|O_CREAT|O_TRUNC, 0666);
            ...
            (void) time(&wd.wd_recvtime);
            (void) write(whod, (char *)&wd, cc);
            (void) close(whod);
        }
        exit(0);
}
```

The second task performed by the server is to supply information regarding the status of its host. This involves periodically acquiring system status information, packaging it up in a message and broadcasting it on the local network for other rwho servers to hear. The supply function is triggered by a timer and runs off a signal. Locating the system status information is somewhat involved, but uninteresting. Deciding where to transmit the resultant packet is somewhat problematic, however.

Status information must be broadcast on the local network. For networks that do not support the notion of broadcast another scheme must be used to simulate or replace broadcasting. One possibility is to enumerate the known neighbors (based on the status messages received from other rwho servers). This, unfortunately, requires some bootstrapping information, for a server will have no idea what machines are its neighbors until it receives status messages from them. Therefore, if all machines on a net are freshly booted, no machine will have any known neighbors and thus never receive, or send, any status information. This is the identical problem faced by the routing table management process in propagating routing status information. The standard solution, unsatisfactory as it may be, is to inform one or more servers of known neighbors and request that they always communicate with these neighbors. If each server has at least one neighbor supplied to it, status information may then propagate through a neighbor to hosts that are not (possibly) directly neighbors. If the server is able to support networks that provide a broadcast capability, as well as those which do not, then networks with an arbitrary topology may share status information[17].

It is important that software operating in a distributed environment not have any site-dependent information compiled into it. This would require a separate copy of the server at each host and make maintenance a severe headache. SunOS attempts to isolate host-specific information from applications by providing system calls that return the necessary information[18]. A mechanism exists, in the form of an `ioctl()` call, for finding the collection of networks to which a host is directly connected. Further, a local network broadcasting mechanism has been

[17] One must, however, be concerned about *loops*. That is, if a host is connected to multiple networks, it will receive status information from itself. This can lead to an endless, wasteful, exchange of information.

[18] An example of such a system call is the `gethostname(2)` call that returns the host's *official* name.

implemented at the socket level. Combining these two features allows a process to broadcast on any directly connected local network which supports the notion of broadcasting in a site independent manner. This allows a solution to the problem of deciding how to propagate status information in the case of `rwho`, or more generally in broadcasting. Such status information is broadcast to connected networks at the socket level, where the connected networks have been obtained via the appropriate `ioctl()` calls. The specifics of such broadcastings are complex, however, and will be covered in the *Advanced Topics* section below.

9.4. Advanced Topics

A number of facilities have yet to be discussed. For most programmers, the mechanisms already described will suffice in constructing distributed applications. However, others will find the need to utilize some of the features that we consider in this section.

Out Of Band Data

The stream socket abstraction includes the notion of *out of band* data. Out of band data is a logically independent transmission channel associated with each pair of connected stream sockets. Out of band data is delivered to the user independently of normal data. The abstraction defines that the out of band data facilities must support the reliable delivery of at least one out of band message at a time. This message may contain at least one byte of data, and at least one message may be pending delivery to the user at any one time. For communications protocols (such as TCP) that support only in-band signaling (i.e. the urgent data is delivered in sequence with the normal data), the system normally extracts the data from the normal data stream and stores it separately. This allows users to choose between receiving the urgent data in order and receiving it out of sequence without having to buffer all the intervening data. It is possible to "peek" (via `MSG_PEEK`) at out of band data. If the socket has a process group, a `SIGURG` signal is generated when the protocol is notified of its existence. A process can set the process group or process id to be informed by the `SIGURG` signal via the appropriate `fcntl()` call, as described below for `SIGIO`. If multiple sockets may have out of band data awaiting delivery, a `select()` call for exceptional conditions may be used to determine those sockets with such data pending. Neither the signal nor the select indicate the actual arrival of the out-of-band data, but only notification that it is pending.

In addition to the information passed, a logical mark is placed in the data stream to indicate the point at which the out of band data was sent. The remote login and remote shell applications use this facility to propagate signals between client and server processes. When a signal flushes any pending output from the remote process(es), all data up to the mark in the data stream is discarded.

To send an out of band message the `MSG_OOB` flag is supplied to a `send()` or `sendto()` calls, while to receive out of band data `MSG_OOB` should be indicated when performing a `recvfrom()` or `recv()` call. To find out if the read pointer is currently pointing at the mark in the data stream, the `SIOCATMARK` `ioctl` is provided:

```
ioctl(s, SIOCATMARK, &yes);
```

If *yes* is 1 on return, the next read will return data after the mark. Otherwise (assuming out of band data has arrived), the next read will provide data sent by the client prior to transmission of the out of band signal. The routine used in the remote login process to flush output on receipt of an interrupt or quit signal is shown in the following example. This code reads the normal data up to the mark (to discard it), then reads the out-of-band byte.

Figure 9-4 *Flushing Terminal I/O on Receipt of Out Of Band Data*

```
#include <sys/ioctl.h>
#include <sys/file.h>
 ...
oob()
{
    int out = FWRITE;
    char waste[BUFSIZ], mark;

    /* flush local terminal output */
    ioctl(1, TIOCFLUSH, (char *)&out);
    for (;;) {
        if (ioctl(rem, SIOCATMARK, &mark) < 0) {
            perror("ioctl");
            break;
        }
        if (mark)
            break;
        (void) read(rem, waste, sizeof waste);
    }
    if (recv(rem, &mark, 1, MSG_OOB) < 0) {
        perror("recv");
        ...
    }
    ...
}
```

A process may also read or peek at the out-of-band data without first reading up to the mark. This is more difficult when the underlying protocol delivers the urgent data in-band with the normal data, and only sends notification of its presence ahead of time (e.g., the TCP protocol used to implement socket streams in the Internet domain). With such protocols, the out-of-band byte may not yet have arrived when a `recv()` is done with the `MSG_OOB` flag. In that case, the call will return an error of `EWOULDBLOCK`. Worse, there may be enough in-band data in the input buffer that normal flow control prevents the peer from sending the urgent data until the buffer is cleared. The process must then read enough of the queued data that the urgent data may be delivered.

Certain programs that use multiple bytes of urgent data and must handle multiple urgent signals (e.g., `telnet`(1C)) need to retain the position of urgent data within the socket stream. This treatment is available as a socket-level option, `SO_OOBINLINE`; see `setsockopt(2)` for usage. With this option, the position of urgent data (the "mark") is retained, but the urgent data immediately follows the mark within the normal data stream returned without the MSG_OOB flag. Reception of multiple urgent indications causes the mark to move, but no out-of-band data are lost.

Non-Blocking Sockets

It is occasionally convenient to make use of sockets that do not block; that is, I/O requests that cannot complete immediately and would therefore cause the process to be suspended awaiting completion are not executed, and an error code is returned. Once a socket has been created via the `socket()` call, it may be marked as non-blocking by `fcntl()` as follows:

```
#include <fcntl.h>
 ...
int s;
 ...
s = socket(AF_INET, SOCK_STREAM, 0);
 ...
if (fcntl(s, F_SETFL, FNDELAY) < 0)
    perror("fcntl F_SETFL, FNDELAY");
    exit(1);
}
 ...
```

When performing non-blocking I/O on sockets, one must be careful to check for the error EWOULDBLOCK (stored in the global variable `errno`), which occurs when an operation would normally block, but the socket it was performed on is marked as non-blocking. In particular, `accept()`, `connect()`, `send()`, `recv()`, `read()`, and `write()` can all return EWOULDBLOCK, and processes should be prepared to deal with such return codes. If an operation such as a `send()` cannot be done in its entirety, but partial writes are sensible (for example, when using a stream socket), the data that can be sent immediately will be processed, and the return value will indicate the amount actually sent.

Interrupt Driven Socket I/O

The SIGIO signal allows a process to be notified via a signal when a socket (or more generally, a file descriptor) has data waiting to be read. Use of the SIGIO facility requires three steps: First, the process must set up a SIGIO signal handler by use of the `signal()` or `sigvec()` calls. Second, it must set the process id or process group id that is to receive notification of pending input to its own process id, or the process group id of its process group (note that the default process group of a socket is group zero). This can be accomplished by use of an `fcntl()` call. Third, it must enable asynchronous notification of pending I/O requests with another `fcntl()` call. Sample code to allow a given process to receive information on pending I/O requests as they occur for a socket `s` is given in Figure *9-5*. With the addition of a handler for SIGURG, this code can also be used to prepare for receipt of SIGURG signals.

Figure 9-5 *Use of Asynchronous Notification of I/O Requests*

```
#include <fcntl.h>
 ...
int io_handler();
 ...
signal(SIGIO, io_handler);

/* Set the process receiving SIGIO/SIGURG signals to us. */

if (fcntl(s, F_SETOWN, getpid()) < 0) {
    perror("fcntl F_SETOWN");
    exit(1);
}

/* Allow receipt of asynchronous I/O signals. */

if (fcntl(s, F_SETFL, FASYNC) < 0) {
    perror("fcntl F_SETFL, FASYNC");
    exit(1);
}
```

Signals and Process Groups

Due to the existence of the `SIGURG` and `SIGIO` signals each socket has an associated process number, just as is done for terminals. This value is initialized to zero, but may be redefined at a later time with the `F_SETOWN` `fcntl()`, such as was done in the code above for `SIGIO`. To set the socket's process id for signals, positive arguments should be given to the `fcntl()` call. To set the socket's process group for signals, negative arguments should be passed to `fcntl()`. Note that the process number indicates either the associated process id or the associated process group; it is impossible to specify both at the same time. A similar `fcntl()`, `F_GETOWN`, is available for determining the current process number of a socket.

Note that the receipt of `SIGURG` and `SIGIO` can also be enabled by using the `ioctl()` call to assign the socket to the user's process group:

```
. . .
/* oobdata is the out-of-band data handling routine */
signal(SIGURG, oobdata);
. . .
int pid = -getpid();

if (ioctl(client, SIOCSPGRP, (char *)&pid) < 0) {
    perror("ioctl: SIOCSPGRP");
}
. . .
```

Another signal that is useful when constructing server processes is SIGCHLD. This signal is delivered to a process when any child processes have changed state. Normally servers use the signal to "reap" child processes that have exited without explicitly awaiting their termination or periodically polling for exit status. For example, the remote login server loop shown in Figure 9-2 may be augmented as shown here:

Figure 9-6 *Use of the SIGCHLD Signal*

```
int reaper();
 ...
signal(SIGCHLD, reaper);
listen(f, 5);
for (;;) {
    int g, len = sizeof from;

    g = accept(f, (struct sockaddr *)&from, &len,);
    if (g < 0) {
        if (errno != EINTR)
            syslog(LOG_ERR, "rlogind: accept: %m");
        continue;
    }
    ...
}
 ...
#include <wait.h>
reaper()
{
    union wait status;

    while (wait3(&status, WNOHANG, 0) > 0)
        continue;
}
```

If the parent server process fails to reap its children, a large number of *zombie* processes may be created.

Pseudo Terminals

Many programs will not function properly without a terminal for standard input and output. Since sockets do not provide the semantics of terminals, it is often necessary to have a process communicating over the network do so through a *pseudo-terminal.* A pseudo-terminal is actually a pair of devices, master and slave, which allow a process to serve as an active agent in communication between processes and users. Data written on the slave side of a pseudo-terminal are supplied as input to a process reading from the master side, while data written on the master side are processed as terminal input for the slave. In this way, the process manipulating the master side of the pseudo-terminal has control over the information read and written on the slave side as if it were manipulating the keyboard and reading the screen on a real terminal. The purpose of this abstraction is to preserve terminal semantics over a network connection— that is, the slave side appears as a normal terminal to any process reading from or writing to it.

For example, the remote login server uses pseudo-terminals for remote login sessions. A user logging in to a machine across the network is provided a shell with a slave pseudo-terminal as standard input, output, and error. The server process then handles the communication between the programs invoked by the remote shell and the user's local client process. When a user sends a character that generates an interrupt on the remote machine that flushes terminal output, the pseudo-terminal generates a control message for the server process. The server then sends an out of band message to the client process to signal a flush of data at the real terminal and on the intervening data buffered in the network.

The name of the slave side of a pseudo-terminal is of the form `/dev/ttyxy`, where *x* is a single letter starting at 'p' and continuing to 't'. *y* is a hexadecimal digit (i.e., a single character in the range 0 through 9 or 'a' through 'f'). The master side of a pseudo-terminal is `/dev/ptyxy`, where *x* and *y* correspond to the slave side of the pseudo-terminal.

In general, the method of obtaining a pair of master and slave pseudo-terminals is to find a pseudo-terminal that is not currently in use. The master half of a pseudo-terminal is a single-open device; thus, each master may be opened in turn until an open succeeds. The slave side of the pseudo-terminal is then opened, and is set to the proper terminal modes if necessary. The process then `fork()`s; the child closes the master side of the pseudo-terminal, and `exec()`s the appropriate program. Meanwhile, the parent closes the slave side of the pseudo-terminal and begins reading and writing from the master side. Sample code making use of pseudo-terminals is given in the following example. This code assumes that a connection on a socket *s* exists, connected to a peer who wants a service of some kind, and that the process has disassociated itself from any previous controlling terminal.

Figure 9-7 *Creation and Use of a Pseudo Terminal*

```
gotpty = 0;
for (c = 'p'; !gotpty && c <= 's'; c++) {
    line = "/dev/ptyXX";
    line[sizeof "/dev/pty" -1] = c;
    line[sizeof "/dev/ptyp" -1] = '0';
    if (stat(line, &statbuf) < 0)
        break;
    for (i = 0; i < 16; i++) {
        line[sizeof "/dev/ptyp" -1]
            = "0123456789abcdef"[i];
        master = open(line, O_RDWR);
        if (master >= 0) {
            gotpty = 1;
            break;
        }
    }
}
if (!gotpty) {
    syslog(LOG_ERR, "All network ports in use");
    exit(1);
}
```

```
line[sizeof "/dev/" -1] = 't';
slave = open(line, O_RDWR);     /* slave is now slave side */
if (slave < 0) {
    syslog(LOG_ERR, "Cannot open slave pty %s", line);
    exit(1);
}

ioctl(slave, TIOCGETP, &b);     /* Set slave tty modes */
b.sg_flags = CRMOD|XTABS|ANYP;
ioctl(slave, TIOCSETP, &b);

i = fork();
if (i < 0) {
    syslog(LOG_ERR, "fork: %m");
    exit(1);
} else if (i) {         /* Parent */
    close(slave);
    ...
} else {          /* Child */
    close(s);
    close(master);
    dup2(slave, 0);
    dup2(slave, 1);
    dup2(slave, 2);
    if (slave > 2)
        close(slave);
    ...
}
```

Selecting Specific Protocols

If the third argument to the `socket()` call is 0, `socket()` will select a default protocol to use with the returned socket of the type requested. The default protocol is usually correct, and alternate choices are not usually available. However, when using "raw" sockets to communicate directly with lower-level protocols or hardware interfaces, the protocol argument may be important for setting up demultiplexing. For example, raw sockets in the Internet domain may be used to implement a new protocol above IP, and the socket will receive packets only for the protocol specified. To obtain a particular protocol one determines the protocol number as defined within the protocol domain. For the Internet domain one may use one of the library routines discussed in the *Library Routines* section above, such as `getprotobyname()`:

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
 ...
pp = getprotobyname("newtcp");
s = socket(AF_INET, SOCK_STREAM, pp->p_proto);
```

This would result in a socket *s* using a stream based connection, but with protocol type of "newtcp" instead of the default "tcp."

Address Binding

As was mentioned in the *Basics* section, binding addresses to sockets in the Internet domain can be fairly complex. As a brief reminder, these associations are composed of local and foreign addresses, and local and foreign ports. Port numbers are allocated out of separate spaces, one for each system and one for each domain on that system. Through the `bind()` system call, a process may specify half of an association, the *<local address, local port>* part, while the `connect()` and `accept()` primitives are used to complete a socket's association by specifying the *<foreign address, foreign port>* part. Since the association is created in two steps the association uniqueness requirement indicated previously could be violated unless care is taken. Further, it is unrealistic to expect user programs to always know proper values to use for the local address and local port since a host may reside on multiple networks and the set of allocated port numbers is not directly accessible to a user.

To simplify local address binding in the Internet domain the notion of a *wildcard address* has been provided. When an address is specified as `INADDR_ANY` (a manifest constant defined in <`netinet/in.h`>), the system interprets the address as *any valid address*. For example, to bind a specific port number to a socket, but leave the local address unspecified, the following code might be used:

```
#include <sys/types.h>
#include <netinet/in.h>
 ...
struct sockaddr_in sin;
 ...
s = socket(AF_INET, SOCK_STREAM, 0);
sin.sin_family = AF_INET;
sin.sin_addr.s_addr = htonl(INADDR_ANY);
sin.sin_port = htons(MYPORT);
bind(s, (struct sockaddr *) &sin, sizeof sin);
```

Sockets with wildcarded local addresses may receive messages directed to the specified port number, and sent to any of the possible addresses assigned to a host. For example, if a host has addresses 128.32.0.4 and 10.0.0.78, and a socket is bound as above, the process will be able to accept connection requests that are addressed to 128.32.0.4 or 10.0.0.78. If a server process wished to only allow hosts on a given network connect to it, it would bind the address of the host on the appropriate network.

In a similar fashion, a local port may be left unspecified (specified as zero), in which case the system will select an appropriate port number for it. For example, to bind a specific local address to a socket, but to leave the local port number unspecified:

```
hp = gethostbyname(hostname);
if (hp == NULL) {
    ...
}
bcopy(hp->h_addr, (char *) sin.sin_addr, hp->h_length);
sin.sin_port = htons(0);
bind(s, (struct sockaddr *) &sin, sizeof sin);
```

The system selects the local port number based on two criteria. The first is that Internet ports below `IPPORT_RESERVED` (1024) are reserved for privileged users (i.e., the super user); Internet ports above `IPPORT_USERRESERVED` (50000) are reserved for non-privileged servers. The second is that the port number is not currently bound to some other socket. In order to find a free Internet port number in the privileged range the `rresvport()` library routine may be used as follows to return a stream socket in with a privileged port number:

```
int lport = IPPORT_RESERVED - 1;
int s;
    ...
s = rresvport(&lport);
if (s < 0) {
    if (errno == EAGAIN)
        fprintf(stderr, "socket: all ports in use\n");
    else
        perror("rresvport: socket");
    ...
}
```

The restriction on allocating ports was done to allow processes executing in a "secure" environment to perform authentication based on the originating address and port number. For example, the `rlogin(1)` command allows users to log in across a network without being asked for a password, if two conditions hold: First, the name of the system the user is logging in from is in the file `/etc/hosts.equiv` on the system s/he is logging in to (or the system name and the user name are in the user's `.rhosts` file in the user's home directory), and second, that the user's rlogin process is coming from a privileged port on the machine from which s/he is logging in. The port number and network address of the machine from which the user is logging in can be determined either by the *from* result of the `accept()` call, or from the `getpeername()` call.

In certain cases the algorithm used by the system in selecting port numbers is unsuitable for an application. This is because associations are created in a two step process. For example, the Internet file transfer protocol, FTP, specifies that data connections must always originate from the same local port. However, duplicate associations are avoided by connecting to different foreign ports. In this situation the system would disallow binding the same local address and port number to a socket if a previous data connection's socket still existed. To override the default port selection algorithm, an option call must be performed prior to address binding:

```
 ...
int on = 1;
 ...
setsockopt(s, SOL_SOCKET, SO_REUSEADDR, &on, sizeof on);
bind(s, (struct sockaddr *) &sin, sizeof sin);
```

With the above call, local addresses may be bound that are already in use. This does not violate the uniqueness requirement as the system still checks at connect time to be sure any other sockets with the same local address and port do not have the same foreign address and port. If the association already exists, the error EADDRINUSE is returned.

Broadcasting and Determining Network Configuration

By using a datagram socket, it is possible to send broadcast packets on many networks connected to the system. The network itself must support broadcast; the system provides no simulation of broadcast in software. Broadcast messages can place a high load on a network since they force every host on the network to service them. Consequently, the ability to send broadcast packets has been limited to sockets that are explicitly marked as allowing broadcasting. Broadcast is typically used for one of two reasons: it is desired to find a resource on a local network without prior knowledge of its address, or important functions such as routing require that information be sent to all accessible neighbors.

To send a broadcast message, a datagram socket should be created:

```
s = socket(AF_INET, SOCK_DGRAM, 0);
```

The socket is marked as allowing broadcasting,

```
int on = 1;
setsockopt(s, SOL_SOCKET, SO_BROADCAST, &on, sizeof on);
```

and at least a port number should be bound to the socket:

```
sin.sin_family = AF_INET;
sin.sin_addr.s_addr = htonl(INADDR_ANY);
sin.sin_port = htons(MYPORT);
bind(s, (struct sockaddr *) &sin, sizeof sin);
```

The destination address of the message to be broadcast depends on the network(s) on which the message is to be broadcast. The Internet domain supports a shorthand notation for broadcast on the local network, the address INADDR_BROADCAST (defined in <netinet/in.h>. To determine the list of addresses for all reachable neighbors requires knowledge of the networks to which the host is connected. Since this information should be obtained in a host-independent fashion and may be impossible to derive, SunOS provides a method of retrieving this information from the system data structures. The SIOCGIFCONF ioctl call returns the interface configuration of a host in the form of a single ifconf structure; this structure contains a "data area" that is made up of an array of of ifreq structures, one for each address domain supported by each network interface to which the host is connected. These structures are defined in <net/if.h> as follows:

```
struct ifconf {
    int ifc_len;                        /* size of associated buffer */
    union {
        caddr_t ifcu_buf;
        struct ifreq *ifcu_req;
    } ifc_ifcu;
};

#define ifc_buf ifc_ifcu.ifcu_buf /* buffer address */
#define ifc_req ifc_ifcu.ifcu_req /* array of structures returned */

struct ifreq {
#define IFNAMSIZ    16
    char ifr_name[IFNAMSIZ];            /* if name, e.g. "en0" */
    union {
        struct sockaddr ifru_addr;
        struct sockaddr ifru_dstaddr;
        char ifru_oname[IFNAMSIZ]; /* other if name */
        short ifru_flags;
        char ifru_data[1];              /* interface dependent data */
    } ifr_ifru;
};

#define ifr_addr    ifr_ifru.ifru_addr    /* address */
#define ifr_dstaddr ifr_ifru.ifru_dstaddr/* other end of link */
#define ifr_oname   ifr_ifru.ifru_oname   /* other if name */
#define ifr_flags   ifr_ifru.ifru_flags   /* flags */
#define ifr_data    ifr_ifru.ifru_data    /* for use by interface */
```

The actual call that obtains the interface configuration is

```
struct ifconf ifc;
char buf[BUFSIZ];

ifc.ifc_len = sizeof buf;
ifc.ifc_buf = buf;
if (ioctl(s, SIOCGIFCONF, (char *) &ifc) < 0) {
    ...
}
```

After this call *buf* will contain a list of `ifreq` structures, one for each network to which the host is connected. These structures will be ordered first by interface name and then by supported address families. `ifc.ifc_len` will have been modified to reflect the number of bytes used by the `ifreq` structures.

For each structure there exists a set of "interface flags" that tell whether the network corresponding to that interface is up or down, point to point or broadcast, etc. The `SIOCGIFFLAGS ioctl` retrieves these flags for an interface specified by an `ifreq` structure as follows:

```
struct ifreq *ifr;

ifr = ifc.ifc_req;

for (n=ifc.ifc_len/sizeof (struct ifreq);
    --n >= 0; ifr++) {
    /*
     * We must be careful that we don't use an interface
     * devoted to an address domain other than those intended;
     * if we were interested in NS interfaces, the
     * AF_INET would be AF_NS.
     */
    if (ifr->ifr_addr.sa_family != AF_INET)
        continue;
    if (ioctl(s, SIOCGIFFLAGS, (char *) ifr) < 0) {
        ...
    }
    /*
     * Skip boring cases
     */
    if ((ifr->ifr_flags & IFF_UP) == 0 ||
        (ifr->ifr_flags & IFF_LOOPBACK) ||
        (ifr->ifr_flags &
        (IFF_BROADCAST | IFF_POINTTOPOINT)) == 0)
        continue;
```

Once the flags have been obtained, the broadcast address must be obtained. In the case of broadcast networks this is done via the `SIOCGIFBRDADDR` `ioctl`, while for point-to-point networks the address of the destination host is obtained with `SIOCGIFDSTADDR`.

```
struct sockaddr dst;

if (ifr->ifr_flags & IFF_POINTTOPOINT) {
    if (ioctl(s, SIOCGIFDSTADDR, (char *) ifr) < 0) {
        ...
    }
    bcopy((char *) ifr->ifr_dstaddr, (char *) &dst,
        sizeof ifr->ifr_dstaddr);
} else if (ifr->ifr_flags & IFF_BROADCAST) {
    if (ioctl(s, SIOCGIFBRDADDR, (char *) ifr) < 0) {
        ...
    }
    bcopy((char *) ifr->ifr_broadaddr, (char *) &dst,
        sizeof ifr->ifr_broadaddr);
}
```

After the appropriate `ioctl()`s have obtained the broadcast or destination address (now in *dst*), the `sendto()` call may be used:

```
sendto(s, buf, buflen, 0, (struct sockaddr *)&dst, sizeof dst);
```

In the above loop one `sendto()` occurs for every interface to which the host is connected that supports the notion of broadcast or point-to-point addressing. If a process only wished to send broadcast messages on a given network, code similar to that outlined above would be used, but the loop would need to find the correct destination address.

Received broadcast messages contain the sender's address and port, as datagram sockets are bound before a message is allowed to go out.

Socket Options

It is possible to set and get a number of options on sockets via the `setsockopt()` and `getsockopt()` system calls. These options include such things as marking a socket for broadcasting, not to route, to linger on close, etc. The general forms of the calls are:

```
setsockopt(s, level, optname, optval, optlen);
```

and

```
getsockopt(s, level, optname, optval, optlen);
```

The parameters to the calls are as follows: *s* is the socket on which the option is to be applied. *level* specifies the protocol layer on which the option is to be applied; in most cases this is the "socket level", indicated by the symbolic constant `SOL_SOCKET`, defined in `<sys/socket.h>`. The actual option is specified in `optname`, and is a symbolic constant also defined in `<sys/socket.h>`. *optval* and *optlen* point to the value of the option (in most cases, whether the option is to be turned on or off), and the length of the value of the option, respectively. For `getsockopt()`, *optlen* is a value-result parameter, initially set to the size of the storage area pointed to by *optval*, and modified upon return to indicate the actual amount of storage used.

An example should help clarify things. It is sometimes useful to determine the type (e.g., stream, datagram, etc.) of an existing socket; programs invoked by `inetd` (described below) may need to perform this task. This can be accomplished as follows via the `SO_TYPE` socket option and the `getsockopt()` call:

```
#include <sys/types.h>
#include <sys/socket.h>

int type, size;

size = sizeof (int);

if (getsockopt(s, SOL_SOCKET, SO_TYPE, (char *) &type,
    &size) < 0) {
    ...
}
```

After the `getsockopt()` call, *type* will be set to the value of the socket type, as defined in <sys/socket.h>. If, for example, the socket were a datagram socket, *type* would have the value corresponding to SOCK_DGRAM.

inetd

One of the daemons provided with SunOS is inetd, the so called "Internet super-server." inetd is invoked at boot time and determines from the file /etc/inetd.conf the services for which it is to listen. Once this information has been read and a pristine environment created, inetd proceeds to create one socket for each service it is to listen for, binding the appropriate port number to each socket.

inetd then performs a select() on all these sockets for read availability, waiting for somebody wishing a connection to the service corresponding to that socket. inetd then performs an accept() on the socket in question, fork()s, dup()s the new socket to file descriptors 0 and 1 (stdin and stdout), closes other open file descriptors, and exec()s the appropriate server.

Servers making use of inetd are considerably simplified, as inetd takes care of the majority of the IPC work required in establishing a connection. The server invoked by inetd expects the socket connected to its client on file descriptors 0 and 1, and may immediately perform any operations such as read(), write(), send(), or recv(). Indeed, servers may use buffered I/O as provided by the "stdio" conventions, as long as as they remember to use fflush() when appropriate.

One call that may be of interest to individuals writing servers to be invoked by inetd is the getpeername() call, which returns the address of the peer (process) connected on the other end of the socket. For example, to log the Internet address in "dot notation" (e.g., "128.32.0.4") of a client connected to a server under inetd, the following code might be used:

```
struct sockaddr_in name;
int namelen = sizeof name;
 ...
if (getpeername(0,
    (struct sockaddr *)&name, &namelen) < 0) {
    syslog(LOG_ERR, "getpeername: %m");
    exit(1);
} else
    syslog(LOG_INFO, "Connection from %s",
        inet_ntoa(name.sin_addr));
 ...
```

While the getpeername() call is especially useful when writing programs to run with inetd, it can be used under other circumstances. Be warned, however, that getpeername will fail on UNIX domain sockets. ".

10

Socket-Based IPC Implementation Notes

10

Socket-Based IPC Implementation Notes

This chapter describes the internal structure of the socket-based networking facilities originally developed for the 4.2BSD version of the UNIX system and subsequently integrated into SunOS. These facilities are based on several central abstractions that structure and unify the external (user) view of network communication as well as the internal (system) implementation. In addition, the implementation introduces a structure for network communications that may be used by system implementors in adding new networking facilities. The internal structure is not visible to the user, rather it is intended to aid implementors of communication protocols and network services by providing a framework that promotes code sharing and minimizes implementation effort.

The reader is expected to be familiar with the C programming language and system interface, as described in the *System Services Overview*. Basic understanding of network communication concepts is assumed; where required any additional ideas are introduced.

The remainder of this document provides a description of the system internals, avoiding, when possible, overlap with the interprocess communication tutorials.

Overview

If we consider the International Standards Organization's (ISO) Open System Interconnection (OSI) model of network communication [ISO81] [Zimmermann80], the networking facilities described here correspond to a portion of the session layer, all of the transport and network layers, and some datalink layers.

The network layer provides possibly imperfect data transport services with minimal addressing structure. Addressing at this level is normally host to host, with implicit or explicit routing optionally supported by the communicating agents.

At the transport layer the notions of reliable transfer, data sequencing, flow control, and service addressing are normally included. Reliability is usually managed by explicit acknowledgement of data delivered. Failure to acknowledge a transfer results in retransmission of the data. Sequencing may be handled by tagging each message handed to the network layer by a *sequence number* and maintaining state at the endpoints of communication to utilize received sequence numbers in reordering data that arrives out of order.

The session layer facilities may provide forms of addressing that are mapped into formats required by the transport layer, service authentication and client authentication, etc. Various systems also provide services such as data encryption and address and protocol translation.

The following sections begin by describing some of the common data structures and utility routines, then examine the internal layering. The contents of each layer and its interface are considered. Certain of the interfaces are protocol implementation specific. For these cases examples have been drawn from the Internet [Cerf78] protocol family. Later sections cover routing issues, the design of the raw socket interface, and other miscellaneous topics.

Goals

The networking system was designed with the goal of supporting multiple *protocol families* and addressing styles. This required information to be "hidden" in common data structures that could be manipulated by all the pieces of the system, but that required interpretation only by the protocols that "controlled" it. The system described here attempts to minimize the use of shared data structures to those kept by a suite of protocols (a *protocol family*), and those used for rendezvous between "synchronous" and "asynchronous" portions of the system (e.g. queues of data packets are filled at interrupt time and emptied based on user requests).

A major goal of the system was to provide a framework within which new protocols and hardware could be easily be supported. To this end, a great deal of effort has been extended to create utility routines that hide many of the more complex and/or hardware dependent chores of networking. Later sections describe the utility routines and the underlying data structures they manipulate.

10.1. Memory, Addressing

Address Representation

Common to all portions of the system are two data structures. These structures are used to represent addresses and various data objects. Addresses are internally described by the `sockaddr` structure,

```
struct sockaddr {
    short   sa_family;      /* address family */
    char    sa_data[14];    /* up to 14 bytes of direct address */
};
```

All addresses belong to one or more *address families* which define their format and interpretation. The `sa_family` field indicates the address family to which the address belongs, and the `sa_data` field contains the actual data value. The size of the data field, 14 bytes, was selected based on a study of current address formats. Specific address formats use private structure definitions that define the format of the data field. The system interface supports larger address structures, although address-family-independent support facilities, for example routing and raw socket interfaces, provide only 14 bytes for address storage. Protocols that do not use those facilities (e.g, the current UNIX domain) may use larger data areas.[19]

[19] Later versions of the system may support variable length addresses.

Memory Management

A single structure is used for data storage — the memory buffer, or "mbuf". There are three kinds of mbufs — "small", "cluster", and "loaned". They differ in the policies and mechanisms by which their associated storage is allocated and managed.

Small mbufs

Small mbufs are the fundamental type and are used both on their own and as building blocks for cluster and loaned mbufs. They contain their own storage in the array (see below) named `m_dat`. That array is defined as containing 112 (`MLEN`) bytes, so that's all the data that a small mbuf can hold. Small mbufs are guaranteed to start on a 128-byte boundary. The `dtom` macro, described below, works correctly only with small mbufs — mistaken attempts to use `dtom` with cluster and loaned mbufs are a common source of insidious error.

Cluster mbufs

Cluster mbufs support the storage and sharing of larger amounts of data. They do so by dynamically allocating storage, as necessary, from a pool of fixed-sized buffers called clusters. These clusters, each of which is `MCLBYTES` (1K) in size, are managed by the mbuf system itself. The mbuf system uses a small mbuf to refer to a given cluster by setting its `m_off` field to refer to a location in the interior (most commonly, the beginning) of the cluster. This combination of a small mbuf and a cluster is what constitutes a cluster mbuf.

Cluster mbufs can be shared because clusters are reference-counted. The routine `mcldup()` arranges to share an existing cluster mbuf by increasing its reference count and attaching a new small mbuf to it. Cluster mbufs always have their `m_cltype` field set to `MCL_STATIC`.

Loaned mbufs

Loaned mbufs provide for treating storage not directly managed by the mbuf system in the same way as normal mbufs. The mbuf system uses small mbufs to store bookkeeping information about loaned mbufs, as it does with cluster mbufs. With loaned mbufs, however, storage is provided by the allocator, who is ultimately responsible of freeing it as well. To allocate a loaned mbuf, one calls `mclgetx`(), which takes as arguments the address of the buffer to be loaned, its length, a pointer to a function, and an argument to be passed to that function when it's called. This function is called when the loaned mbuf is freed, and must do whatever is necessary to clean up the loaned buffer. The `m_clfun` and `m_clarg` fields of the mbuf structure record the pointer to this function and its argument. Loaned mbufs have their `m_cltype` field set to `MCL_LOANED`.

An mbuf structure has the form:

```
#define MSIZE   128
#define MMINOFF 12
#define MTAIL   4
#define MLEN    (MSIZE-MMINOFF-MTAIL)

struct mbuf {
    struct  mbuf *m_next;        /* next buffer in chain */
    u_long  m_off;               /* offset of data */
    short   m_len;               /* amount of data in this mbuf */
    short   m_type;              /* mbuf type (0 == free) */
    union {
            u_char  mun_dat[MLEN];  /* data storage*/
            struct {
                short mun_cltype;   /* "cluster" type*/
                int (*mun_clfun)();
                int mun_clarg;
                int (*mun_clswp)();
            } mun_cl;
    } m_un;
    struct  mbuf *m_act;         /* link in higher-level mbuf list */

#define m_dat   m_un.mun_dat
#define m_cltype    m_un.mun_cl.mun_cltype
#define m_clfun m_un.mun_cl.mun_clfun
#define m_clarg m_un.mun_cl.mun_clarg
};
```

The `m_next` field is used to chain mbufs together on linked lists, while the `m_act` field allows lists of mbuf chains to be accumulated. By convention, the mbufs common to a single object (for example, a packet) are chained together with the `m_next` field, while groups of objects are linked via the `m_act` field (possibly when in a queue).

The `m_len` field indicates the amount of data, while the `m_off` field is an offset to the beginning of the data from the base of the mbuf. Thus, for example, the macro `mtod`(), which converts a pointer to an mbuf to a pointer to the data stored in the mbuf, has the form

```
#define mtod(x,t)    ((t)((int)(x) + (x)->m_off))
```

(note the *t* parameter, a C type cast, which is used to cast the resultant pointer for proper assignment). Since a small mbuf's data always resides in the mbuf's own `m_dat` array, its `m_off` value is always less than `MSIZE`. On the other hand, storage for cluster and loaned mbufs is external to the mbufs themselves, so their `m_off` values are always at least `MSIZE`. The `M_HASCL` macro distinguishes these two cases and is defined as

```
#define M_HASCL(m)  ((m)->m_off >= MSIZE)
```

AS mentioned above, the `dtom` macro is safe to use only if `M_HASCL` evaluates false.

The following routines and macros may be used to allocate and free mbufs:

```
m = m_get(wait, type);
MGET(m, wait, type);
```

The subroutine `m_get()` and the macro `MGET()` each allocate an mbuf, placing its address in *m*. The argument *wait* is either `M_WAIT` or `M_DONTWAIT` according to whether allocation should block or fail if no mbuf is available. The *type* is one of the predefined mbuf types for use in accounting of mbuf allocation.

`MCLGET(m);`

This macro attempts to allocate an mbuf cluster to associate with the mbuf *m*. If successful, the length of the mbuf is set to `MCLSIZE`. The routine `mclget()` is similar, but returns success/failure.

`mclgetx(fun, arg, addr, len, wait)`

This routine wraps the storage defined by *addr* and *len* with an `MCL_LOANED` mbuf. The *fun* argument gives a function to be called when the resulting loaned mbuf is freed, and *arg* is a value that will be supplied to that function as its argument. The argument *wait* is either `M_WAIT` or `M_DONTWAIT` according to whether allocation should block or fail if no mbuf is available.

`mcldup(m, n, off);`

A duplicator for cluster and loaned mbufs, which duplicates *m* into *n*. If *m* is a cluster mbuf, `mcldup()` simply bumps its reference count and ignores *off*. But if *m* is a loaned mbuf, `mcldup()` allocates a chunk of memory and copies it, starting at offset *off*.

```
n = m_free(m);
MFREE(m,n);
```

The routine `m_free()` and the macro `MFREE()` each free a single mbuf, *m*, and any associated external storage area, placing a pointer to its successor in the chain it heads, if any, in *n*.

`m_freem(m);`

This routine frees an mbuf chain headed by *m*.

By insuring that mbufs always reside on 128 byte boundaries, it is always possible to locate the mbuf associated with a data area by masking off the low bits of the virtual address. This allows modules to store data structures in mbufs and pass them around without concern for locating the original mbuf when it comes time to free the structure. Note that this works only with objects stored in the internal data buffer of the mbuf. The `dtom` macro is used to convert a pointer into an mbuf's data area to a pointer to the mbuf,

```
#define dtom(x) ((struct mbuf *)((int)x & ~(MSIZE-1)))
```

Mbufs are used for dynamically allocated data structures such as sockets as well as memory allocated for packets and headers. Statistics are maintained on mbuf usage and can be viewed by users using the `netstat()` program. The following utility routines are available for manipulating mbuf chains:

`m = m_copy(m0, off, len);`

The `m_copy()` routine create a copy of all, or part, of a list of the mbufs in *m0*. *len* bytes of data, starting *off* bytes from the front of the chain, are copied. Where possible, reference counts are manipulated in preference to core to core copies. The original mbuf chain must have at least *off* + *len* bytes of data. If *len* is specified as *M_COPYALL*, all the data present, offset as before, is copied.

`m_cat(m,n);`

The mbuf chain, *n*, is appended to the end of *m*. Where possible, compaction is performed.

`m_cpytoc(m, off, len, cp)`

Copies a part of the contents of the mbuf *m* to the contiguous memory pointed to by *cp*, skipping the first *off* bytes and copying the next *len* bytes. It returns the number of bytes remaining in the mbuf following the portion copied. *m* is left unaltered.

`m_adj(m, diff);`

The mbuf chain, *m* is adjusted in size by *diff* bytes. If *diff* is non-negative, *diff* bytes are shaved off the front of the mbuf chain. If *diff* is negative, the alteration is performed from back to front. No space is reclaimed in this operation; alterations are accomplished by changing the *m_len* and *m_off* fields of mbufs.

`m = m_pullup(m0, size);`

After a successful call to `m_pullup()`, the mbuf at the head of the returned list, *m*, is guaranteed to have at least *size* bytes of data in contiguous memory within the data area of the mbuf (allowing access via a pointer, obtained using the `mtod()` macro, and allowing the mbuf to be located from a pointer to the data area using `dtom`, defined below). If the original data was less than *size* bytes long, *len* was greater than the size of an mbuf data area (112 bytes), or required resources were unavailable, *m* is 0 and the original mbuf chain is deallocated.

This routine is particularly useful when verifying packet header lengths on reception. For example, if a packet is received and only 8 of the necessary 16 bytes required for a valid packet header are present at the head of the list of mbufs representing the packet, the remaining 8 bytes may be "pulled up" with a single `m_pullup()` call. If the call fails the invalid packet will have been discarded.

10.2. Internal Layering

The internal structure of the network system is divided into three layers. These layers correspond to the services provided by the socket abstraction, those provided by the communication protocols, and those provided by the hardware interfaces. The communication protocols are normally layered into two or more individual cooperating layers, though they are collectively viewed in the system as one layer providing services supportive of the appropriate socket abstraction.

The following sections describe the properties of each layer in the system and the interfaces to which each must conform.

Socket Layer

The socket layer deals with the interprocess communication facilities provided by the system. A socket is a bidirectional endpoint of communication which is "typed" by the semantics of communication it supports. For more information about the system calls used to manipulate sockets, see *A Socket-Based Interprocess Communications Tutorial* and *An Advanced Socket-Based Interprocess Communications Tutorial*, both sections of *Network Programming*.

A socket consists of the following data structure:

```
struct socket {
    short    so_type;                 /* generic type, see socket.h */
    short    so_options;              /* from socket call */
    short    so_linger;               /* time to linger while closing */
    short    so_state;                /* internal state flags SS_*, below */
    caddr_t  so_pcb;                  /* protocol control block */
    struct   protosw *so_proto;       /* protocol handle */
/*
 * Variables for connection queueing. A socket where accepts occur is so_head
 * in all subsidiary sockets. If so_head is 0, the socket is not related to an
 * accept. For head socket so_q0 queues partially completed connections, while
 * so_q is a queue of connections ready to be accepted. If a connection is
 * aborted and it has so_head set, then it has to be pulled out of either
 * so_q0 or so_q. We allow connections to queue up based on current
 * queue lengths and limit on number of queued connections for this socket.
 */
    struct   socket *so_head;         /* back pointer to accept socket */
    struct   socket *so_q0;           /* queue of partial connections */
    struct   socket *so_q;            /* queue of incoming connections */
    short    so_q0len;                /* partials on so_q0 */
    short    so_qlen;                 /* number of connections on so_q */
    short    so_qlimit;               /* max # of queued connections */
    short    so_timeo;                /* connection timeout */
    u_short  so_error;                /* error affecting connection */
    short    so_pgrp;                 /* pgrp for signals */
    u_short  so_oobmark;              /* chars to oob mark */
/*
 * Variables for socket buffering.
 */
    struct   sockbuf   so_rcv;        /* receive buffer */
    struct   sockbuf   so_snd;        /* send buffer */
/*
 * Hooks for alternative wakeup strategies.
 * These are used by kernel subsystems wishing to access the socket
 * abstraction. If so_wupfunc is nonnull, it is called in place of
 * wakeup any time that wakeup would otherwise be called with an
 * argument whose value is an address lying within a socket structure.
 */
    struct wupalt   *so_wupalt;
};

struct wupalt {
    int   (*wup_func)();             /* function to call instead of wakeup */
    caddr_t   wup_arg;               /* argument for so_wupfunc */
```

```
        /* Other state information here, e.g. for a stream
         * connected to a socket
         */
};
```

Each socket contains two send and receive data queues, `so_rcv` and `so_snd` (see below for a discussion), as well as protocol information, private data, error information and pointers to routines which provide supporting services.

The type of the socket, `so_type` is defined at socket creation time and used in selecting those services that are appropriate to support it. The supporting protocol is selected at socket creation time and recorded in the socket data structure for later use. Protocols are defined by a table of procedures, the `protosw` structure, which will be described in detail later. A pointer to a protocol-specific data structure, the "protocol control block," is also present in the socket structure. Protocols control this data structure, which normally includes a back pointer to the parent socket structure to allow easy lookup when returning information to a user (for example, placing an error number in the `so_error` field). Other entries in the socket structure are used in queuing connection requests, validating user requests, storing socket characteristics (e.g. options supplied at the time a socket is created), and maintaining a socket's state.

Processes "rendezvous at a socket" in many instances. For instance, when a process wishes to extract data from a socket's receive queue and it is empty, or lacks sufficient data to satisfy the request, the process blocks, supplying the address of the receive queue as a "wait channel' to be used in notification. When data arrives for the process and is placed in the socket's queue, the blocked process is identified by the fact it is waiting "on the queue."

Socket State

A socket's state is defined from the following:

```
#define SS_NOFDREF          0x001 /* no file table ref any more */
#define SS_ISCONNECTED      0x002 /* socket connected to a peer */
#define SS_ISCONNECTING     0x004 /*in process of connecting to peer*/
#define SS_ISDISCONNECTING  0x008 /* in process of disconnecting */
#define SS_CANTSENDMORE     0x010 /* can't send more data to peer */
#define SS_CANTRCVMORE      0x020 /* can't take more data from peer */
#define SS_RCVATMARK        0x040 /* at mark on input */

#define SS_PRIV             0x080 /* privileged */
#define SS_NBIO             0x100 /* non-blocking ops */
#define SS_ASYNC            0x200 /* async i/o notify */
```

The state of a socket is manipulated both by the protocols and the user (through system calls). When a socket is created, the state is defined based on the type of socket. It may change as control actions are performed, for example connection establishment. It may also change according to the type of input/output the user wishes to perform, as indicated by options set with `fcntl()`. "Non-blocking" I/O implies that a process should never be blocked to await resources. Instead, any call that would block returns prematurely with the error `EWOULDBLOCK`, or the service request (e.g. a request for more data than is present) may be only partially fulfilled.

If a process requested "asynchronous" notification of events related to the socket, the `SIGIO` signal is posted to the process when such events occur. An event is a change in the socket's state; examples of such occurrences are space becoming available in the send queue, new data available in the receive queue, connection establishment or disestablishment, etc.

A socket may be marked "privileged" if it was created by the super-user. Only privileged sockets may bind addresses in privileged portions of an address space or use "raw" sockets to access lower levels of the network.

Socket Data Queues

A socket's data queue contains a pointer to the data stored in the queue and other entries related to the management of the data. The structure of a data queue, `struct sockbuf`, is:

```
struct  sockbuf {
    u_short sb_cc;              /* actual chars in buffer */
    u_short sb_hiwat;           /* max actual char count */
    u_short sb_mbcnt;           /* chars of mbufs used */
    u_short sb_mbmax;           /* max chars of mbufs to use */
    u_short sb_lowat;           /* low water mark (not used yet) */
    struct  mbuf *sb_mb;        /* the mbuf chain */
    struct  proc *sb_sel;       /* process selecting read/write */
    short   sb_timeo;           /* timeout (not used yet) */
    short   sb_flags;           /* flags, see below */
} so_rcv, so_snd;
```

Data is stored in a queue as a chain of mbufs. The actual count of data characters as well as high and low water marks are used by the protocols in controlling the flow of data. The amount of buffer space (characters of mbufs and associated data clusters) is also recorded along with the limit on buffer allocation. The socket routines cooperate in implementing the flow control policy by blocking a process when it requests to send data and the high water mark has been reached, or when it requests to receive data and less than the low water mark is present (assuming non-blocking I/O has not been specified).[20]

A socket queue has a number of flags used in synchronizing access to the data and in acquiring resources:

```
#define SB_MAX   65535   /* max chars in sockbuf */
#define SB_LOCK  0x01    /* lock on data queue (so_rcv only)*/
#define SB_WANT  0x02    /* someone is waiting to lock */
#define SB_WAIT  0x04    /* someone is waiting for data/space */
#define SB_SEL   0x08    /* buffer is selected */
#define SB_COLL  0x10    /* collision selecting */
```

[20] The low-water mark is always presumed to be 0 in the current implementation.

The last two flags are manipulated by the system in implementing the select mechanism.

When a socket is created, the supporting protocol "reserves" space for the send and receive queues of the socket. The limit on buffer allocation is set somewhat higher than the limit on data characters to account for the granularity of buffer allocation. The actual storage associated with a socket queue may fluctuate during a socket's lifetime, but it is assumed that this reservation will always allow a protocol to acquire enough memory to satisfy the high water marks.

The timeout and select values are manipulated by the socket routines in implementing various portions of the interprocess communications facilities and will not be described here.

Data queued at a socket is stored in one of two styles. Stream-oriented sockets queue data with no addresses, headers or record boundaries. The data are in mbufs linked through the `m_next` field. Buffers containing access rights may be present within the chain if the underlying protocol supports passage of access rights. Record-oriented sockets, including datagram sockets, queue data as a list of packets; the sections of packets are distinguished by the types of the mbufs containing them. The mbufs that comprise a record are linked through the `m_next` field; records are linked from the `m_act` field of the first mbuf of one packet to the first mbuf of the next. Each packet begins with an mbuf containing the "from" address if the protocol provides it, then any buffers containing access rights, and finally any buffers containing data. If a record contains no data, no data buffers are required unless neither address nor access rights are present.

Socket Connection Queuing

In dealing with connection oriented sockets (e.g. `SOCK_STREAM`) the two ends are considered distinct. One end is termed *active*, and generates connection requests. The other end is called *passive* and accepts connection requests.

From the passive side, a socket is marked with `SO_ACCEPTCONN` when a `listen()` call is made, creating two queues of sockets: `so_q0` for connections in progress and `so_q` for connections already made and awaiting user acceptance. As a protocol is preparing incoming connections, it creates a socket structure queued on `so_q0` by calling the routine `sonewconn()`. When the connection is established, the socket structure is then transferred to `so_q`, making it available for an `accept()`.

If an `SO_ACCEPTCONN` socket is closed with sockets on either `so_q0` or `so_q`, these sockets are dropped, with notification to the peers as appropriate.

Protocol Layer(s)

Each socket is created in a communications domain, which usually implies both an addressing structure (address family) and a set of protocols that implement various socket types within the domain (protocol family). Each domain is defined by the following structure:

```
struct domain {
        int     dom_family;             /* PF_xxx */
        char    *dom_name;
        int     (*dom_init)();          /* initialize domain structures */
        int     (*dom_externalize)();/* externalize access rights */
        int     (*dom_dispose)();       /*dispose of internalized rights*/
        struct  protosw *dom_protosw, *dom_protoswNPROTOSW;
        struct  domain *dom_next;
};
```

At boot time, each domain configured into the kernel is added to a linked list of domains. The initialization procedure of each domain is then called. After that time, the domain structure is used to locate protocols within the protocol family. It may also contain procedure references for externalization of access rights at the receiving socket and the disposal of access rights that are not received.

Protocols are described by a set of entry points and certain socket-visible characteristics, some of which are used in deciding which socket type(s) they may support.

An entry in the "protocol switch" table exists for each protocol module configured into the system. It has the following form:

```
struct protosw {
        short   pr_type;                /* socket type used for */
        struct  domain *pr_domain;      /* domain protocol a member of */
        short   pr_protocol;            /* protocol number */
        short   pr_flags;               /* socket visible attributes */
        /* protocol-protocol hooks */
        int     (*pr_input)();          /* input to protocol (from below) */
        int     (*pr_output)();         /* output to protocol (from above) */
        int     (*pr_ctlinput)();       /* control input (from below) */
        int     (*pr_ctloutput)();      /*control output (from above)*/
        /* user-protocol hook */
        int     (*pr_usrreq)();         /* user request */
        /* utility hooks */
        int     (*pr_init)();           /* initialization routine */
        int     (*pr_fasttimo)();       /*fast timeout (200ms) */
        int     (*pr_slowtimo)();       /* slow timeout (500ms) */
        int     (*pr_drain)();          /* flush any excess space possible */
};
```

A protocol is called through the `pr_init` entry before any other. Thereafter it is called every 200 milliseconds through the `pr_fasttimo` entry and every 500 milliseconds through the `pr_slowtimo` for timer based actions. The system will call the `pr_drain` entry if it is low on space and this should throw away any non-critical data.

Protocols pass data between themselves as chains of mbufs using the `pr_input()` and `pr_output()` routines. `pr_input()` passes data up (towards the user) and pr_output() passes it down (towards the network); control information passes up and down on pr_ctlinput() and pr_ctloutput(). The protocol is responsible for the space occupied by any of the arguments to these entries and must either pass it onward or dispose of it. (On output, the lowest level reached must free buffers storing the arguments; on input, the highest level is responsible for freeing buffers.)

The pr_usrreq() routine interfaces protocols to the socket code and is described below.

The pr_flags field is constructed from the following values:

```
#define PR_ATOMIC           0x01   /* exchange atomic messages only */
#define PR_ADDR             0x02   /* addresses given with messages */
#define PR_CONNREQUIRED     0x04   /* connection required by protocol */
#define PR_WANTRCVD         0x08   /* want PRU_RCVD calls */
#define PR_RIGHTS           0x10   /* passes capabilities */
```

Protocols that are connection-based specify the PR_CONNREQUIRED flag so that the socket routines will never attempt to send data before a connection has been established. If the PR_WANTRCVD flag is set, the socket routines will notify the protocol when the user has removed data from the socket's receive queue. This allows the protocol to implement acknowledgement on user receipt, and also update windowing information based on the amount of space available in the receive queue. The PR_ADDR field indicates that any data placed in the socket's receive queue will be preceded by the address of the sender. The PR_ATOMIC flag specifies that each *user* request to send data must be performed in a single *protocol* send request; it is the protocol's responsibility to maintain record boundaries on data to be sent. The PR_RIGHTS flag indicates that the protocol supports the passing of capabilities; this is currently used only by the protocols in the UNIX protocol family.

When a socket is created, the socket routines scan the protocol table for the domain looking for an appropriate protocol to support the type of socket being created. The pr_type field contains one of the possible socket types (e.g. SOCK_STREAM), while the pr_domain is a back pointer to the domain structure. The pr_protocol field contains the protocol number of the protocol, normally a well-known value.

Network-Interface Layer

Each network-interface configured into a system defines a path through which packets may be sent and received. Normally a hardware device is associated with this interface, though there is no requirement for this (for example, all systems have a software "loopback" interface used for debugging and performance analysis). In addition to manipulating the hardware device, an interface module is responsible for encapsulation and decapsulation of any link-layer header information required to deliver a message to its destination. The selection of which interface to use in delivering packets is a routing decision carried out at a higher level than the network-interface layer. An interface may have addresses in one or more address families. The address is set at boot time using an ioctl() on a socket in the appropriate domain; this operation is implemented by the protocol family, after verifying the operation through the device `ioctl()` entry.

An interface is defined by the following structure,

```
struct ifnet {
    char    *if_name;              /* name, e.g. "en" or "lo" */
    short    if_unit;              /* sub-unit for lower level driver */
    short    if_mtu;               /* maximum transmission unit */
    short    if_flags;             /* up/down, broadcast, etc. */
    short    if_timer;             /* time 'til if_watchdog called */
    u_short if_promisc;         /* # of requests for promiscuous mode */
    int     if_metric;             /* routing metric (external only) */
    struct  ifaddr *if_addrlist;   /* linked list of addresses per if */
    struct  ifqueue {
        struct  mbuf *ifq_head;
        struct  mbuf *ifq_tail;
        int ifq_len;
        int ifq_maxlen;
        int ifq_drops;
    } if_snd;                      /* output queue */
/* procedure handles */
    int     (*if_init)();          /* init routine */
    int     (*if_output)();        /* output routine */
    int     (*if_ioctl)();         /* ioctl routine */
    int     (*if_reset)();         /* bus reset routine */
    int     (*if_watchdog)();      /* timer routine */
/* generic interface statistics */
    int     if_ipackets;           /* packets received on interface */
    int     if_ierrors;            /* input errors on interface */
    int     if_opackets;           /* packets sent on interface */
    int     if_oerrors;            /* output errors on interface */
    int     if_collisions;         /* collisions on csma interfaces */
/* end statistics */
    struct    ifnet *if_next;
    struct    ifnet *if_upper;      /* next layer up */
    struct    ifnet *if_lower;      /* next layer down */
    int  (*if_input)();             /* input routine */
    int  (*if_ctlin)();             /* control input routine */
    int  (*if_ctlout)();            /* control output routine */
#ifdef sun
    struct map *if_memmap;   /* rmap for interface specific memory */
#endif
};
```

Each interface address has the following form:

```
struct ifaddr {
    struct    sockaddr ifa_addr;     /* address of interface */
    union {
        struct   sockaddr ifu_broadaddr;
        struct   sockaddr ifu_dstaddr;
    } ifa_ifu;
```

```
    struct     ifnet  *ifa_ifp;       /* back-pointer to interface */
    struct     ifaddr *ifa_next;      /* next address for interface */
};
#define ifa_broadaddr ifa_ifu.ifu_broadaddr /*brdcast address*/
#define ifa_dstaddr ifa_ifu.ifu_dstaddr /*other end of link*/
```

The protocol generally maintains this structure as part of a larger structure containing additional information concerning the address.

Each interface has a send queue and routines used for initialization (`if_init`), input (`if_input`), and output (`if_output`). If the interface resides on a system bus, the routine `if_reset` will be called after a bus reset has been performed. An interface may also specify a timer routine, `if_watchdog`; if `if_timer` is non-zero, it is decremented once per second until it reaches zero, at which time the watchdog routine is called.

The state of an interface and certain characteristics are stored in the `if_flags` field. The following values are possible:

```
#define IFF_UP           0x1     /* interface is up */
#define IFF_BROADCAST    0x2     /* broadcast is possible */
#define IFF_DEBUG        0x4     /* turn on debugging */
#define IFF_LOOPBACK     0x8     /* is a loopback net */
#define IFF_POINTOPOINT  0x10    /* interface is point-to-point link */
#define IFF_NOTRAILERS   0x20    /*avoid use of trailers */
#define IFF_RUNNING      0x40i   /* resources allocated */
#define IFF_NOARP        0x80    /* no address resolution protocol */
#define IFF_PROMISC      0x100   /* receive all packets */
#define IFF_ALLMULTI     0x200   /* receive all multicast packets */
```

If the interface is connected to a network that supports transmission of *broadcast* packets, the `IFF_BROADCAST` flag will be set and the `ifa_broadaddr` field will contain the address to be used in sending or accepting a broadcast packet. If the interface is associated with a point-to-point hardware link (for example, Sunlink/INR), the `IFF_POINTOPOINT` flag will be set and `ifa_dstaddr` will contain the address of the host on the other side of the connection. These addresses and the local address of the interface, `if_addr`, are used in filtering incoming packets. The interface sets `IFF_RUNNING` after it has allocated system resources and posted an initial read on the device it manages. This state bit is used to avoid multiple allocation requests when an interface's address is changed. The `IFF_NOTRAILERS` flag indicates the interface should refrain from using a *trailer* encapsulation on outgoing packets, or (where per-host negotiation of trailers is possible) that trailer encapsulations should not be requested; *trailer* protocols are described in section 14. The `IFF_NOARP` flag indicates the interface should not use an "address resolution protocol" in mapping internetwork addresses to local network addresses. The `IFF_PROMISC` bit is set when the interface is in *promiscuous mode*, indicating that it should receive all incoming packets regardless of their intended destination.

Various statistics are also stored in the interface structure. These may be viewed by users using the `netstat(1)` program.

The interface address and flags may be set with the SIOCSIFADDR and SIOC-SIFFLAGS ioctls. SIOCSIFADDR is used initially to define each interface's address; SIOGSIFFLAGS can be used to mark an interface down and perform site-specific configuration. The destination address of a point-to-point link is set with SIOCSIFDSTADDR. Corresponding operations exist to read each value. Protocol families may also support operations to set and read the broadcast address. The SIOCADDMULTI and SCIODELMULTI ioctls may be used to add and remove multicast addresses from the set that the interface accepts. In addition, the SIOCGIFCONF ioctl retrieves a list of interface names and addresses for all interfaces and address families on the host.

10.3. Socket/Protocol Interface

The interface between the socket routines and the communication protocols is through the pr_usrreq() routine defined in the protocol switch table. The following requests to a protocol module are possible:

```
#define PRU_ATTACH       0   /* attach protocol */
#define PRU_DETACH       1   /* detach protocol */
#define PRU_BIND         2   /* bind socket to address */
#define PRU_LISTEN       3   /* listen for connection */
#define PRU_CONNECT      4   /* establish connection to peer */
#define PRU_ACCEPT       5   /* accept connection from peer */
#define PRU_DISCONNECT   6   /* disconnect from peer */
#define PRU_SHUTDOWN     7   /* won't send any more data */
#define PRU_RCVD         8   /* have taken data; more room now */
#define PRU_SEND         9   /* send this data */
#define PRU_ABORT        10  /* abort (fast DISCONNECT, DETATCH) */
#define PRU_CONTROL      11  /* control operations on protocol */
#define PRU_SENSE        12  /* return status into m */
#define PRU_RCVOOB       13  /* retrieve out of band data */
#define PRU_SENDOOB      14  /* send out of band data */
tdefine PRU_SOCKADDR     15  /* fetch socket's address */
#define PRU_PEERADDR     16  /* fetch peer's address */
#define PRU_CONNECT2     17  /* connect two sockets */
/* begin for protocol's internal use */
#define PRU_FASTTIMO     18  /* 200ms timeout */
#define PRU_SLOWTIMO     19  /* 500ms timeout */
#define PRU_PROTORCV     20  /* receive from below */
#define PRU_PROTOSEND    21  /* send to below */
```

A call on the user request routine is of the form,

```
error = (*protosw[].pr_usrreq)(so, req, m, addr, rights);
    int error;
    struct socket *so; int req;
    struct mbuf *m, *addr, *rights;
```

The mbuf data chain *m* is supplied for output operations and for certain other operations where it is to receive a result. The address *addr* is supplied for address-oriented requests such as PRU_BIND and PRU_CONNECT. The *rights* parameter is an optional pointer to an mbuf chain containing user-specified capabilities (see the `sendmsg()` and `recvmsg()` system calls). The protocol is responsible for disposal of the data mbuf chains on output operations. A non-zero return value gives a UNIX error number that should be passed to higher level software. The following paragraphs describe each of the requests possible.

`PRU_ATTACH`
: When a protocol is bound to a socket (with the `socket()` system call) the protocol module is called with this request. It is the responsibility of the protocol module to allocate any resources necessary. The "attach" request will always precede any of the other requests, and should not occur more than once.

`PRU_DETACH`
: This is the antithesis of the attach request, and is used at the time a socket is deleted. The protocol module may deallocate any resources assigned to the socket.

`PRU_BIND`
: When a socket is initially created it has no address bound to it. This request indicates that an address should be bound to an existing socket. The protocol module must verify that the requested address is valid and available for use.

`PRU_LISTEN`
: The "listen" request indicates the user wishes to listen for incoming connection requests on the associated socket. The protocol module should perform any state changes needed to carry out this request (if possible). A "listen" request always precedes a request to accept a connection.

`PRU_CONNECT`
: The "connect" request indicates the user wants to a establish an association. The `addr` parameter supplied describes the peer to be connected to. The effect of a connect request may vary depending on the protocol. Virtual circuit protocols, such as TCP [Postel81b], use this request to initiate establishment of a TCP connection. Datagram protocols, such as UDP [Postel80], simply record the peer's address in a private data structure and use it to tag all outgoing packets. There are no restrictions on how many times a connect request may be used after an attach. If a protocol supports the notion of *multi-casting*, it is possible to use multiple connects to establish a multi-cast group. Alternatively, an association may be broken by a `PRU_DISCONNECT` request, and a new association created with a subsequent connect request; all without destroying and creating a new socket.

`PRU_ACCEPT`
: Following a successful `PRU_LISTEN` request and the arrival of one or more connections, this request is made to indicate the user has accepted the first connection on the queue of pending connections. The protocol module should fill in the supplied address buffer with the address of the connected party.

`PRU_DISCONNECT`
: Eliminate an association created with a `PRU_CONNECT` request.

`PRU_SHUTDOWN`
: This call is used to indicate no more data will be sent and/or received (the *addr* parameter indicates the direction of the shutdown, as encoded in the `soshutdown()` system call). The protocol may, at its discretion, deallocate any data structures related to the shutdown and/or notify a connected peer of the shutdown.

`PRU_RCVD`
: This request is made only if the protocol entry in the protocol switch table includes the `PR_WANTRCVD` flag. When a user removes data from the receive queue this request will be sent to the protocol module. It may be used to trigger acknowledgements, refresh windowing information, initiate data transfer, etc.

`PRU_SEND`
: Each user request to send data is translated into one or more `PRU_SEND` requests (a protocol may indicate that a single user send request must be translated into a single `PRU_SEND` request by specifying the `PR_ATOMIC` flag in its protocol description). The data to be sent is presented to the protocol as a list of mbufs, and an address is, optionally, supplied in the *addr* parameter. The protocol is responsible for preserving the data in the socket's send queue if it is not able to send it immediately, or if it may need it at some later time (e.g. for retransmission).

`PRU_ABORT`
: This request indicates an abnormal termination of service. The protocol should delete any existing association(s).

`PRU_CONTROL`
: The "control" request is generated when a user performs a UNIX `ioctl()` system call on a socket (and the ioctl is not intercepted by the socket routines). It allows protocol-specific operations to be provided outside the scope of the common socket interface. The `addr` parameter contains a pointer to a static kernel data area where relevant information may be obtained or returned. The *m* parameter contains the actual `ioctl()` request code (note the non-standard calling convention). The *rights* parameter contains a pointer to an `ifnet` structure if the `ioctl()` operation pertains to a particular network interface.

`PRU_SENSE`
: The "sense" request is generated when the user makes an `fstat()` system call on a socket; it requests status of the associated socket. This currently returns a standard `stat()` structure. It typically contains only the optimal transfer size for the connection (based on buffer size, windowing information and maximum packet size). The *m* parameter contains a pointer to a static kernel data area where the status buffer should be placed.

`PRU_RCVOOB`
: Any "out-of-band" data presently available is to be returned. An mbuf is passed to the protocol module, and the protocol should either place data in the mbuf or attach new mbufs to the one supplied if there is insufficient space in the single mbuf. An error may be returned if out-of-band data is not

(yet) available or has already been consumed. The *addr* parameter contains any options such as `MSG_PEEK` to examine data without consuming it.

`PRU_SENDOOB`
: Like `PRU_SEND`, but for out-of-band data.

`PRU_SOCKADDR`
: The local address of the socket is returned, if any is currently bound to it. The address (with protocol specific format) is returned in the *addr* parameter.

`PRU_PEERADDR`
: The address of the peer to which the socket is connected is returned. The socket must be in a `SS_ISCONNECTED` state for this request to be made to the protocol. The address format (protocol specific) is returned in the *addr* parameter.

`PRU_CONNECT2`
: The protocol module is supplied two sockets and requested to establish a connection between the two without binding any addresses, if possible. This call is used in implementing the `socketpair(2)` system call.

The following requests are used internally by the protocol modules and are never generated by the socket routines. In certain instances, they are handed to the `pr_usrreq` routine solely for convenience in tracing a protocol's operation (e.g. `PRU_SLOWTIMO`).

`PRU_FASTTIMO`
: A "fast timeout" has occurred. This request is made when a timeout occurs in the protocol's `pr_fastimo` routine. The *addr* parameter indicates which timer expired.

`PRU_SLOWTIMO`
: A "slow timeout" has occurred. This request is made when a timeout occurs in the protocol's `pr_slowtimo()` routine. The *addr* parameter indicates which timer expired.

`PRU_PROTORCV`
: This request is used in the protocol-protocol interface, not by the routines. It requests reception of data destined for the protocol and not the user. No protocols currently use this facility.

`PRU_PROTOSEND`
: This request allows a protocol to send data destined for another protocol module, not a user. The details of how data is marked "addressed to protocol" instead of "addressed to user" are left to the protocol modules. No protocols currently use this facility.

10.4. Protocol to Protocol Interface

The interface between protocol modules is through the `pr_usrreq()`, `pr_input()`, `pr_output()`, `pr_ctlinput()`, and `pr_ctloutput()` routines. The calling conventions for all but the `pr_usrreq()` routine are expected to be specific to the protocol modules and are not guaranteed to be consistent across protocol families. We will examine the conventions used for some of the Internet protocols in this section as an example.

pr_output()

The Internet protocol UDP uses the convention,

```
error = udp_output(inp, m);
    int error;
    struct inpcb *inp;
    struct mbuf *m;
```

where the *inp*, "*in*ternet *p*rotocol *c*ontrol *b*lock", passed between modules conveys per connection state information, and the mbuf chain contains the data to be sent. UDP performs consistency checks, appends its header, calculates a checksum, etc. before passing the packet on. UDP is based on the Internet Protocol, IP [Postel81a], as its transport. UDP passes a packet to the IP module for output as follows:

```
error = ip_output(m, opt, ro, flags);
    int error;
    struct mbuf *m, *opt;
    struct route *ro; int flags;
```

The call to IP's output routine is more complicated than that for UDP, as befits the additional work the IP module must do. The *m* parameter is the data to be sent, and the *opt* parameter is an optional list of IP options which should be placed in the IP packet header. The *ro* parameter is is used in making routing decisions (and passing them back to the caller for use in subsequent calls). The final parameter, `flags`, contains flags indicating whether the user is allowed to transmit a broadcast packet and if routing is to be performed. The broadcast flag may be inconsequential if the underlying hardware does not support the notion of broadcasting.

All output routines return 0 on success and a UNIX error number if a failure occurred that could be detected immediately (no buffer space available, no route to destination, etc.).

pr_input()

Both UDP and TCP use the following calling convention,

```
(void) (*protosw[].pr_input)(m, ifp);
    struct mbuf *m;
    struct ifnet *ifp;
```

Each mbuf list passed is a single packet to be processed by the protocol module. The interface from which the packet was received is passed as the second parameter.

The IP input routine is a software interrupt level routine, and so is not called with any parameters. It instead communicates with network interfaces through a queue, `ipintrq`, which is identical in structure to the queues used by the network interfaces for storing packets awaiting transmission. The software interrupt is enabled by the network interfaces when they place input data on the input queue.

pr_ctlinput()

This routine is used to convey "control" information to a protocol module (i.e. information that might be passed to the user, but is not data).

The common calling convention for this routine is,

```
(void) (*protosw[].pr_ctlinput)(req, addr);
    int req;
    struct sockaddr *addr;
```

The *req* parameter is one of the following,

```
#define   PRC_IFDOWN             0    /* interface transition */
#define   PRC_ROUTEDEAD          1    /* select new route if possible */
#define   PRC_QUENCH             4    /* some said to slow down */
#define   PRC_MSGSIZE            5    /* message size forced drop */
#define   PRC_HOSTDEAD           6    /* normally from IMP */
#define   PRC_HOSTUNREACH        7    /* ditto */
#define   PRC_UNREACH_NET        8    /* no route to network */
#define   PRC_UNREACH_HOST       9    /* no route to host */
#define   PRC_UNREACH_PROTOCOL  10    /* dst says bad protocol */
#define   PRC_UNREACH_PORT      11    /* bad port # */
#define   PRC_UNREACH_NEEDFRAG  12    /* IP_DF caused drop */
#define   PRC_UNREACH_SRCFAIL   13    /* source route failed */
#define   PRC_REDIRECT_NET      14    /* net routing redirect */
#define   PRC_REDIRECT_HOST     15    /* host routing redirect */
#define   PRC_REDIRECT_TOSNET   16    /* redirect for type & net */
#define   PRC_REDIRECT_TOSHOST  17    /* redirect for tos & host */
#define   PRC_TIMXCEED_INTRANS  18    /* packet expired in transit */
#define   PRC_TIMXCEED_REASS    19    /* lifetime expired on reass q */
#define   PRC_PARAMPROB         20    /* header incorrect */
```

while the *addr* parameter is the address to which the condition applies. Many of the requests have obviously been derived from ICMP (the Internet Control Message Protocol [Postel81c]), and from error messages defined in the 1822 host/IMP convention [BBN78]. Mapping tables exist to convert control requests to UNIX error codes that are delivered to a user.

pr_ctloutput()

This is the routine that implements per-socket options at the protocol level for `getsockopt()` and `setsockopt()`. The calling convention is,

```
error = (*protosw[].pr_ctloutput)(op,so,level,optname,mp);
    int op;
    struct socket *so;
    int level, optname;
    struct mbuf **mp;
```

where *op* is one of `PRCO_SETOPT` or `PRCO_GETOPT`, *so* is the socket whence the call originated, and `level` and *optname* are the protocol level and option name supplied by the user. The results of a `PRCO_GETOPT` call are returned in an mbuf whose address is placed in *mp* before return. On a `PRCO_SETOPT` call, *mp* contains the address of an mbuf containing the option data; the mbuf should be freed before return.

10.5. Protocol/Network-Interface Interface

The lowest layer in the set of protocols that comprise a protocol family must interface itself to one or more network interfaces in order to transmit and receive packets. It is assumed that any routing decisions have been made before handing a packet to a network interface; in fact this is absolutely necessary in order to locate any interface at all (unless, of course, one uses a single "hardwired" interface). There are two cases with which to be concerned, transmission of a packet and receipt of a packet; each will be considered separately.

Packet Transmission

Assuming a protocol has a handle on an interface, *ifp*, a (struct ifnet *), it transmits a fully formatted packet with the following call,

```
error = (*ifp->if_output)(ifp, m, dst)
    int error;
    struct ifnet *ifp;
    struct mbuf *m;
    struct sockaddr *dst;
```

The output routine for the network interface transmits the packet *m* to the *dst* address, or returns an error indication (a UNIX error number). In reality transmission may not be immediate or successful; normally the output routine simply queues the packet on its send queue and primes an interrupt driven routine to actually transmit the packet. For unreliable media, such as the Ethernet, "successful" transmission simply means that the packet has been placed on the cable without a collision. On the other hand, an 1822 interface guarantees proper delivery or an error indication for each message transmitted. The model employed in the networking system attaches no promises of delivery to the packets handed to a network interface, and thus corresponds more closely to the Ethernet. Errors returned by the output routine are only those that can be detected immediately, and are normally trivial in nature (no buffer space, address format not handled, etc.). No indication is received if errors are detected after the call has returned.

Packet Reception

Each protocol family must have one or more "lowest level" protocols. These protocols deal with internetwork addressing and are responsible for the delivery of incoming packets to the proper protocol processing modules. In the PUP model [Boggs78] these protocols are termed Level 1 protocols, in the ISO model, network layer protocols. In this system each such protocol module has an input packet queue assigned to it. Incoming packets received by a network interface are queued for the protocol module, and a software interrupt is posted to initiate processing.

Three macros are available for queuing and dequeuing packets:

`IF_ENQUEUE(ifq, m)`
: This places the packet *m* at the tail of the queue *ifq*.

`IF_DEQUEUE(ifq, m)`
: This places a pointer to the packet at the head of queue *ifq* in *m* and removes the packet from the queue. A zero value will be returned in *m* if the queue is empty.

`IF_DEQUEUEIF(ifq, m, ifp)`
: Like `IF_DEQUEUE`, this removes the next packet from the head of a queue and returns it in *m*. A pointer to the interface on which the packet was received is placed in *ifp*, a `(struct ifnet *)`.

`IF_PREPEND(ifq, m)`
: This places the packet *m* at the head of the queue *ifq*.

Each queue has a maximum length associated with it as a simple form of congestion control. The macro `IF_QFULL(`*ifq*`)` returns 1 if the queue is filled, in which case the macro `IF_DROP(`*ifq*`)` should be used to increment the count of the number of packets dropped, and the offending packet is dropped. For example, the following code fragment is commonly found in a network interface's input routine,

```
if (IF_QFULL(inq)) {
    IF_DROP(inq);
    m_freem(m);
} else
    IF_ENQUEUE(inq, m);
```

10.6. Gateways and Routing Issues

The system has been designed with the expectation that it will be used in an internetwork environment. The "canonical" environment was envisioned to be a collection of local area networks connected at one or more points through hosts with multiple network interfaces (one on each local area network), and possibly a connection to a long haul network (for example, the ARPANET). In such an environment, issues of gatewaying and packet routing become very important. Certain of these issues, such as congestion control, have been handled in a simplistic manner or specifically not addressed. Instead, where possible, the network system attempts to provide simple mechanisms upon which more involved policies may be implemented. As some of these problems become better understood, the solutions developed will be incorporated into the system.

This section will describe the facilities provided for packet routing. The simplistic mechanisms provided for congestion control are described in the *Buffering, Congestion Control* section below.

Routing Tables

The network system maintains a set of routing tables for selecting a network interface to use in delivering a packet to its destination. These tables are of the form:

```
struct rtentry {
      u_long  rt_hash;                 /* hash key for lookups */
      struct  sockaddr rt_dst;         /* destination net or host */
      struct  sockaddr rt_gateway;     /* forwarding agent */
      short   rt_flags;                /* see below */
      short   rt_refcnt;               /* # of references to structure */
      u_long  rt_use;                  /* packets sent using route */
      struct  ifnet *rt_ifp;           /* interface to give packet to */
};
```

The routing information is organized in two separate tables, one for routes to a host and one for routes to a network. The distinction between hosts and networks is necessary so that a single mechanism may be used for both broadcast and multi-drop type networks, and also for networks built from point-to-point links.

Each table is organized as a hashed set of linked lists. Two 32-bit hash values are calculated by routines defined for each address family; one based on the destination being a host, and one assuming the target is the network portion of the address. Each hash value is used to locate a hash chain to search (by taking the value modulo the hash table size) and the entire 32-bit value is then used as a key in scanning the list of routes. Lookups are applied first to the routing table for hosts, then to the routing table for networks. If both lookups fail, a final lookup is made for a "wildcard" route (by convention, network 0). The first appropriate route discovered is used. By doing this, routes to a specific host on a network may be present as well as routes to the network. This also allows a "fall back" network route to be defined to a "smart" gateway which may then perform more intelligent routing.

Each routing table entry contains a destination (the desired final destination), a gateway to which to send the packet, and various flags which indicate the route's status and type (host or network). A count of the number of packets sent using the route is kept, along with a count of "held references" to the dynamically allocated structure to insure that memory reclamation occurs only when the route is not in use. Finally, a pointer to the a network interface is kept; packets sent using the route should be handed to this interface.

Routes are typed in two ways: either as host or network, and as "direct" or "indirect". The host/network distinction determines how to compare the `rt_dst` field during lookup. If the route is to a network, only a packet's destination network is compared to the `rt_dst` entry stored in the table. If the route is to a host, the addresses must match bit for bit.

The distinction between "direct" and "indirect" routes indicates whether the destination is directly connected to the source. This is needed when performing local network encapsulation. If a packet is destined for a peer at a host or network which is not directly connected to the source, the internetwork packet header will contain the address of the eventual destination, while the local network header will address the intervening gateway. Should the destination be directly connected, these addresses are likely to be identical, or a mapping between the two exists. The `RTF_GATEWAY` flag indicates that the route is to an "indirect" gateway agent, and that the local network header should be filled in from the rt_gateway field instead of from the final internetwork destination address.

It is assumed that multiple routes to the same destination will not be present; only one of multiple routes, that most recently installed, will be used.

Routing redirect control messages are used to dynamically modify existing routing table entries as well as dynamically create new routing table entries. On hosts where exhaustive routing information is too expensive to maintain (e.g. work stations), the combination of wildcard routing entries and routing redirect messages can be used to provide a simple routing management scheme without the use of a higher level policy process. Current connections may be rerouted after notification of the protocols by means of their pr_ctlinput() entries. Statistics are kept by the routing table routines on the use of routing redirect messages and their affect on the routing tables. These statistics may be viewed using .netstat(1)

Status information other than routing redirect control messages may be used in the future, but at present they are ignored. Likewise, more intelligent "metrics" may be used to describe routes in the future, possibly based on bandwidth and monetary costs.

Routing Table Interface

A protocol accesses the routing tables through three routines, one to allocate a route, one to free a route, and one to process a routing redirect control message. The routine rtalloc() performs route allocation; it is called with a pointer to the following structure containing the desired destination:

```
struct route {
    struct  rtentry *ro_rt;
    struct  sockaddr ro_dst;
};
```

The route returned is assumed "held" by the caller until released with an rtfree() call. Protocols which implement virtual circuits, such as TCP, hold onto routes for the duration of the circuit's lifetime, while connection-less protocols, such as UDP, allocate and free routes whenever their destination address changes.

The routine rtredirect() is called to process a routing redirect control message. It is called with a destination address, the new gateway to that destination, and the source of the redirect. Redirects are accepted only from the current router for the destination. If a non-wildcard route exists to the destination, the gateway entry in the route is modified to point at the new gateway supplied. Otherwise, a new routing table entry is inserted reflecting the information supplied. Routes to interfaces and routes to gateways which are not directly accessible from the host are ignored.

User Level Routing Policies

Routing policies implemented in user processes manipulate the kernel routing tables through two `ioctl()` calls. The commands `SIOCADDRT` and `SIOCDELRT` add and delete routing entries, respectively; the tables are read through the /dev/kmem device. The decision to place policy decisions in a user process implies that routing table updates may lag a bit behind the identification of new routes, or the failure of existing routes, but this period of instability is normally very small with proper implementation of the routing process. Advisory information, such as ICMP error messages and IMP diagnostic messages, may be read from raw sockets (described in the next section).

Several routing policy processes have already been implemented. The system standard "routing daemon" uses a variant of the Xerox NS Routing Information Protocol [Xerox82] to maintain up-to-date routing tables in our local environment. Interaction with other existing routing protocols, such as the Internet EGP (Exterior Gateway Protocol), has been accomplished using a similar process.

10.7. Raw Sockets

A raw socket is an object that allows users direct access to a lower-level protocol. Raw sockets are intended for knowledgeable processes that wish to take advantage of some protocol feature not directly accessible through the normal interface, or for the development of new protocols built atop existing lower level protocols. For example, a new version of TCP might be developed at the user level by utilizing a raw IP socket for delivery of packets. The raw IP socket interface attempts to provide an identical interface to the one a protocol would have if it were resident in the kernel.

The raw socket support is built around a generic raw socket interface, (possibly) augmented by protocol-specific processing routines. This section will describe the core of the raw socket interface.

Control Blocks

Every raw socket has a protocol control block of the following form:

```
struct rawcb {
   struct    rawcb *rcb_next;        /* doubly linked list */
   struct    rawcb *rcb_prev;
   struct    socket *rcb_socket;     /* back pointer to socket */
   struct    sockaddr rcb_faddr;     /* destination address */
   struct    sockaddr rcb_laddr;     /* socket's address */
   struct    sockproto rcb_proto;    /* protocol family, protocol */
   caddr_t   rcb_pcb;                /* protocol specific stuff */
   struct    mbuf *rcb_options;      /* protocol specific options */
   struct    route rcb_route;        /* routing information */
   int       rcb_cc;                 /*bytes of rawintr queued data*/
   int       rcb_mbcnt;              /*bytes of rawintr queued mbufs*/
   short     rcb_flags;
};
```

All the control blocks are kept on a doubly linked list for performing lookups during packet dispatch. Associations may be recorded in the control block and used by the output routine in preparing packets for transmission. The `rcb_proto` structure contains the protocol family and protocol number with which the raw socket is associated. The protocol, family, and addresses are used to filter packets on input; this will be described in more detail shortly. If any protocol-specific information is required, it may be attached to the control block using the `rcb_pcb` field. Protocol-specific options for transmission in outgoing packets may be stored in `rcb_options`. `rcb_cc` and `rcb_mbcnt` are used to keep track of the resources consumed by the raw socket.

A raw socket interface is datagram oriented. That is, each send or receive on the socket requires a destination address. This address may be supplied by the user or stored in the control block and automatically installed in the outgoing packet by the output routine. Since it is not possible to determine whether an address is present or not in the control block, two flags, `RAW_LADDR` and `RAW_FADDR`, indicate if a local and foreign address are present. Routing is expected to be performed by the underlying protocol if necessary.

Input Processing

Input packets are "assigned" to raw sockets based on a simple pattern matching scheme. Each network interface or protocol gives unassigned packets to the raw input routine with the call:

```
raw_input(m, proto, src, dst)
    struct mbuf *m;
    struct sockproto *proto;
    struct sockaddr *src, *dst;
```

The data packet then has a generic header prepended to it of the form

```
struct raw_header {
    struct sockproto raw_proto;
    struct sockaddr raw_dst;
    struct sockaddr raw_src;
};
```

and it is placed in a packet queue for the "raw input protocol" module. Packets taken from this queue are copied into any raw sockets that match the header according to the following rules,

1) The protocol family of the socket and header agree.

2) If the protocol number in the socket is non-zero, then it agrees with that found in the packet header.

3) If a local address is defined for the socket, the address format of the local address is the same as the destination address's and the two addresses agree bit for bit.

4) The rules of 3) are applied to the socket's foreign address and the packet's source address.

A basic assumption is that addresses present in the control block and packet header (as constructed by the network interface and any raw input protocol module) are in a canonical form that may be "block compared".

Output Processing

On output the raw `pr_usrreq()` routine passes the packet and a pointer to the raw control block to the raw protocol output routine for any processing required before it is delivered to the appropriate network interface. The output routine is normally the only code required to implement a raw socket interface.

10.8. Buffering, Congestion Control

One of the major factors in the performance of a protocol is the buffering policy used. Lack of a proper buffering policy can force packets to be dropped, cause falsified windowing information to be emitted by protocols, fragment host memory, degrade the overall host performance, etc. Due to problems such as these, most systems allocate a fixed pool of memory to the networking system and impose a policy optimized for "normal" network operation.

The networking system developed for UNIX is little different in this respect. At boot time a fixed amount of memory is allocated by the networking system. At later times more system memory may be requested as the need arises, but at no time is memory ever returned to the system. It is possible to garbage collect memory from the network, but difficult. In order to perform this garbage collection properly, some portion of the network will have to be "turned off" as data structures are updated. The interval over which this occurs must kept small compared to the average inter-packet arrival time, or too much traffic may be lost, impacting other hosts on the network, as well as increasing load on the interconnecting mediums. In our environment we have not experienced a need for such compaction, and thus have left the problem unresolved.

The mbuf structure was introduced in the *Memory, Addressing* section, above. In this section a brief description will be given of the allocation mechanisms, and policies used by the protocols in performing connection level buffering.

Memory Management

The basic memory allocation routines manage a private page map, the size of which determines the maximum amount of memory that may be allocated by the network. A small amount of memory is allocated at boot time to initialize the mbuf and mbuf cluster free lists. When the free lists are exhausted, more memory is requested from the system memory allocator if space remains in the map. If memory cannot be allocated, callers may block awaiting free memory, or the failure may be reflected to the caller immediately. The allocator will not block awaiting free map entries, however, as exhaustion of the resource map usually indicates that buffers have been lost due to a "leak." An array of reference counts parallels the cluster pool and is used when multiple references to a cluster are present.

64 mbufs fit into a 8Kbyte page of memory. Data can be placed into a mbuf by copying, or, better, the memory that contains that data can be treated as a temporary ("loaned") mbuf. This second alternative is far more efficient than an actual copy.

Protocol Buffering Policies

Protocols reserve fixed amounts of buffering for send and receive queues at socket creation time. These amounts define the high and low water marks used by the socket routines in deciding when to block and unblock a process. The reservation of space does not currently result in any action by the memory management routines.

Protocols that provide connection level flow control do this based on the amount of space in the associated socket queues. That is, send windows are calculated based on the amount of free space in the socket's receive queue, while receive windows are adjusted based on the amount of data awaiting transmission in the send queue. Care has been taken to avoid the "silly window syndrome" described in [Clark82] at both the sending and receiving ends.

Queue Limiting

Incoming packets from the network are always received unless memory allocation fails. However, each Level 1 protocol input queue has an upper bound on the queue's length, and any packets exceeding that bound are discarded. It is possible for a host to be overwhelmed by excessive network traffic (for instance a host acting as a gateway from a high bandwidth network to a low bandwidth network). As a "defensive" mechanism the queue limits may be adjusted to throttle network traffic load on a host. Consider a host willing to devote some percentage of its machine to handling network traffic. If the cost of handling an incoming packet can be calculated so that an acceptable "packet handling rate" can be determined, then input queue lengths may be dynamically adjusted based on a host's network load and the number of packets awaiting processing. Obviously, discarding packets is not a satisfactory solution to a problem such as this (simply dropping packets is likely to increase the load on a network); the queue lengths were incorporated mainly as a safeguard mechanism.

Packet Forwarding

When packets can not be forwarded because of memory limitations, the system attempts to generate a "source quench" message. In addition, any other problems encountered during packet forwarding are also reflected back to the sender in the form of ICMP packets. This helps hosts avoid unneeded retransmissions.

Broadcast packets are never forwarded due to possible dire consequences. In an early stage of network development, broadcast packets were forwarded and a "routing loop" resulted in network saturation and every host on the network crashing.

10.9. Out of Band Data

Out of band data is a facility peculiar to the stream socket abstraction defined. Little agreement appears to exist as to what its semantics should be. TCP defines the notion of "urgent data" as in-line, while the NBS protocols [Burruss81] and numerous others provide a fully independent logical transmission channel along which out of band data is to be sent. In addition, the amount of the data which may be sent as an out of band message varies from protocol to protocol; everything from 1 bit to 16 bytes or more.

A stream socket's notion of out of band data has been defined as the lowest reasonable common denominator (at least reasonable in our minds); clearly this is subject to debate. Out of band data is expected to be transmitted out of the normal sequencing and flow control constraints of the data stream. A minimum of 1 byte of out of band data and one outstanding out of band message are expected to be supported by the protocol supporting a stream socket. It is a protocol's prerogative to support larger-sized messages, or more than one outstanding out of band message at a time.

Out of band data is maintained by the protocol and is usually not stored in the socket's receive queue. A socket-level option, `SO_OOBINLINE`, is provided to force out-of-band data to be placed in the normal receive queue when urgent data is received; this sometimes ameliorates problems due to loss of data when multiple out-of-band segments are received before the first has been passed to the user. The `PRU_SENDOOB` and `PRU_RCVOOB` requests to the `pr_usrreq()` routine are used in sending and receiving data.

10.10. Acknowledgements

The internal structure of the system is patterned after the Xerox PUP architecture [Boggs79], while in certain places the Internet protocol family has had a great deal of influence in the design. The use of software interrupts for process invocation is based on similar facilities found in the VMS operating system. Many of the ideas related to protocol modularity, memory management, and network interfaces are based on Rob Gurwitz's TCP/IP implementation for the 4.1BSD version of the UNIX system [Gurwitz81].

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