Sockets

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Internet Connections (1)

- **Connection**
  
  - Clients and servers communicate by sending streams of bytes over connections:
    - Point-to-point, full-duplex, and reliable.
  
  - A **socket** is an endpoint of a connection
    - Socket address is an <IP address : port> pair
  
  - A **port** is a 16-bit integer that identifies a process
    - Ephemeral port: assigned automatically on client when client makes a connection request
    - Well-known port: associated with some service provided by a server (e.g. port 80 is associated with web servers.)
  
  - A connection is uniquely identified by the socket addresses of its endpoints (**socket pair**)
    - <client IP:client port, server IP:server port>
Internet Connections (2)

Client socket address
128.2.194.242:51213

Server socket address
208.216.181.15:80

Client host address
128.2.194.242

Server host address
208.216.181.15

Note: 51213 is an ephemeral port allocated by the kernel

Note: 80 is a well-known port associated with Web servers
Most network application is based on the client-server model:

- A server process and one or more client processes
  - Clients and servers are processes running on hosts (can be the same or different hosts)
- Server manages some resource
- Server provides service by manipulating resource for clients
Clients

- Examples of client programs
  - Web browsers, ftp, telnet, ssh

- How does a client find the server?
  - The IP address in the server socket address identifies the host.
  - The (well-known) port in the server socket address identifies the service, and thus implicitly identifies the server process that performs that service.
  - Examples of well-known ports (cf. /etc/services)
    - Port 21: ftp
    - Port 23: telnet
    - Port 25: mail
    - Port 80: web
Using Ports

Client host

Service request for 128.2.194.242:80 (i.e., the Web server)

Client

Server host 128.2.194.242

Kernel

Web server (port 80)

Echo server (port 7)

Client

Service request for 128.2.194.242:7 (i.e., the echo server)

Client

Kernel

Web server (port 80)

Echo server (port 7)
Servers

- Servers are long-running processes (daemons)
  - Created at boot-time (typically) by the init process (process 1)
  - Run continuously until the machine is turned off.

- Each server waits for requests to arrive on a well-known port associated with a particular service
  - Port 21: ftp server
  - Port 23: telnet server
  - Port 25: mail server
  - Port 80: HTTP server

- A machine that runs a server process is also often referred to as a “server”
**Sockets (1)**

- **Sockets interface**
  - Introduced in BSD4.1 UNIX, 1981.
  - Provides a user-level interface to the network.
  - Explicitly created, used, released by applications.
  - Based on client/server paradigm
  - Two types of transport service
    - Unreliable datagram
    - Reliable, connection-oriented byte stream
  - Underlying basis for all Internet applications
Sockets (2)

What is a socket?

- A host-local, application-created/owned, OS-controlled interface to network (a "door")
  - To the kernel, a socket is an endpoint of communication.
  - To an application, a socket is a file descriptor.
    » Applications read/write from/to the network using the file descriptor.
    » Remember: All Unix I/O devices, including networks, are modeled as files.

- Clients and servers communicate with each by reading from and writing to socket descriptors.
  - The main distinction between regular file I/O and socket I/O is how the application "opens" the socket descriptors.
Sockets (3)

- Hardware/Software organization of an Internet application

![Diagram of Internet application organization](image)

- Sockets interface (system calls)
- Hardware interface (interrupts)

Global IP Internet

User code

Kernel code

Hardware and firmware
Sockets (4)

Connection-oriented service

- `socket()`
- `bind()`
- `listen()`
- `accept()`
- `read()`
- `write()`

Connectionless service

- `socket()`
- `bind()`
- `recvfrom()`
- `sendto()`
- `recvfrom()`
- `sendto()`

Connection-oriented service:

Client
- `socket()`
- `connect()`
- `write()`
- `read()`

Server
- `socket()`
- `bind()`
- `listen()`
- `accept()`
- `read()`

Connectionless service:

Client
- `socket()`
- `bind()`
- `sendto()`

Server
- `socket()`
- `bind()`
- `recvfrom()`
- `sendto()`
Socket Address Structure

- **Generic socket address**
  - For address arguments to `connect()`, `bind()`, and `accept()`

  ```c
  struct sockaddr {
    unsigned short  sa_family;    /* protocol family */
    char            sa_data[14];  /* address data. */
  };
  ```

- **Internet-specific socket address**
  - Must cast `(sockaddr_in *)` to `(sockaddr *)` for `connect()`, `bind()`, and `accept()`

  ```c
  struct sockaddr_in  {
    unsigned short  sin_family;  /* address family (always AF_INET) */
    unsigned short  sin_port;    /* port num in network byte order */
    struct in_addr  sin_addr;    /* IP addr in network byte order */
    unsigned char   sin_zero[8]; /* pad to sizeof(struct sockaddr) */
  };
  ```
socket()

- **int socket (int family, int type, int protocol)**
  - **socket**() creates a socket descriptor.
  - **family** specifies the protocol family.
    - **AF_UNIX**: Local Unix domain protocols
    - **AF_INET**: IPv4 Internet protocols
  - **type** specifies the communication semantics.
    - **SOCK_STREAM**: provides sequenced, reliable, two-way, connection-based byte streams
    - **SOCK_DGRAM**: supports datagrams (connectionless, unreliable messages of a fixed maximum length)
    - **SOCK_RAW**: provides raw network protocol access
  - **protocol** specifies a particular protocol to be used with the socket.
**connect()**

- **int connect (int sockfd, const struct sockaddr *servaddr, socklen_t addrlen)**

  - Used by a TCP client to establish a connection with a TCP server.
  - **servaddr** contains <IP address, port number> of the server.
  - The client does not have to call **bind()** before calling **connect()**.
    - The kernel will choose both an ephemeral port and the source IP address if necessary.
  - Client process suspends (blocks) until the connection is created.
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
#include <stdio.h>
#include <stdlib.h>
#include <strings.h>

#define MAXLINE 80

int main (int argc, char *argv[]) {
    int n, cfd;
    struct hostent *h;
    struct sockaddr_in saddr;
    char buf[MAXLINE];
    char *host = argv[1];
    int port = atoi(argv[2]);

    if ((cfd = socket(AF_INET, SOCK_STREAM, 0)) < 0) {
        printf(“socket() failed.\n”);
        exit(1);
    }
if ((h = gethostbyname(host)) == NULL) {
    printf(“invalid hostname %s\n”, host);
    exit(2);
}
bzero((char *)&saddr, sizeof(saddr));
saddr.sin_family = AF_INET;
bcopy((char *)h->h_addr, (char *)&saddr.sin_addr.s_addr, h->h_length);
saddr.sin_port = htons(port);

if (connect(cfd,(struct sockaddr *)&saddr,sizeof(saddr)) < 0) {
    printf(“connect() failed.\n”);
    exit(3);
}
while ((n = read(0, buf, MAXLINE)) > 0) {
    write(cfd, buf, n);
    n = read(cfd, buf, MAXLINE);
    write(1, buf, n);
}
close(cfd);
bind() is a system call that allows a socket to be bound to a specific address and port. The syntax for bind() is:

```c
int bind(int sockfd, struct sockaddr *myaddr, socklen_t addrlen);
```

- `bind()` gives the socket `sockfd` the local address `myaddr`.
- `myaddr` is `addrlen` bytes long.
- Servers bind their well-known port when they start.
- If a TCP server binds a specific IP address to its socket, this restricts the socket to receive incoming client connections destined only to that IP address.
- Normally, a TCP client lets the kernel choose an ephemeral port and a client IP address.
listen()

- **int listen (int sockfd, int backlog)**
  
  - `listen()` converts an unconnected socket into a passive socket, indicating that the kernel should accept incoming connection requests.
    - When a socket is created, it is assumed to be an active socket, that is, a client socket that will issue a `connect()`.
  
  - **backlog** specifies the maximum number of connections that the kernel should queue for this socket.
  
  - Historically, a backlog of 5 was used, as that was the maximum value supported by 4.2BSD.
    - Busy HTTP servers must specify a much larger backlog, and newer kernels must support larger values.
**accept() (1)**

- **int accept (int sockfd, struct sockaddr *cliaddr, socklen_t *addrlen)**
  - `accept()` blocks waiting for a connection request.
  - `accept()` returns a connected descriptor with the same properties as the listening descriptor.
    - The kernel creates one connected socket for each client connection that is accepted.
    - Returns when the connection between client and server is created and ready for I/O transfers.
    - All I/O with the client will be done via the connected socket.
  - The `cliaddr` and `addrlen` arguments are used to return the address of the connected peer process (the client)
accept() (2)

1. Server blocks in `accept`, waiting for connection request on listening descriptor `listenfd`.

2. Client makes connection request by calling and blocking in `connect`.

3. Server returns `connfd` from `accept`. Client returns from `connect`. Connection is now established between `clientfd` and `connfd`.
accept() (3)

- **Listening descriptor**
  - End point for client connection requests
  - Created once and exists for lifetime of the server

- **Connected descriptor**
  - End point of the connection between client and server
  - A new descriptor is created each time the server accepts a connection request from a client.
  - Exists only as long as it takes to service client.

- **Why the distinction?**
  - Allows for concurrent servers that can communicate over many client connections simultaneously.
Echo Server (1)

#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
#include <stdio.h>
#include <stdlib.h>
#include <strings.h>
#include <arpa/inet.h>

#define MAXLINE 80

int main (int argc, char *argv[]) {
    int n, listenfd, connfd, caddrlen;
    struct hostent *h;
    struct sockaddr_in saddr, caddr;
    char buf[MAXLINE];
    int port = atoi(argv[1]);

    if ((listenfd = socket(AF_INET, SOCK_STREAM, 0)) < 0) {
        printf("socket() failed.\n");
        exit(1);
    }
bzero((char *)&saddr, sizeof(saddr));
saddr.sin_family = AF_INET;
saddr.sin_addr.s_addr = htonl(INADDR_ANY);
saddr.sin_port = htons(port);
if (bind(listenfd, (struct sockaddr *)&saddr,
        sizeof(saddr)) < 0) {
    printf("bind() failed.\n");
    exit(2);
}
if (listen(listenfd, 5) < 0) {
    printf("listen() failed.\n");
    exit(3);
}
while (1) {
    caddrlen = sizeof(caddr);
    if ((connfd = accept(listenfd, (struct sockaddr *)&caddr,
                         &caddrlen)) < 0) {
        printf ("accept() failed.\n");
        continue;
    }
Echo Server (3)

\[
\text{h = gethostbyaddr((const char *)&caddr.sin_addr.s_addr,}
\text{ sizeof(caddr.sin_addr.s_addr), AF_INET);} \\
\text{printf(“server connected to %s (%s)\n”,}
\text{ h->h_name,}
\text{ inet_ntoa(*(struct in_addr *)&caddr.sin_addr));}
\]

// echo
while ((n = read(connfd, buf, MAXLINE)) > 0) {
    printf(“got %d bytes from client.\n”, n);
    write(connfd, buf, n);
}

printf(“connection terminated.\n”);
close(connfd);
Echo Server (4)

Client

socket

connect

write

read

close

Server

socket

bind

listen

accept

read

write

read

close

Connection request

Await connection request from next client