Socket Programming

Kameswari Chebrolu

Reference: Beej's Guide to Network Programming

Quote

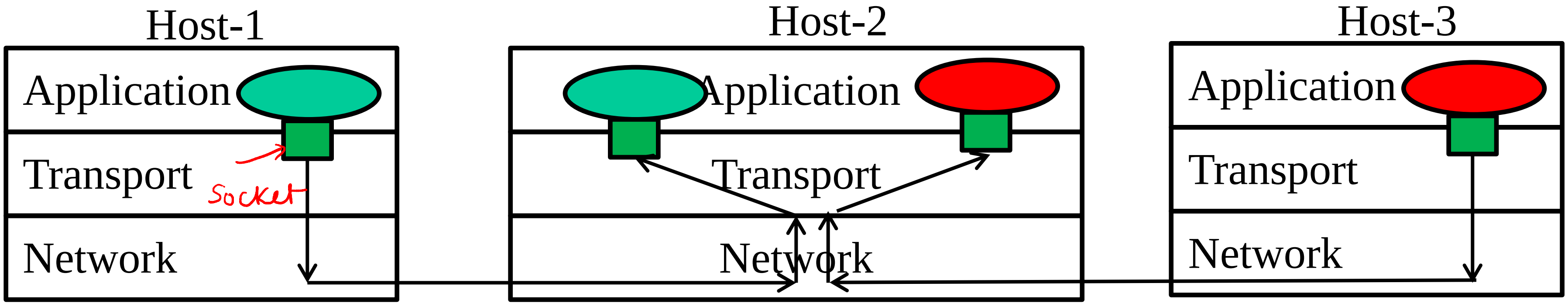
I hear and I forget

I see and I remember

I do and I understand

-- Chinese Proverb

Multiplexing/Demultiplexing



Demultiplexing: Deliver segments to the right socket

Multiplexing: Assemble segments such that they get delivered to right socket

src & Dest
IP

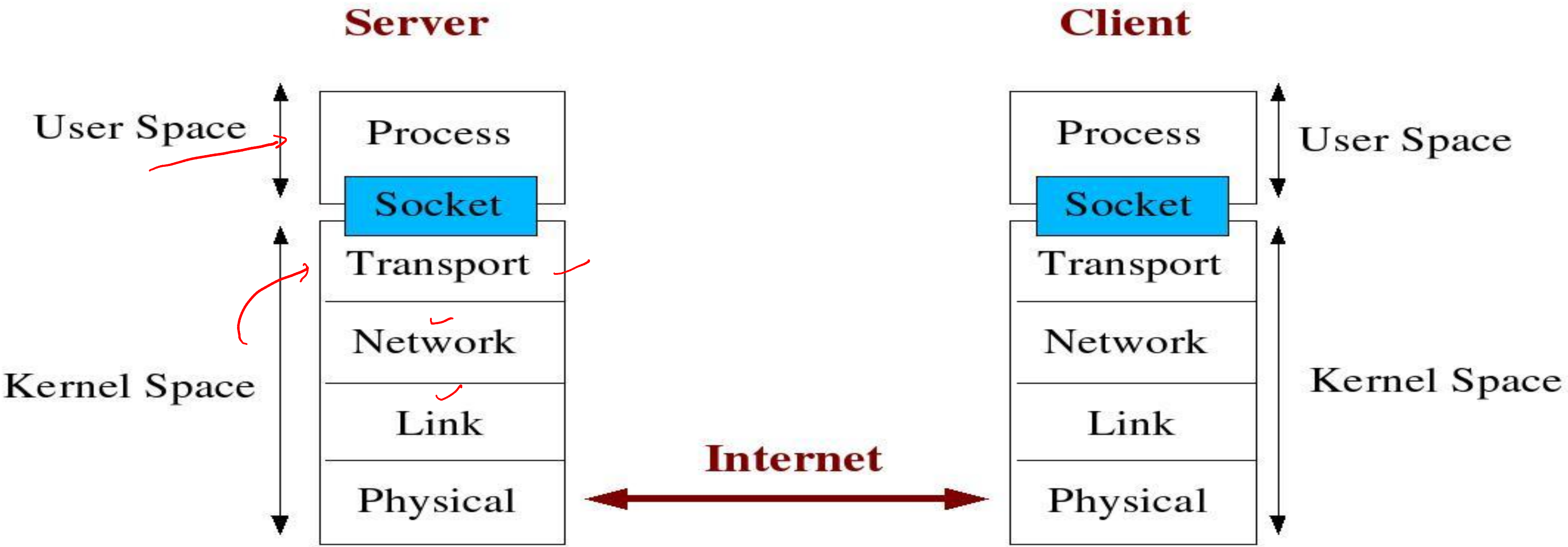
Source Port	**Destination Port**
Other fields in header	
Application Data	

Transport Layer Segment

What is a socket?

- Socket: An interface between an application process and transport layer
  - The application process can send/receive messages to/from another application process (local or remote) via a socket
- In Unix jargon, a socket is a file descriptor – an integer associated with an open file
- Types of Sockets: **Internet Sockets**, unix sockets, X.25 sockets etc
  - Internet sockets characterized by IP Address (4 bytes), port number (2 bytes)

Socket Description



Types of Internet Sockets

- Stream Sockets (SOCK_STREAM)
  - Connection oriented
  - Rely on TCP to provide reliable two-way connected communication
- Datagram Sockets (SOCK_DGRAM)
  - Rely on UDP
  - Connection is unreliable

Byte Ordering

- Two types of "Byte ordering"
  - Big-Endian (Network Byte Order): High-order byte of the number is stored in memory at the lowest address
  - Little-Endian: Low-order byte of the number is stored in memory at the lowest address
    - Some hosts use this ordering
  - Network stack (TCP/IP) expects Network Byte Order

Byte Ordering

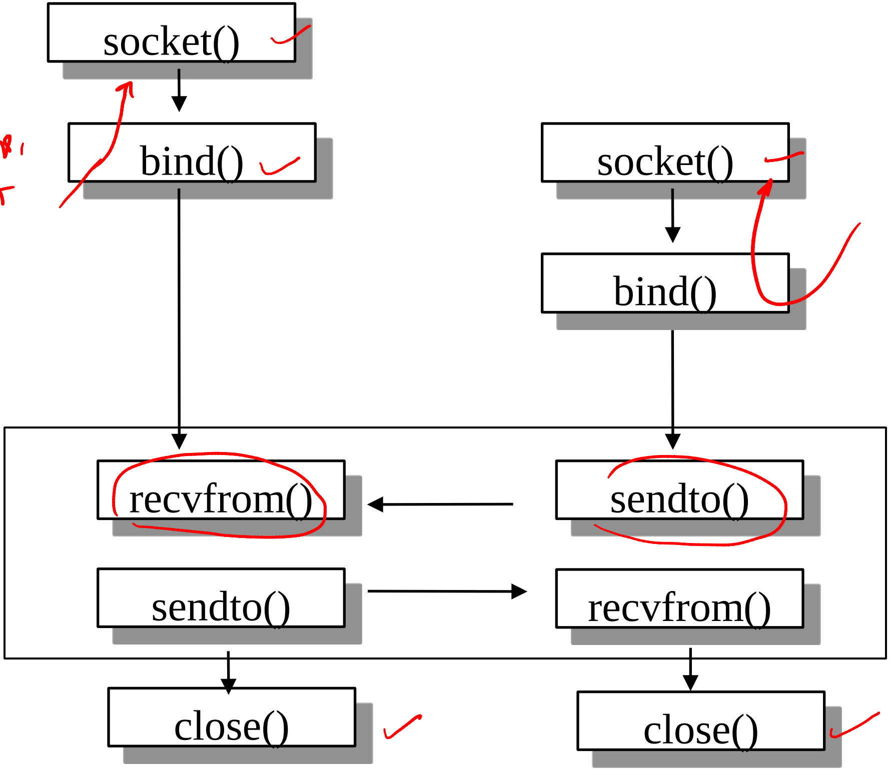
- Conversions:
  - htons() - Host to Network Short
  - htonl() - Host to Network Long
  - ntohs() - Network to Host Short
  - ntohl() - Network to Host Long

Connectionless Protocol

UDP

Server **Client**

IPaddress,
port



socket()

bind()

recvfrom()

sendto()

close()

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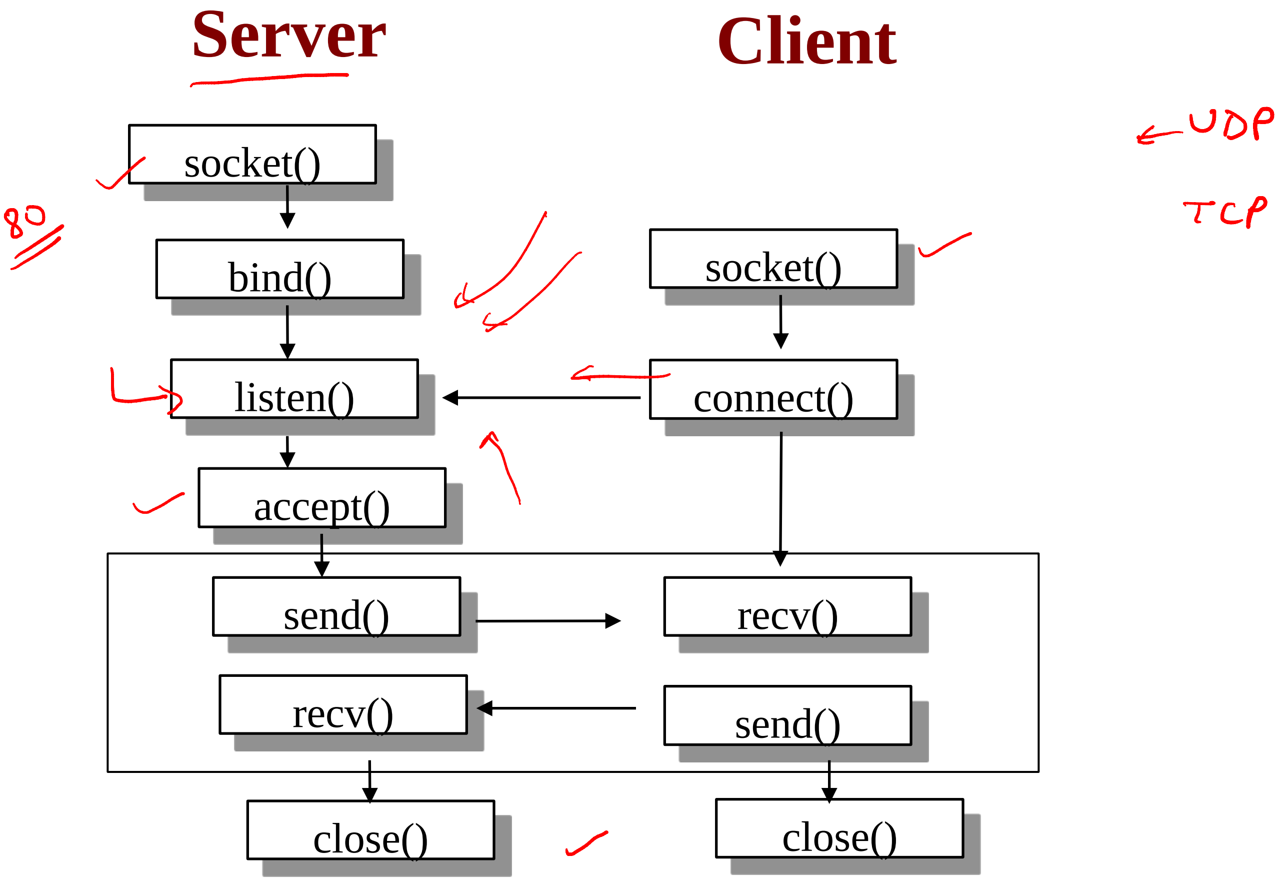
Connection Oriented Protocol



socket() -- Get the file descriptor

- int socket(int domain, int type, int protocol);
  - domain should be set to PF_INET
  - type can be SOCK_STREAM or SOCK_DGRAM

    ↳ TCP ↳ UDP
  - set protocol to 0 to have socket choose the correct protocol based on type
  - socket() returns a socket descriptor for use in later system calls or -1 on error

```
int sockfd;
sockfd = socket (PF_INET, SOCK_STREAM, 0);
```

bind() - what port am I on?

- Used to associate a socket with a port on the local machine
  - The port number is used by the kernel to match an incoming packet to a process
- int bind(int sockfd, struct sockaddr *my_addr, int addrlen)
  - sockfd is the socket descriptor returned by socket()
  - my_addr is pointer to struct sockaddr that contains information about your IP address and port
  - addrlen is set to sizeof(struct sockaddr)
  - returns -1 on error

bind() - failure

- All ports below 1024 are reserved
- You can use ports above 1024 upto 65535 provided there are not already in use
- Re-running a server may result in bind failure
  - Why? Socket still around in kernel using the port
  - Solution: Wait a minute or two or use function setsockopt() to clear the socket

Socket Structures

- struct sockaddr: Holds socket address information for many types of sockets

```
struct sockaddr {
                                                              INET
      ✓unsigned short  sa_family;     //address family AF_xxx
      ✓unsigned short  sa_data[14]; //14 bytes of protocol addr
                                 ↑
}
```

Socket Structures

- struct sockaddr_in: A parallel structure that makes it easy to reference elements of the socket address

host byte order

```
struct sockaddr_in {
        short int              sin_family;      // set to AF_INET
✓       unsigned short int     sin_port;  - 2   // Port number
        struct in_addr         sin_addr; → 4    // Internet address
        unsigned char          sin_zero[8];     //set to all zeros
}
```

- sin_port and sin_addr must be in **network byte order**

Populating the structure

```
struct in_addr {
    unsigned long s_addr; // that's 32-bit long, or 4 bytes
};
```

- int inet_aton(const char *cp, struct in_addr *inp);

#define MYPORT 80

```
struct sockaddr_in   my_addr;
my_addr.sin_family = AF_INET;
my_addr.sin_port = htons(MYPORT);
inet_aton("10.0.0.5",&(my_addr.sin_addr));
memset(&(my_addr.sin_zero),'\0',8);
```

  - inet_aton() gives non-zero on success; zero on failure

- To convert binary IP to string: inet_noa()

  printf(“%s”, inet_ntoa(my_addr.sin_addr));

- my_addr.sin_port = 0; //choose an unused port at random

- my_addr.sin_addr.s_addr = INADDR_ANY; //use my IP adr

Example

```
int sockfd;
struct sockaddr_in my_addr;
sockfd = socket(PF_INET, SOCK_STREAM, 0);
my_addr.sin_family = AF_INET;         // host byte order
my_addr.sin_port = htons(MYPORT);     // short, network byte order
my_addr.sin_addr.s_addr = inet_addr("10.0.0.1");
memset(&(my_addr.sin_zero), '\0', 8); // zero the rest of the struct
bind(sockfd, (struct sockaddr *)&my_addr, sizeof(struct sockaddr));
/******  Code needs error checking. Don't forget to do that ****** /
```

sendto() and recvfrom() - DGRAM style

→ UDP SOCK_DGRAM

- int sendto(int sockfd, const void *msg, int len, int flags, const struct sockaddr *to, int tolen);

600 bytes

  - sockfd: socket descriptor you want to send data to
  - msg is pointer to the data you want to send
  - *to* is a pointer to a struct sockaddr which contains the destination IP and port
  - *tolen* is sizeof(struct sockaddr)
  - Set flags to zero
  - Function returns the number of bytes actually sent or -1 on error

500 bytes → 100
400 bytes

sendto() and recvfrom() - DGRAM style

dst.

- int recvfrom(int sockfd, void *buf, int len, int flags, struct sockaddr *from, int *fromlen);

  source

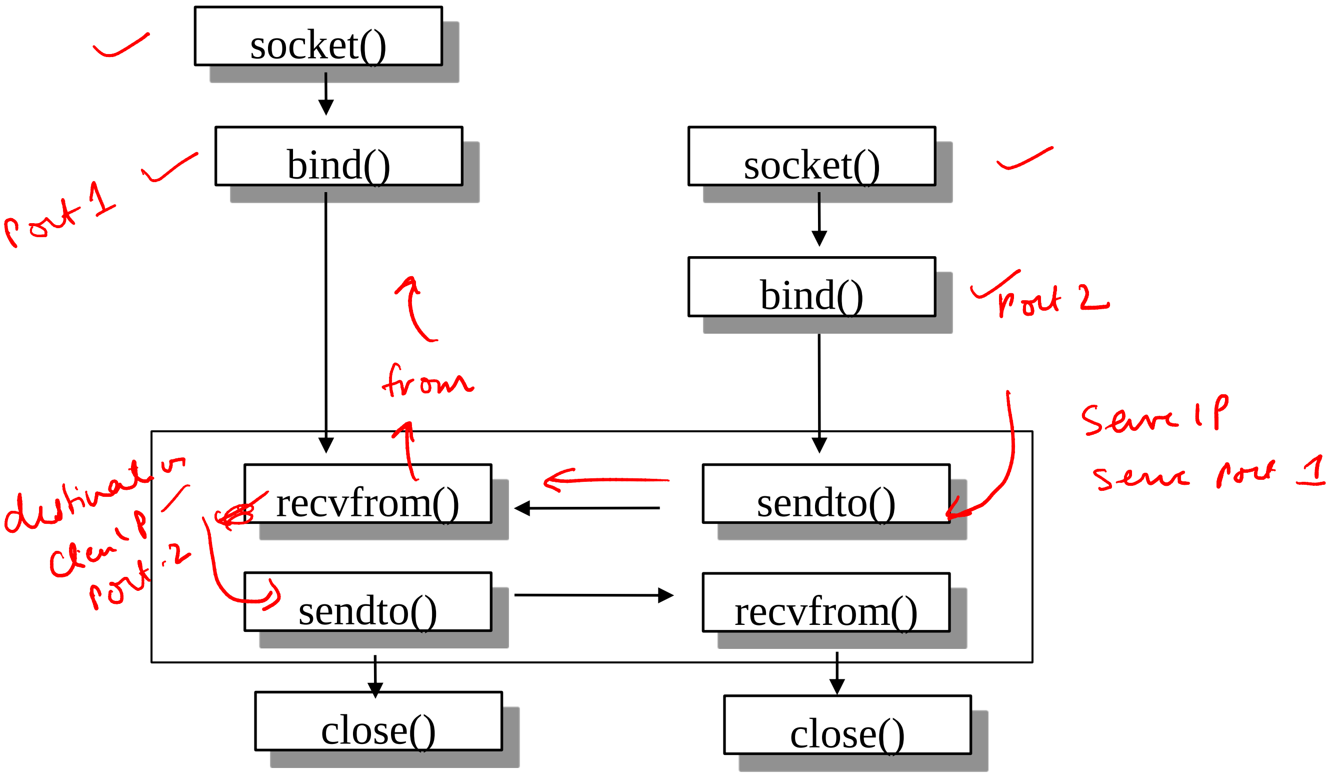
  - *sockfd: socket descriptor to read from*
  - *buf*: buffer to read the information from
  - *len:* maximum length of the buffer
  - *flags* set to zero
  - *from* is a pointer to a local struct sockaddr that will be filled with IP address and port of the originating machine
  - *fromlen* will contain length of address stored in *from*
  - *Returns the number of bytes received or -1 on error*

close() - Bye Bye!

- int close(int sockfd);
  - Closes connection corresponding to the socket descriptor and frees the socket descriptor
  - Will prevent any more sends and recieves

Connectionless Protocol

Server **Client**



socket()

bind()

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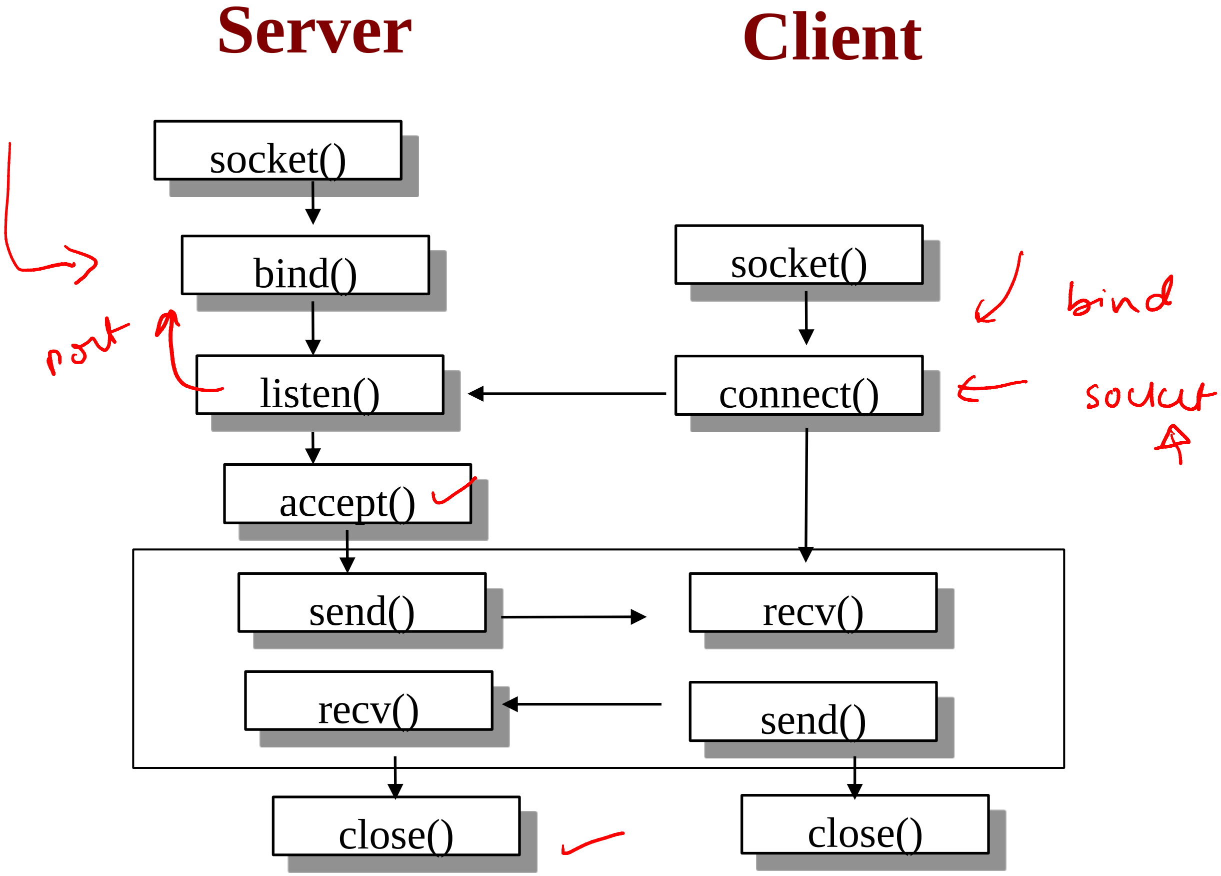
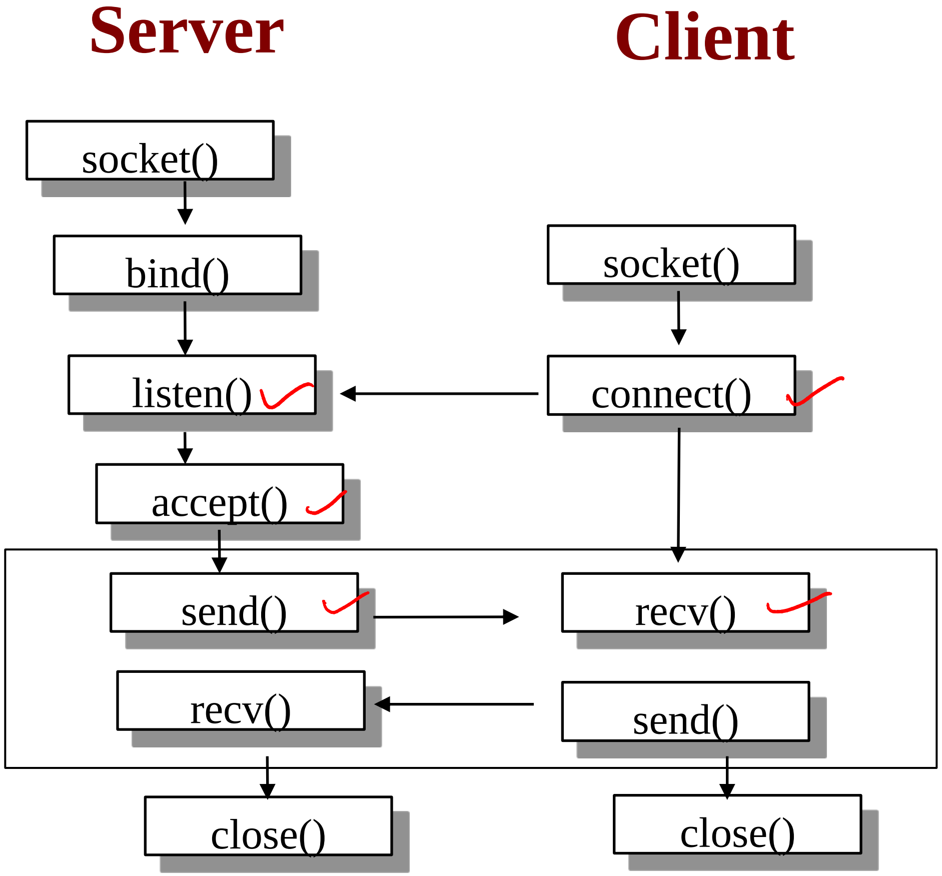
Connection Oriented Protocol



Break

Connection Oriented Protocol



connect() - Hello!

4 tuple
↳ socket

src   srcIP
random

- Connects to a remote host
- int connect(int sockfd, struct sockaddr *serv_addr, int addrlen)
  - sockfd is the socket descriptor returned by socket()
  - serv_addr is pointer to struct sockaddr that contains information on destination IP address and port
  - addrlen is set to sizeof(struct sockaddr)
  - returns -1 on error
- No need to bind(), kernel will choose a port

Example

client

random src port

```
#define DEST_IP   "10.2.44.57"
#define DEST_PORT 5000
main(){
   int sockfd;
   struct sockaddr_in dest_addr;   // will hold the destination addr
```

→ TCP

```
   sockfd = socket(PF_INET, SOCK_STREAM, 0);
    dest_addr.sin_family = AF_INET;          // host byte order
    dest_addr.sin_port = htons(DEST_PORT);   // network byte order
    dest_addr.sin_addr.s_addr = inet_addr(DEST_IP);
    memset(&(dest_addr.sin_zero), '\0', 8);  // zero the rest of the struct
    connect(sockfd, (struct sockaddr *)&dest_addr, sizeof(struct sockaddr));
  /******** Don't forget error checking *********/
```

listen() - Call me please!

- Waits for incoming connections
- int listen(int sockfd, int backlog);
  - sockfd is the socket file descriptor returned by socket()
  - backlog is the number of connections allowed on the incoming queue
  - listen() returns -1 on error
  - Need to call bind() before you can listen()

accept() - Thank you for calling !

- accept() gets the pending connection on the port you are listen()ing on
- int accept(int sockfd, void *addr, int *addrlen);

  A

  - sockfd is the listening socket descriptor
  - information about incoming connection is stored in addr which is a pointer to a local struct sockaddr_in
  - addrlen is set to sizeof(struct sockaddr_in)
  - accept returns *a new socket file descriptor* to use for this accepted connection and -1 on error

    ↳ Send/recv data

Example

server side

```
#include <string.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#define MYPORT 3490    // the port users will be connecting to
#define BACKLOG 10     // pending connections queue will hold
main(){
    int sockfd, new_fd;  // listen on sock_fd, new connection on new_fd
    struct sockaddr_in my_addr;    // my address information
    struct sockaddr_in their_addr; // connector's address information
    int sin_size;
   sockfd = socket(PF_INET, SOCK_STREAM, 0);
```

✓ TCP

```
my_addr.sin_family = AF_INET;         // host byte order
my_addr.sin_port = htons(MYPORT);     // short, network byte order
my_addr.sin_addr.s_addr = INADDR_ANY; // auto-fill with my IP
memset(&(my_addr.sin_zero), '\0', 8); // zero the rest of the struct
// don't forget your error checking for these calls:
bind(sockfd, (struct sockaddr *)&my_addr, sizeof(struct sockaddr));
listen(sockfd, BACKLOG);
sin_size = sizeof(struct sockaddr_in);
new_fd = accept(sockfd, (struct sockaddr *)&their_addr, &sin_size);
```

↳ client info

send() and recv() - Let's talk!

- The two functions are for communicating over stream sockets or connected datagram sockets.

bind, listin, accept

- int send(int sockfd, const void *msg, int len, int flags);
  - sockfd is the socket descriptor you want to send data to (got from accept())
  - msg is a pointer to the data you want to send
  - len is the length of that data in bytes
  - set flags to 0 for now
  - sen~~t~~d() returns the number of bytes actually sent (may be less than the number you told it to send) or -1 on error

Example

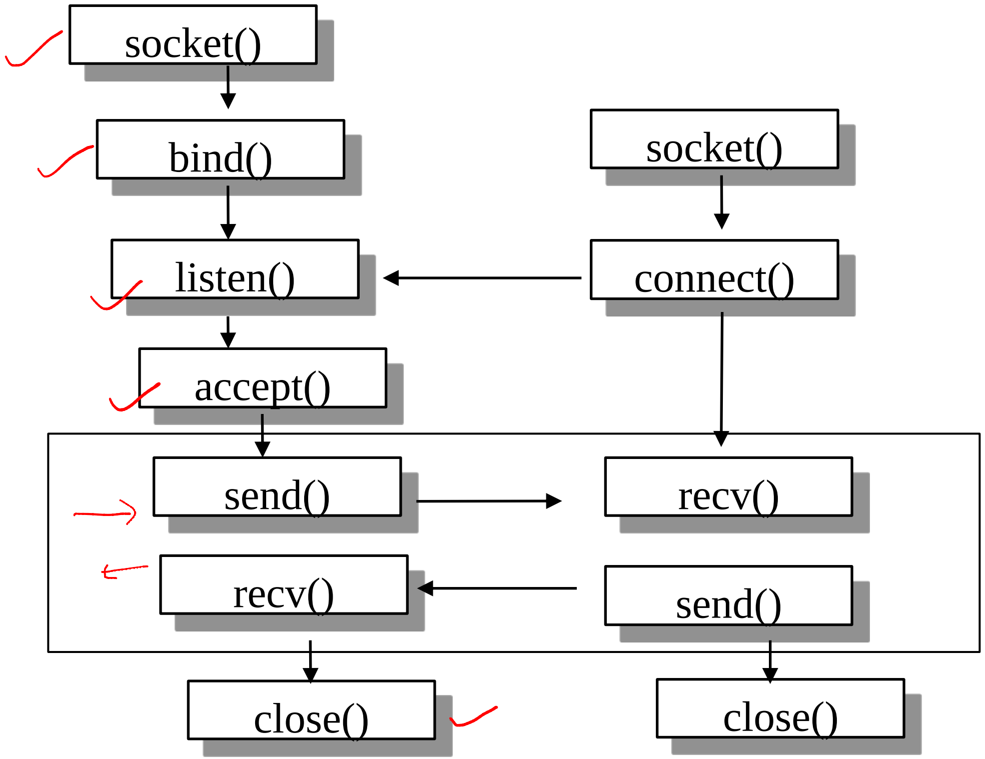
```
char *msg = “hello!”;
int len, bytes_sent;
……….
len = strlen(msg);
bytes_sent = send(sockfd, msg, len 0);
```

send() and recv() - Let's talk!

- int recv(int sockfd, void *buf, int len, int flags);
  - sockfd is the socket descriptor to read from
  - buf is the buffer to read the information into
  - len is the maximum length of the buffer
  - set flags to 0 for now
  - recv() returns the number of bytes actually read into the buffer or -1 on error
  - If recv() returns 0, the remote side has closed connection on you

Connection Oriented Protocol

Server **Client**



socket()

bind()

listen()

accept()

send()

recv()

close()

socket()

connect()

recv()

send()

close()

80 port

single client

Break

Miscellaneous Routines

- int getpeername(int sockfd, struct sockaddr *addr, int *addrlen);

  other end point

  - Will tell who is at the other end of a connected stream socket and store that info in *addr*
- int gethostname(char *hostname, size_t size);
  - Will get the name of the computer your program is running on and store that info in hostname

Miscellaneous Routines

- Provides DNS service: struct hostent *gethostbyname(const char *name);

```
struct hostent {
        char   *h_name;             //official name of host
        char   **h_aliases;         //alternate names for the host
        int           h_addrtype;        //usually AF_NET
        int           h_length;          //length of the address in bytes
        char   **h_addr_list; //array of network addresses for the host
}
#define h_addr h_addr_list[0]
```

- Example Usage:

```
struct hostent *h;
h = gethostbyname("www.iitb.ac.in");
printf("Host name : %s \n", h->h_name);
printf("IP Address: %s\n",inet_ntoa(*((struct in_addr *)h->h_addr)));
```

Input/Output Multiplexing

client 1 ✓
client 2 ✓

- Some routines like accept(), recv() block
- Make sockets non-blocking

```
sockfd = socket(PF_INET, SOCK_STREAM, 0);
fcntl(sockfd, F_SETFL, O_NONBLOCK);
```

  - Polling (consumes CPU time)
- Fork a separate process for each I/O channel ✓
- Threading ✓
- Select system call (HIGHLY RECOMMENDED)

listen( )
accept( )
recv( )

Select()

→ list of file desc

list → listen, client 1, client 2

sockfd

- int select(int numfds, fd_set *readfds, fd_set *writefds, fd_set *exceptfds, struct timeval *timeout);
  - numfds: highest file descriptor + 1
  - Readfds, writefds, exceptfds: set of file descriptors to monitor for read, write and exception operations
  - When select() returns, the set of file descriptors is modified to reflect the one that is currently ready
  - Timeout: select returns after this period if it still hasn't found any ready file descriptors

```
struct timeval {
int tv_sec; // seconds
int tv_usec; // microseconds
};
```

Useful Macros

- FD_ZERO(fd_set *set)
  - clears a file descriptor set
- FD_SET(int fd, fd_set *set)
  - adds fd to the set
- FD_CLR(int fd, fd_set *set)
  - removes fd from the set
- FD_ISSET(int fd, fd_set *set)
  - tests to see if fd is in the set

Example

```
#define STDIN 0 // file descriptor for standard input
int main(void) {
struct timeval tv;
fd_set readfds;
tv.tv_sec = 2;
tv.tv_usec = 500000;
FD_ZERO(&readfds);
FD_SET(STDIN, &readfds);
// don’t care about writefds and exceptfds:
select(STDIN+1, &readfds, NULL, NULL, &tv);
```

Example Cont....

```
if (FD_ISSET(STDIN, &readfds))
printf("A key was pressed!\n");
else
printf("Timed out.\n");
return 0;
}
```

Summary

- Sockets help application process to communicate with each other using standard Unix file descriptors
- Two types of Internet sockets: SOCK_STREAM → TCP and SOCK_DGRAM → UDP
- Many routines exist to help ease the process of communication

References

- Books:
  - Unix Network Programming, volumes 1-2 by W. Richard Stevens.
  - TCP/IP Illustrated, volumes 1-3 by W. Richard Stevens and Gary R. Wright
- Web Resources:
  - Beej's Guide to Network Programming

  (These slides followed 2001 version, there is a 2012 version that includes IPv6)