Network Programming with Sockets

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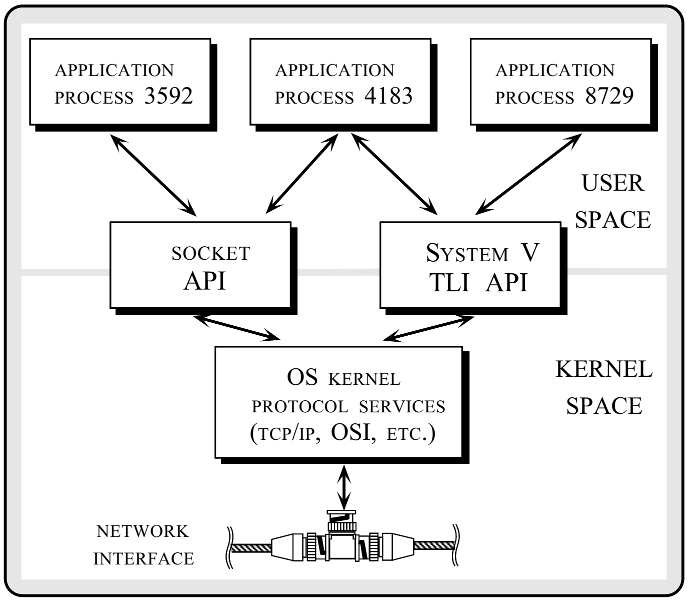
Introduction

- Sockets are a local and remote OS IPC abstraction defined in 4.2 BSD UNIX and beyond
  - Now part of most major operating systems, including Windows and Win32 systems
- Sockets were originally developed for TCP/IP protocols
  - Later generalized to include other protocol families
    - *e.g.*, Novell IPX/SPX, TP4, ATM
- Socket routine control communication between processes and protocols
  - Also provide buffering between *synchronous* application domain and the *asynchronous* kernel domain

The Socket Interface (cont'd)



- An application process using TCP/IP protocols resides in its own address space

The Socket Interface (cont'd)

- Originally, sockets were implemented as a set of system calls
  - For efficiency, they were tightly-coupled with the BSD networking architecture in the OS kernel
- Recent versions of sockets are implemented as a library of functions in user-space
  - *e.g.*, SVR4 UNIX and Win32
- User-space implementations improve flexibility and portability at the expense of some performance

Communication Domains (cont'd)

- *UNIX domain* (PF_UNIX)
  - Communicate only with a process on the same machine
    - Uses UNIX filenames for rendezvous between client and server processes
  - Really a form of intra-machine IPC, similar to SVR4 STREAM pipes
    - Supports both reliable (SOCK_STREAM) and unreliable (SOCK_DGRAM) local IPC
    - Used for local X-windows traffic...

Communication Domains (cont'd)

- *Internet domain or TCP/IP* (PF_INET)
  - Communicate across network or on same machine (uses "dotted-decimal Internet addresses")
    - *e.g.*, "128.195.1.1 @ port 21"
  - General-purpose addressing, but existing versions don't scale well due to fixed-sized addressing
    - This is fixed in IPv6
  - *e.g.*, TCP, UDP, IP, ftp, rlogin, telnet
- Xerox XNS (later evolved into Novell IPX)
  - SPP, PEX, IDP
- ISO OSI
  - *e.g.*, TP4-TP1, CLNS, CONS

Communication Domains

- Communication domains are a key structuring concept in the BSD networking architecture
  - *e.g.*, Internet domain and UNIX domain
- Domains specify:
  1. The scope over which two processes may communicate
     - *e.g.*, local only vs. local/remote
  2. How names and addresses are formed and interpreted in subsequent socket calls
     - *e.g.*, pathnames vs. IP/port numbers
- Most socket implementations provide several domains represented as "protocol families"
  - The `socket` interface is used for all these protocol family domains

Communication Domains (cont'd)

- *UNIX domain* (PF_UNIX) (cont'd)
  - 4.3 BSD and SunOS 4.1.x implement pipes via "lobotomized" connection-oriented Unix domain socket protocol implementations
  - SVR4-based UNIX systems use the STREAMS facility
    - In general, UNIX domain sockets have been subsumed by STREAM-pipes and `connld` in SVR4
  - Not surprisingly, Win32 does not support UNIX domain sockets

Stream Socket

- *Type of service*
  - Reliable (*i.e.*, sequenced, non-duplicated, non-corrupted) bi-directional delivery of byte-stream data
- *Metaphor*
  - A “network pipe”
- *e.g.*,

```
int s = socket (PF_INET, SOCK_STREAM, 0);
/* Note, s is an internal id...*/
```

- Note, we’ll use **int** as the socket type, although Win32 uses SOCKET...

Reliably-delivered Message Socket

- *Type of service*
  - Reliable datagram
- *Metaphor*
  - Sending a registered letter
- *e.g.*,

```
int s = socket (PF_NS, SOCK_RDM, 0);
```


Socket Types

- There are five Types of Sockets
  1. *Stream Socket*
  2. *Datagram Socket*
  3. *Reliably-delivered Message Socket*
  4. *Sequenced Packet Stream Socket*
  5. *Raw Sockets*
- SOCK_STREAM and SOCK_DGRAM are the most common types of sockets...

Datagram Socket

- *Type of service*
  - Unreliable, unsequenced datagram
- *Metaphor*
  - Sending a letter
- *e.g.*,

```
int s = socket (PF_INET, SOCK_DGRAM, 0);
```

Raw Sockets

- *Type of service*
  - Allows user-defined protocols that interface with IP
  - Requires *root* access
- *Metaphor*
  - Playing with an erector set. . . ;-)
- *e.g.*,

```
int s = socket (PF_INET, SOCK_RAW, 0);
```


Socket Addresses (cont'd)

- *General Format*

```
struct sockaddr { u_short sa_family; char sa_data[14]; };
```

- *UNIX Domain*

```
struct sockaddr_un {
      short sun_family; char sun_path[108];
};
```

- *Internet Domain*

```
struct in_addr { unsigned long s_addr; };
struct sockaddr_in {
      short sin_family; u_short sin_port;
      struct in_addr sin_addr; char sin_zero[8];
};
```


Sequenced Packet Stream Socket

- *Type of service*
  - Reliable, bi-directional delivery of record-oriented data
- *Metaphor*
  - Record-oriented TCP (*e.g.*, TP4 and XTP)
- *e.g.*,

```
int s = socket (PF_NS, SOCK_SEQPACKET, 0);
```


Socket Addresses

- UNIX supports multiple communication domains, protocol families, and address families
  - The socket API provides a single address interface for all these families
- The type of `sockaddr` structure used with `accept`, `bind`, `connect`, `sendto`, and `recvfrom` differs according to the domain (UNIX vs. Internet vs. XNS)
- The addressing API has a somewhat confusing and error-prone design
  - Motivation was to save space for the "common case". . .

Socket Operations

- *Local context management*

```
int socket (int domain, int type, int protocol);
int bind (int fd, struct sockaddr *, int len);
int listen (int fd, int backlog);
int close (int fd);
int getpeername (int fd, struct sockaddr *, int *len);
int getsockname (int fd, struct sockaddr *, int *len);
```

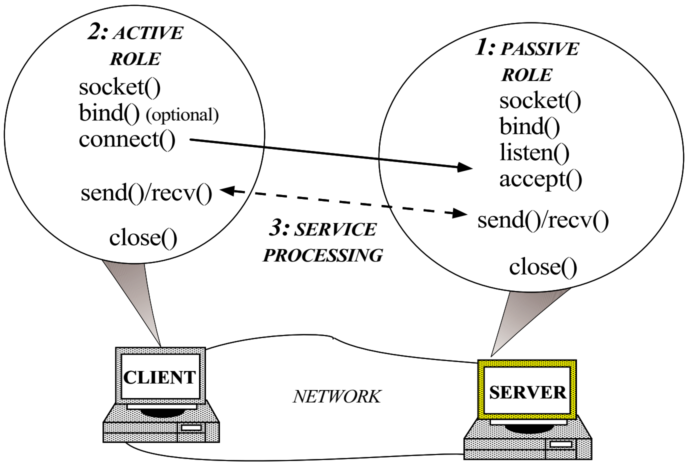
- *Connection establishment and termination*

```
int connect (int fd, struct sockaddr *, int len);
int accept (int fd, struct sockaddr *, int *len);
int shutdown (int fd, int how);
```

- *Option management*

```
int ioctl (int fd, int request, char *arg);
int fcntl (int fd, int cmd, int arg);
int getsockopt (int, int, int, char *, int *);
int setsockopt (int, int, int, char *, int);
```


Connection-oriented Socket Usage



Socket Addresses (cont'd)

- General usage for Internet-domain service:

```
struct sockaddr_in addr;

memset (&addr, 0, sizeof addr);
addr.sin_family = AF_INET;
addr.sin_port = htons (port_number);
addr.sin_addr.s_addr = htonl (INADDR_ANY);

if (bind (sd, (struct sockaddr *) &addr, sizeof addr)
      == −1)
      ...;
```

- Note the use of a cast
  - In C++, this whole mess can be cleaned-up via inheritance and dynamic binding!

Socket Operations

- *Data transfer*

```
int read (int fd, void *buf, int len);
int write (int fd, void *buf, int len);
int send (int fd, void *buf, int len, int flags);
int recv (int fd, void *buf, int len, int *flags);
int readv (int fd, struct iovec [], int len);
int writev (int fd, struct iovec [], int len);
int sendto (int fd, void *buf, int len, int flags,
          struct sockaddr *, int len);
int recvfrom (int fd, void *buf, int len, int flags,
          struct sockaddr *, int *len);
int sendmsg (int fd, struct msghdr *msg, int flags);
int recvmsg (int fd, struct msghdr *msg, int flags);
```

- *Event demultiplexing*

```
int select (int maxfdp1, fd_set *rdfds,
          fd_set *wrfds, fd_set *exfds,
          struct timeval *);
```

Client and Server Operations

- `socket`
  - Creates and opens a socket and returns a descriptor
  - **int** s = socket (**int** domain, **int** type, **int** protocol);
    - *domain* → PF_UNIX, PF_INET
    - *type of service* → SOCK_STREAM, SOCK_DGRAM
    - *protocol* → generally 0, but could be TCP, VMTP, NETBLT, XTP

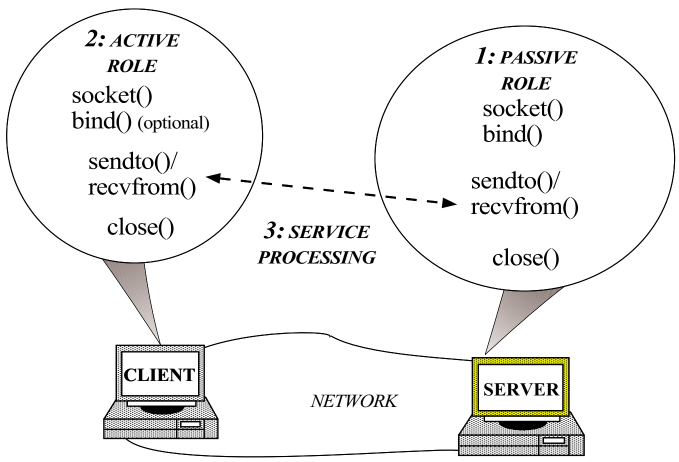
- Note, this call only fills in the first part of the 5-tuple *association*

Client and Server Operations (cont'd)

- `close`
  - Close a socket
  - **int** close (**int** s);
    - Note, there are subtle semantics related to "grace termination..." of protocols

- `shutdown`
  - Shutdown part or all of full-duplex connection
  - **int** shutdown (**int** s, **int** how);
    - *how* is 0, then further receives will be disallowed
    - *how* is 1, then further sends will be disallowed
    - *how* is 2, then further sends and receives will be disallowed
  - Note, `shutdown` does *not* close the descriptor...

Connectionless Socket Usage



Client and Server Operations (cont'd)

- `bind`
  - Associates a local address (*e.g.*, an IP address, address family, and port number) to an unnamed socket
  - **int** bind (**int** s, **struct** sockaddr *addr, **int** addrlen);
    - *addr* → local address (*e.g.*, points to an Internet addr or a UNIX domain addr)
    - *addrlen* → length of address
  - Note
    - `bind` is not necessary for clients (which implicitly allocate transient port numbers)
    - The address INADDR_ANY is a wildcard for any server host/network interface
    - Always "zero-out" the address structure before using it...

Typical Client Operations

- `connect`
  - Specify foreign/remote destination address (*e.g.*, IP/port numbers) and joins two sockets for I/O:
  - **int** connect (**int** s, **struct** sockaddr *addr, **int** addrlen);
    - *addr* → address of remote client
    - *addrlen* → length of address

Typical Server Operations

- `accept`
  - Returns a unique descriptor to the next available completed connection from the connection queue
  - **int** accept (**int** s, **struct** sockaddr *addr, **int** *addrlenptr);
    - *addr* → address of remote server
    - *addrlenptr* → ptr to length of address
    - Returns new socket descriptor specifying the full association
  - Notes:
    1. Server may decide to reject connection only after first accepting it!
    2. *addr* and *addrlenptr* may be 0...

Client and Server Operations (cont'd)

- `getsockname`
  - Returns address info describing the local socket `s`
  - **int** getsockname (**int** s, **struct** sockaddr *addr, **int** *addrlenptr);
    - *addr* → address of local binding
    - *addrlenptr* → ptr to length of address
- `getpeername`
  - Returns the current "name" for the specified connected peer socket
  - **int** getpeername (**int** s, **struct** sockaddr *addr, **int** *addrlenptr);
    - *addr* → address of remote peer
    - *addrlenptr* → ptr to length of address

Typical Server Operations

- `listen`
  - Set the length of a TCP passive open queue, places the socket into "passive-mode"
    - This tells kernel to accept connection requests for a listening socket on behalf of a client
  - **int** listen (**int** s, **int** backlog);
    - *backlog* → specifies how many connection requests can be queued
  - Note, the kernel will queue a certain number of incoming connection requests on behalf of the server
    - Otherwise, pending requests would be dropped due to finite limits on OS queue sizes...
    - These limits prevent "denial of service" attacks...

Typical Server Operations

- `select`
  - Synchronous event demultiplexer that queries the status of a set of socket descriptors under timer control:
  - **int** select (**int** maxfdp1, fd_set *readfds, fd_set *writefds, fd_set *exceptfds, **struct** timeval *timeout);
    - *maxfdp1* → max file descriptor to consider plus 1
    - *readfds* → set of descriptors to check for reading and incoming connections
    - *writefds* → set of descriptors to check for writing and outgoing connections
    - *exceptfds* → set of descriptors to check for urgent data
    - *timeout* → length of time to wait for activity on the descriptors

Data Transfer Operations

- `write`
  - Send a message to a socket:
  - **int** write (**int** s, **char** *msg, **int** len);
    - *msg* → buffer of data to send
    - *len* → length of buffer
- `send`
  - Send a message to a socket:
  - **int** send (**int** s, **char** *msg, **int** len, **int** flags);
    - *flags*

    1. MSG_OOB → send *out-of-band* data on sockets that support this operation
- Note that neither `write` nor `send` are guaranteed to write all the bytes!

Data Transfer Operations

- `read`
  - Receive a message from a socket:
  - **int** read (**int** s, **char** *buf, **int** len);
- `recv`
  - Receive a message from a socket:
  - **int** recv (**int** s, **char** *buf, **int** len, **int** flags);
    - *flags*

    1. MSG_OOB → read any *out-of-band* data present on the socket, rather than the regular *in-band* data
    2. MSG_PEEK → "Peek" at the data present on the socket; the data are returned, but not consumed, so that a subsequent receive operation will see the same data

Data Transfer Operations

- `sendto`
  - Send a datagram message from a UDP socket:
  - **int** sendto (**int** s, **char** *msg, **int** len, **int** flags, **struct** sockaddr *addr, **int** addrlen);
    - *addr* → address of remote server
    - *addrlen* → length of address
- `recvfrom`
  - Receive a datagram message from a UCP socket:
  - **int** recvfrom (**int** s, **char** *buf, **int** len, **int** flags, **struct** sockaddr *addr, **int** *addrlenptr);
    - *addr* → address of remote server
    - *addrlenptr* → ptr to length of address

Option Management

- `setsockopt`
  - Sets options on a socket
  - **int** setsockopt (**int** s, **int** level, **int** optname, **void** *optval, **int** optlen);
- `getsockopt`
  - Gets options regarding a socket
  - **int** getsockopt (**int** s, **int** level, **int** optname, **void** *optval, **int** *optlenptr);

Option Management (cont'd)

- Arguments for `setsockopt` and `getsockopt`
  - *level* → protocol level (*e.g.*, IP, TCP, socket, etc.)
    - *e.g.*, SOL_SOCKET, IPPROTO_TCP, IPPROTO_IP
  - *optname* → name of option
    - *e.g.*, SO_REUSEADDR, SO_ERROR, SO_BROADCAST SO_SNDBUF, SO_RCVBUF
  - *optval* → value of option
  - *optlen* → length of option

Auxiliary Networking Functions

- `gethostname`
  - Returns the primary name of the current host as an ASCII string

    int gethostname (**char** *name, **int** namelen);
- `gethostbyname/gethostbyaddr`

  struct hostent *gethostbyname (**char** *name);
  struct hostent *gethostbyaddr (**char** *, **int** len, **int** type);
- **struct** hostent

```
struct hostent {
      char *n_name; /* name of host */
      char **h_aliases; /* alias list */
      int h_addrtype; /* address type */
      int h_length; /* length of addr */
      char **h_addr_list; /* list of addrs */
};
#define h_addr h_addr_list[0]
```

- Note, hostnames/host numbers are stored in /etc/hosts
  - Also accessible via DNS...

Network Databases and Address Mapping

- /etc/hosts (supplanted by NIS and DNS)
  - List of Internet and local hosts accessible from local machine
  - Accessed via `gethostbyname`, `gethostbyaddr`
  - *e.g.*,

```
# Subnet 3: Machines on CS subnet
# Address Full name            Aliases
128.252.165.140 tango.cs.wustl.edu le0-tango
128.252.114.18 tango.cs.wustl.edu encip1-tango
128.252.165.145 merengue.cs.wustl.edu le0-merengue
128.252.165.142 lambada.cs.wustl.edu le0-lambada
128.252.165.10 cs.wustl.edu cs nfs.cs.wustl.edu nfs
```

Network Databases and Address Mapping

- /etc/networks
  - List of local/Internet networks
  - Accessed via `getnetbyaddr`, `getnetbyname`
  - *e.g.*,

```
# Net name       Net number       Alias
uciics-net       128.195
uciics-main      128.195.1        localnet
uciicslab        128.195.3        ucilabnet uci-labnet
uciicsrsh        128.195.4        ucirshnet uci-rshnet
```


- /etc/services
  - List of available network services
  - Accessed via `getservbyname`, `getservbyport`
  - *e.g.*,

```
# Service name  Port/Protocol   Alias
ftp-data        20/tcp
ftp             21/tcp
telnet          23/tcp
tftp            69/udp
http            80/tcp
talk            517/udp
uucp            540/tcp         uucpd
chforw          701/tcp         chforwd
exec            512/tcp         execserver
login           513/tcp         loginserver
```

- /etc/protocols
  - information about preconfigured protocols
  - *e.g.*,

```
# Internet (ip) protocols
# name  Number  Alias   # Comment
ip      0       ip      # internet protocol, pseudo protocol number
icmp    1       icmp    # internet control message protocol
ggp     3       ggp     # gateway-gateway protocol
tcp     6       tcp     # transmission control protocol
pup     12      pup     # parc universal packet protocol
udp     17      udp     # user datagram protocol
```


Unix Domain Stream Sockets

- Both of the following Unix domain and Internet domain examples use the following library routine:

```
int process_msg (int ifd, int ofd) {
    for (char msg[BUFSIZ];;) {
        ssize_t len = read (ifd, msg, sizeof msg);
        if (len > 0) {
            if (send_n (ofd, msg, len) != len)
                return −1;
        } else return len;
    }
    return 0;
}
```

- `send_n` is a handy utility routine

```
ssize_t send_n (int handle, const void *buf, size_t len) {
    size_t bytes_written;
    ssize_t n;

    for (bytes_written = 0;
        bytes_written < len;
        bytes_written += n)
        if ((n = write (handle, buf + bytes_written,
            len − bytes_written)) == −1)
            return −1;
    return bytes_written;
}
```


Unix Domain Stream Sockets

- UNIX-domain socket reader header

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <signal.h>
#include <sys/un.h>
#include <string.h>

#define SOCK_NAME "/tmp/foo"
#define STDOUT 1
#define STDIN 0

int process_msg (int ifd, int ofd);
```

Unix Domain Stream Sockets (cont'd)

- Become a passive-mode "server"

```
int s_server (const char sock_name[]) {
      struct sockaddr_un name;
      name.sun_family = AF_UNIX;
      strncpy (name.sun_path, sock_name, sizeof name.sun_pa

      int s_fd = socket (PF_UNIX, SOCK_STREAM, 0);
      if (s_fd == −1)
            return −1;
      else if (bind (s_fd, (struct sockaddr *) &name,
                  sizeof name.sun_family +
                  strlen (name.sun_path)) == −1)
            return −1;
      else if (listen (s_fd, 5) == −1)
            return −1;
      return s_fd;
}
```


Unix Domain Stream Sockets (cont'd)

- Become an active-mode "client"

```
int s_client (const char sock_name[]) {
      struct sockaddr_un name;
      name.sun_family = AF_UNIX;
      strcpy (name.sun_path, sock_name);

      int s_fd = socket (PF_UNIX, SOCK_STREAM, 0);

      if (s_fd == −1)
            return −1;
      else if (connect (s_fd,
                  (struct sockaddr *) &name,
                  sizeof name.sun_family
                  + strlen (name.sun_path)) == −1)
            return −1;
      return s_fd;
}
```


Unix Domain Stream Sockets (cont'd)

- UNIX-domain server

```
#include "header.h"
void clean_up (void) { unlink (SOCK_NAME), exit (1); }

int main (int argc, char *argv[]) {
      signal (SIGINT, clean_up);

      int s_fd = s_server (SOCK_NAME);

      if (s_fd == −1)
            perror ("s_server"), clean_up ();
      for (;;) {
            int cli_fd = accept (s_fd, 0, 0);
            if (cli_fd == −1)
                  perror ("accept");
            else if (process_msg (cli_fd, STDOUT) == −1)
                  perror ("process_msg");
            else if (close (cli_fd) == −1)
                  perror ("close");
      }
      /* NOTREACHED */
}
```


Unix Domain Stream Sockets (cont'd)

- UNIX-domain socket sender

```
#include "header.h"

int main (int argc, char *argv[]) {
      int s_fd = s_client (SOCK_NAME);
      int status = 1;

      if (s_fd == −1)
            perror ("s_client");
      else if (process_msg (STDIN, s_fd) == −1)
            perror ("process_msg");
      else
            status = 0;
      close (s_fd);
      return status;
}
```

Internet Domain Stream Sockets (cont'd)

- read a message with TCP (server)

```
#include "header.h"
int main (int argc, char *argv[]) {
      int s_fd = s_server (SRV_PORT);

      if (s_fd == -1)
            perror ("s_server");
      for (;;) {
            int cli_fd = accept (s_fd, 0, 0);

            if (cli_fd == -1)
                  perror ("accept");
            else if (process_msg (cli_fd, STDOUT) == -1)
                  perror ("process_msg");
            else if (close (cli_fd) == -1)
                  perror ("close");
      }
      /* NOTREACHED */
}
```


Internet Domain Stream Sockets (cont'd)

- Write a message (client)

```
#include "header.h"
int main (int argc, char *argv[]) {
      int status = 1;
      int s_fd = s_client (SRV_PORT, SRV_ADDR);

      if (s_fd == -1)
            perror ("s_client");
      else if (process_msg (STDIN, s_fd) == -1)
            perror ("process_msg");
      else
            status = 0;
      close (s_fd);
      return status;
}
```


Internet Domain Stream Sockets

- Header file

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <string.h>
#include <netinet/in.h>
#include <netdb.h>

#define SRV_PORT 7734
#define SRV_ADDR "128.195.13.4"
#define STDOUT 1
#define STDIN 0

int process_msg (int ifd, int ofd);
```


Internet Domain Stream Sockets (cont'd)

- Become a passive-mode "server"

```
int s_server (unsigned short port) {
      struct sockaddr_in name;

      memset ((void *), &name, 0, sizeof name);
      name.sin_family = AF_INET;
      name.sin_port = htons (port);
      name.sin_addr.s_addr = htonl (INADDR_ANY);

      int s_fd = socket (PF_INET, SOCK_STREAM, 0);

      if (s_fd == -1)
            return -1;
      else if (bind (s_fd, &name, sizeof name) == -1)
            return -1;
      else if (listen (s_fd, 5) == -1)
            return -1;
      return s_fd;
}
```

Internet Domain Stream Sockets (cont'd)

- Become an active-mode "client"

```
int s_client (u_short port, const char *addr) {
      struct sockaddr_in name;

      memset ((void *) &name, 0, sizeof name);
      name.sin_family = AF_INET;
      name.sin_port = htons (port);
      name.sin_addr.s_addr = inet_addr (addr);

      int s_fd = socket (PF_INET, SOCK_STREAM, 0);

      if (s_fd == −1)
            return −1;
      else if (connect (s_fd, (struct sockaddr *) &name,
                        sizeof name) == −1)
            return −1;
      return s_fd;
}
```


Concurrent Server using Select

- Single-threaded concurrent socket server

```
int main (void)
{
  // Create a server end-point.
  int s_fd = s_server (PORT_NUM);
  fd_set temp_fds;
  fd_set read_fds;
  int maxfdp1 = s_fd + 1;

  // Check for constructor failure.
  if (s_fd == -1)
    perror ("server"), exit (1);

  FD_ZERO (&temp_fds);
  FD_ZERO (&read_fds);
  FD_SET (s_fd, &read_fds);
```



```
  // Loop forever performing logging server processing.
  for (;;) {
    temp_fds = read_fds; // Structure assignment.

    // Wait for client I/O events (handle interrupts).
    while (select (maxfdp1, &temp_fds, 0, 0, 0) == -1
           && errno == EINTR)
      continue;

    // Handle pending logging records first (s_fd + 1
    // is guaranteed to be lowest client descriptor).
    for (int fd = s_fd + 1; fd < maxfdp1; fd++)
      if (FD_ISSET (fd, &temp_fds)) {
        int n = handle_logging_record (fd);
        // Guaranteed not to block in this case!
        if (n == -1)
          perror ("logging failed");
        else if (n == 0) {
          // Handle client connection shutdown.
          FD_CLR (fd, &read_fds);
          close (fd);
          if (fd + 1 == maxfdp1) {
            // Skip past unused descriptors.
            while (!FD_ISSET (--fd, &read_fds))
              continue;
            maxfdp1 = fd + 1;
          }
        }
      }
```



```
    // Check for incoming connections.
    if (FD_ISSET (s_fd, &temp_fds)) {
      static struct timeval poll_tv = {0, 0};

      // Handle all pending connection requests
      // (note use of "polling" feature).
      while (select (s_fd + 1, &temp_fds,
                     0, 0, &poll_tv) > 0) {
        int cli_fd = accept (s_fd, 0, 0);

        if (cli_fd == -1) perror ("accept");
        else {
          FD_SET (cli_fd, &read_fds);
          if (cli_fd >= maxfdp1)
            maxfdp1 = cli_fd + 1;
        }
      }
    }
  }
}
```

Internet Domain Datagram Sockets (cont'd)

- Main driver program

```
#define SERVICE "daytime"
int do_service (int, u_short, const char *);

int main (int argc, char *argv[]) {
    int s = socket (PF_INET, SOCK_DGRAM, 0);
    if (s == -1)
        perror ("argv[0]"), exit (1);

    struct servent *sp =
        getservbyname (SERVICE, "udp");
    if (sp == 0)
        fprintf (stderr, "%s/udp: unknown service.\n",
        SERVICE), exit (1);

    for (++argv ;--argc; ++argv)
        if (do_service (s, sp->s_port, *argv) == -1)
            perror (*argv);

    close (s);
    return 0;
}
```


Internet Domain Datagram Sockets (cont'd)

- Performed "timed receives" for datagrams

```
int timed_recv (struct timeval *tv, int fd,
        char buf[], int buf_size,
        struct sockaddr *sin, int *slen) {
    fd_set read_fd;
    FD_ZERO (&read_fd);
    FD_SET (fd, &read_fd);

    switch (select (fd + 1, &read_fd, 0, 0, tv)) {
        case 0: errno = ETIMEDOUT; /* FALLTHRU */
        case -1: return -1;
        default:
        return recvfrom (fd, buf, buf_size,
                0, &sin, &slen);
    }
}
```


Internet Domain Datagram Sockets

- Uses UDP to return the current time of day from a specified list of Internet hosts
- *e.g.*,

```
% hostdate tango mambo lambada merengue
tango: timeout at host

mambo: Tue Aug 20 15:55:59 1996

lambada: Tue Aug 20 15:55:59 1996

merengue: Tue Aug 20 15:56:00 1996
```

- Note the use of `select` to prevent hanging from hosts that are "down" or non-existent

Internet Domain Datagram Sockets (cont'd)

- *e.g.*,

```
int do_service (int sfd, u_short port, const char *host) {
    struct hostent *hp = gethostbyname (host);
    if (hp == 0) return -1;
    struct sockaddr_in sin;
    sin.sin_family = AF_INET;
    sin.sin_port = port;
    memset (&sin.sin_addr, hp->h_addr, hp->h_length);
    printf ("%s: ", host); fflush (stdout);
    char buf[BUFSIZ];

    if (sendto (sfd, "", 0, /* Note zero size! */
        0, &sin, sizeof sin) < 0)
        return -1;

    struct timeval tv = {5, 0};
    int len = sizeof sin;
    ssize_t n = timed_recv (&tv, sfd, buf, sizeof buf,
            &sin, &len);
    if (n == -1) return n;
    printf ("%*s\n", n, buf);
    return 0;
}
```

Advanced Socket Operations

- *Non-blocking connections*
- *Checking for invalid sockets*
- *Checking for terminated peers*

Non-blocking Connections

- `connect` may be used in non-blocking mode
- A combination of `select`, `getpeername`, and `getsockopt` may be used to determine when the connection setup is complete
- This is useful to avoid long timeouts if client may not be accessible

Example of Non-Blocking Connect

- This is easier in C++...

```
int nblock_connect (int sfd, struct sockaddr *sin, int sinl
{
  struct timeval timeout = {1, 0};
  set_fl (sfd, O_NONBLOCK);

  if (connect (sfd, sin, sinlen) == -1) {
    if (errno == EINPROGRESS) {
      fd_set write_fds;
      FD_ZERO (&write_fds);
      FD_SET (sfd, &write_fds);
      if (select (sfd + 1, 0, write_fds, 0, timeout) == 1) {
        if (FD_ISSET (sfd, &write_fds)) {
          if (getpeername (sfd, &sin, &sinlen) < 0)
            return -1; /* Connection failed */
        }
      } else
        /* select() timed out, do something else here ... */
    } else return -1; /* connect failed unexpectedly */
  return sfd; /* Success, we're connected! */
}
```


Creating a Non-blocking Socket

- Enable I/O descriptor flags
  - *e.g.*, O_NONBLOCK

```
int set_fl (int flags)
{
  int val = fcntl (fd, F_GETFL, 0);
  if (val == -1)
    return -1;

  val |= flags; /* turn on flags */

  if (fcntl (fd, F_SETFL, val) == -1)
    return -1;
  return 0;
}
```

Checking for Terminated Peers

- A question that often arises is "how do I get the first write after the other end has terminated to generate SIGPIPE"

- The answer is "you can not"

- If you want to know as soon as the process at the other end of a connection terminates, use `select()`, testing for readability, then the `read` will return 0

Checking for Invalid Sockets

- It is often useful to have the client test if a previously established socket is still active before trying to write to it
  - This avoids catching SIGPIPE and such...

- To do this, first try to `read` from the socket
  - If the client has closed the connection the `read` should return EOF

- To keep from hanging in `read`, first put the socket descriptor in non-blocking mode
  - Conversely, use `select` to find out whether `read` will block...