Introduction to Unix Network Programming

Reference: Stevens Unix Network Programming

Network Programming

- Key Components:
  - Internet protocols
    - IP, TCP, UDP, etc
  - Sockets
    - API - application programming interface
- Why focus on the Internet?
  - Internet Protocol (IP)
    - IP is standard
    - allows a common namespace across most of Internet
    - reduces number of translations, which incur overhead
  - Sockets
    - reasonably simple and elegant, Unix interface

Network Programming with Sockets

- Socket
  - Host-local, application-created, OS-controlled Application process can both send and receive messages to/from another application process
- Sockets API
  - A transport layer service interface
    - Introduced in 1981 by BSD 4.1
    - Implemented as library and/or system calls
    - Similar interfaces to TCP and UDP
    - Also interface to IP (for super-user); “raw sockets”

Beej's Guide

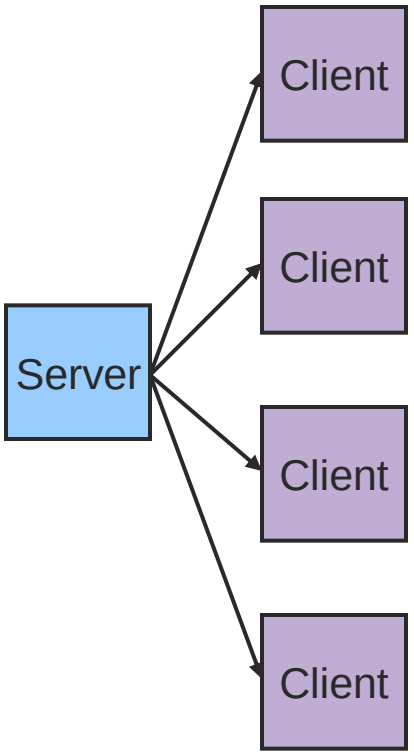
- How-to guide on network programming using Internet sockets, or "sockets programming"

  http://beej.us/guide/bgnet/

Outline

- Client-Sever Model
- TCP Connection
- UDP Services
- Addresses and Data
- Sockets API
- Example

Client-Server Model



- Asymmetric Communication
  - Client sends requests
  - Server sends replies
- Server/Daemon
  - Well-known name
  - Waits for contact
  - Processes requests, sends replies
- Client
  - Initiates contact
  - Waits for response

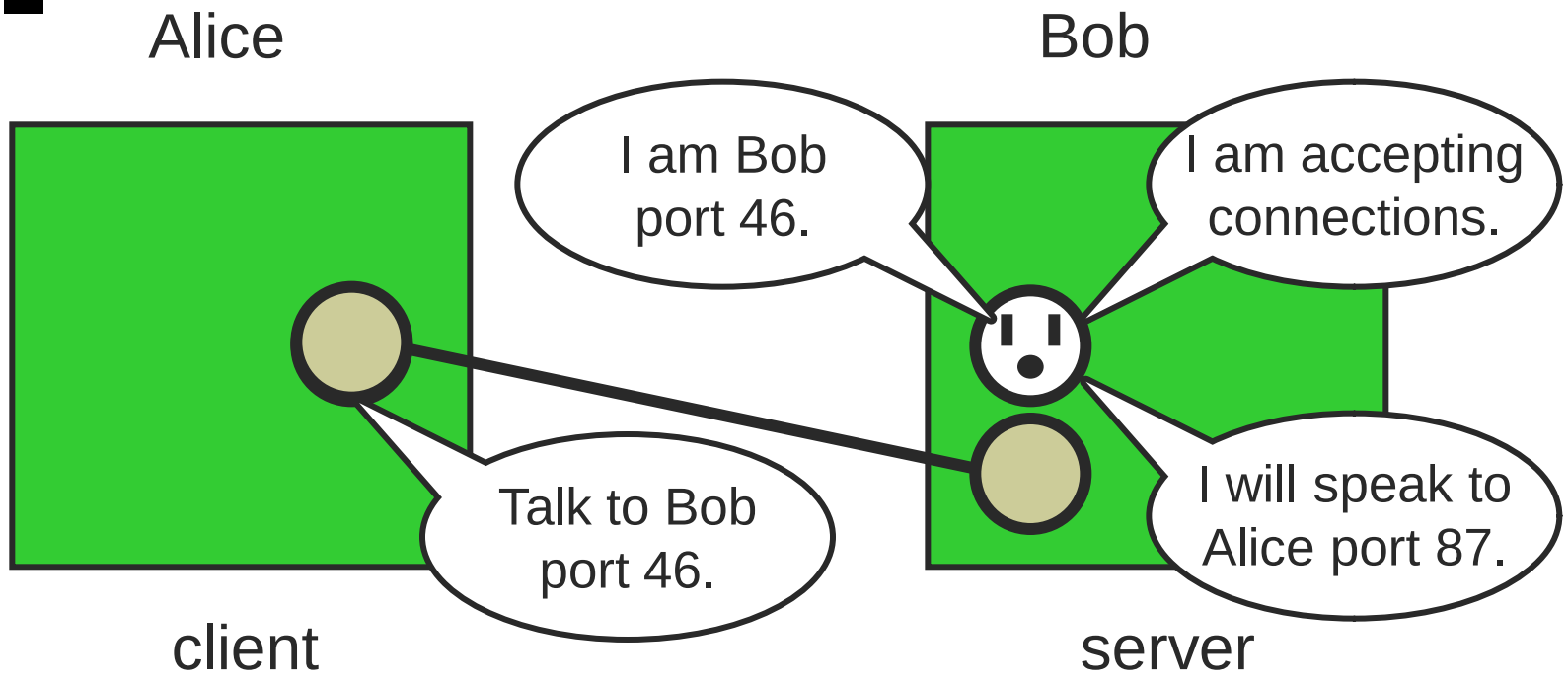
Client-Server Model

- Client contacts server
  - Server process must first be running
  - Server must have created socket that accepts client's contact

- Client: To initiate contact
  - Create client-local TCP socket
  - Specify IP address, port number of server process
  - When client creates socket: client TCP establishes connection to server TCP

- Server: When contacted by client
  - Create new socket for server process to communicate with client
  - Allows server to talk with multiple clients
  - Source port numbers used to distinguish clients

Example Client-Server Setup



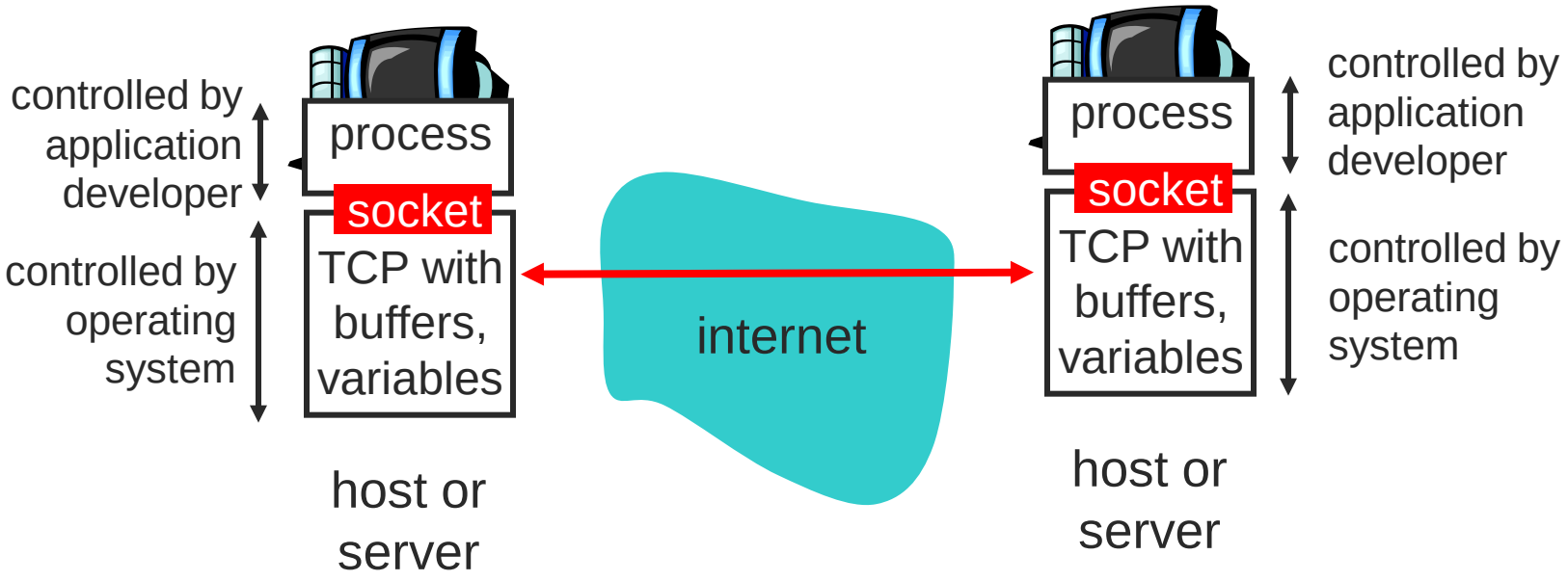
resulting TCP connection identified by (Alice:87, Bob:46)

Client-Server Model

- Service Model
  - Concurrent
    - Server processes multiple clients' requests simultaneously
  - Sequential
    - Server processes only one client's requests at a time
  - Hybrid
    - Server maintains multiple connections, but processes responses sequentially
- Client and server categories are not disjoint
  - A server can be a client of another server
  - A server can be a client of its own client
- Examples
  - Web
  - FTP
  - Telnet

TCP Connections

- Transmission Control Protocol (TCP) Service
  - OSI Transport Layer



TCP Connections

- Transmission Control Protocol (TCP) Service
  - OSI Transport Layer
  - Service Model
    - Byte stream (interpreted by application)
    - 16-bit port space allows multiple connections on a single host
    - Connection-oriented
      - Set up connection before communicating
      - Tear down connection when done

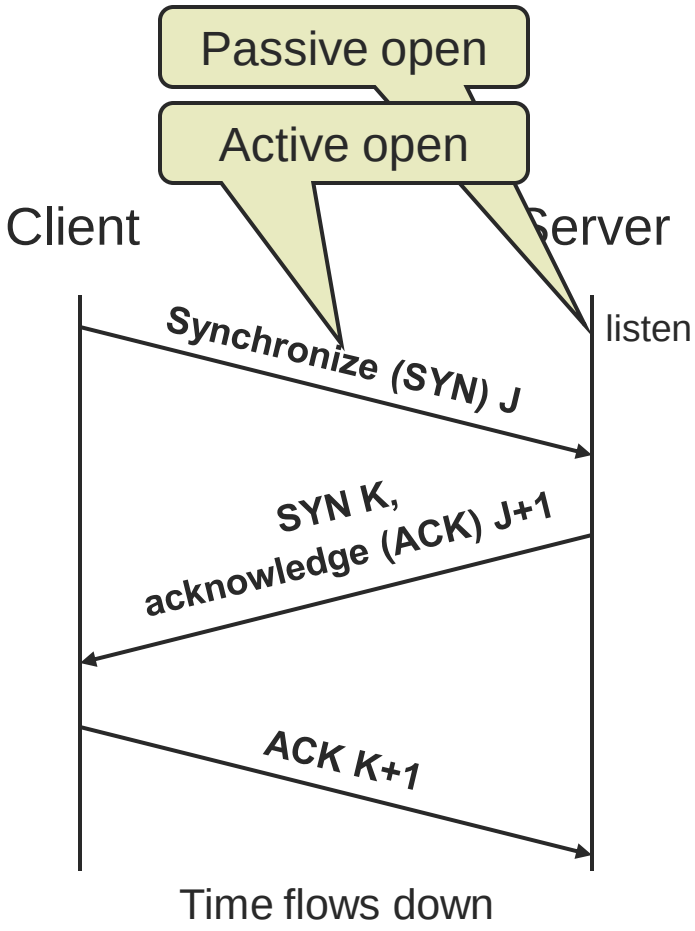
TCP Service

- Reliable Data Transfer
  - Guaranteed delivery
  - Exactly once if no catastrophic failures
- Sequenced Data Transfer
  - In-order delivery
- Regulated Data Flow
  - Monitors network and adjusts transmission appropriately
- Data Transmission
  - Full-Duplex byte stream

- Telephone Call
  - Guaranteed delivery
  - In-order delivery
  - Connection-oriented
  - Setup connection followed by conversation

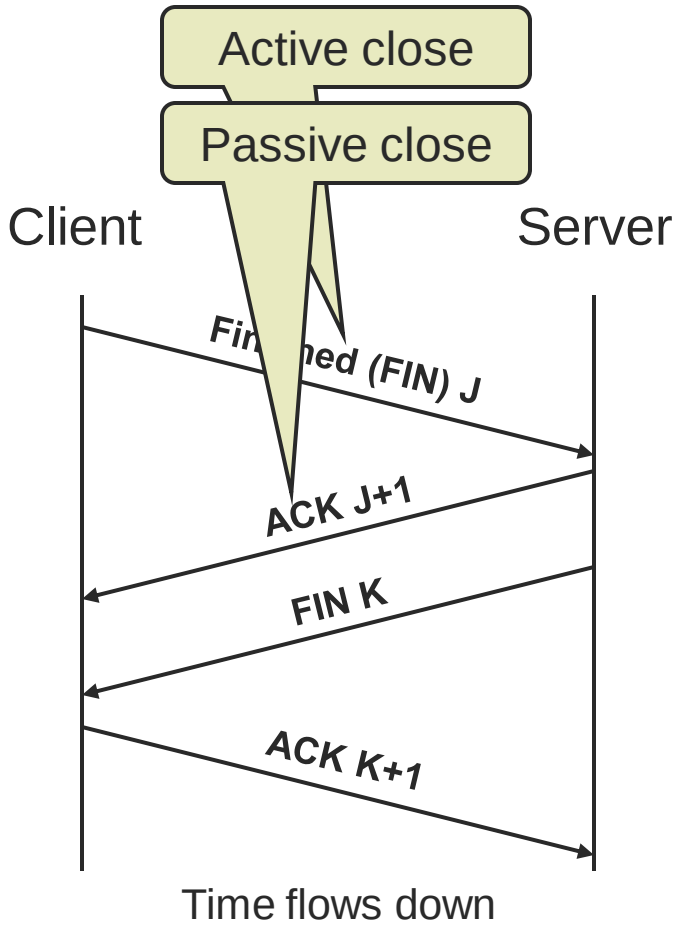
TCP Connection Establishment

- 3-Way Handshake
  - Sequence Numbers
    - J,K
  - Message Types
    - Synchronize (SYN)
    - Acknowledge (ACK)
  - Passive Open
    - Server listens for connection from client
  - Active Open
    - Client initiates connection to server



TCP Connection Termination

- Either client or server can initiate connection teardown
- Message Types
  - Finished (FIN)
  - Acknowledge (ACK)
- Active Close
  - Sends no more data
- Passive close
  - Accepts no more data



UDP Services

- User Datagram Protocol Service
  - OSI Transport Layer
  - Provides a thin layer over IP
  - 16-bit port space (distinct from TCP ports) allows multiple recipients on a single host

UDP Services

- Unit of Transfer
  - Datagram (variable length packet)
- Unreliable
  - No guaranteed delivery
  - Drops packets silently
- Unordered
  - No guarantee of maintained order of delivery
- Unlimited Transmission
  - No flow control

- Postal Mail
  - Single mailbox to receive all letters
  - Unreliable
  - Not necessarily in-order
  - Letters sent independently
  - Must address each reply

Addresses and Data

- Internet domain names
  - Human readable
  - Variable length
  - Ex: **`sal.cs.uiuc.edu`**
- IP addresses
  - Each attachment point on Internet is given unique address
  - Easily handled by routers/computers
  - Fixed length
  - Somewhat geographical
  - Ex: **`128.174.252.217`**

Byte Ordering

- Big Endian vs. Little Endian
  - Little Endian (Intel, DEC):
    - Least significant byte of word is stored in the lowest memory address
  - Big Endian (Sun, SGI, HP):
    - Most significant byte of word is stored in the lowest memory address
  - Example: **`128.2.194.95`**

Big Endian	128	2	194	95
Little Endian	95	194	2	128

Byte Ordering

- Big Endian vs. Little Endian
  - Little Endian (Intel, DEC):
    - Least significant byte of word is stored in the lowest memory address
  - Big Endian (Sun, SGI, HP):
    - Most significant byte of word is stored in the lowest memory address
  - Network Byte Order = Big Endian
    - Allows both sides to communicate
    - Must be used for some data (i.e. IP Addresses)
    - Good form for all binary data

Byte Ordering Functions

- 16- and 32-bit conversion functions (for platform independence)
- Examples:

```
int m, n;
short int s,t;

m = ntohl (n)    // net-to-host long (32-bit) translation
s = ntohs (t)    // net-to-host short (16-bit) translation
n = htonl (m)    // host-to-net long (32-bit) translation
t = htons (s)    // host-to-net short (16-bit) translation
```


Socket Address Structure

- IP address:

```
struct in_addr {
    in_addr_t s_addr;        /* 32-bit IP address */
};
```

- TCP or UDP address:

```
struct sockaddr_in {
    short sin_family;        /* e.g., AF_INET */
    ushort sin_port;         /* TCP/UDP port */
    struct in_addr;          /* IP address */
};
```

- all but **`sin_family`** in network byte order

Structure: addrinfo

- The **`addrinfo`** data structure (from **`/usr/include/netdb.h`**)
  - Canonical domain name and aliases
  - List of addresses associated with machine
  - Also address type and length information

```
int ai_flags              Input flags
int ai_family             Address family of socket
int ai_socktype           Socket type
int ai_protocol           Protocol of socket
socklen_t ai_addrlen      Length of socket address
struct sockaddr *ai_addr  Socket address of socket
char *ai_canonname        Canonical name of service location
struct addrinfo *ai_next  Pointer to next in list
```


Address Access/Conversion Functions

```
#include <sys/types.h>
#include <sys/socket.h>
#include <netdb.h>
int getaddrinfo(const char *restrict node,
          const char *restrict service,
          const struct addrinfo *restrict hints,
          struct addrinfo **restrict res);
```

- Parameters
  - **node**: host name or IP address to connect to
  - **service**: a port number (“80“) or the name of a service (found /etc/services: “http”)
  - **hints**: a filled out struct addrinfo

Example: Server

```
int status;
struct addrinfo hints;
struct addrinfo *servinfo; // point to the results

memset(&hints, 0, sizeof hints); // empty struct
hints.ai_family = AF_UNSPEC; // IPv4 or IPv6
hints.ai_socktype = SOCK_STREAM; // TCP stream sockets
hints.ai_flags = AI_PASSIVE; // fill in my IP for me

if ((status = getaddrinfo(NULL, "3490", &hints, &servinfo)) != 0) {
    fprintf(stderr, "getaddrinfo error: %s\n", gai_strerror(status));
    exit(1);
}
// servinfo now points to a linked list of 1 or more struct addrinfos
// ... do everything until you don't need servinfo anymore ....

freeaddrinfo(servinfo); // free the linked-list
```


Example: Client

```
int status;
struct addrinfo hints;
struct addrinfo *servinfo; // will point to the results

memset(&hints, 0, sizeof hints); // make sure the struct is empty
hints.ai_family = AF_UNSPEC; // don't care IPv4 or IPv6
hints.ai_socktype = SOCK_STREAM; // TCP stream sockets

// get ready to connect
status = getaddrinfo("www.example.net", "3490", &hints, &servinfo);

// servinfo now points to a linked list of 1 or more struct addrinfos

// etc.
```


Structure: hostent (older)

- The **hostent** data structure (from **/usr/include/netdb.h**)
  - Canonical domain name and aliases
  - List of addresses associated with machine
  - Also address type and length information

```
struct hostent {
    char* h_name;              /* official name of host */
    char** h_aliases;          /* NULL-terminated alias list */
    int h_addrtype;            /* address type (AF_INET) */
    int h_length;              /* length of addresses (4B) */
    char** h_addr_list;        /* NULL-terminated address list */
#define h_addr h_addr_list[0];/* backward-compatibility */
};
```


Address Access/Conversion Functions (older)

- All binary values are network byte ordered

```
struct hostent* gethostbyname (const char*
   hostname);
```

  - Translate English host name to IP address (uses DNS)

```
struct hostent* gethostbyaddr (const char*
   addr, size_t len, int family);
```

  - Translate IP address to English host name (not secure)

```
char* inet_ntoa (struct in_addr inaddr);
```

  - Translate IP address to ASCII dotted-decimal notation (e.g., “128.32.36.37”); not thread-safe

Address Access/Conversion Functions

```
in_addr_t inet_addr (const char* strptr);
```

- Translate dotted-decimal notation to IP address; returns -1 on failure, thus cannot handle broadcast value “255.255.255.255”

```
int inet_aton (const char* strptr, struct
   in_addr inaddr);
```

- Translate dotted-decimal notation to IP address; returns 1 on success, 0 on failure

```
int gethostname (char* name, size_t
   namelen);
```

- Read host’s name (use with **`gethostbyname`** to find local IP)

Sockets API

- Basic Unix Concepts
- Creation and Setup
- Establishing a Connection (TCP)
- Sending and Receiving Data
- Tearing Down a Connection (TCP)
- Advanced Sockets

Basic Unix Concepts

- Input/Output – I/O
  - Per-process table of I/O channels
  - Table entries describe files, sockets, devices, pipes, etc.
  - Unifies I/O interface
  - Table entry/index into table called “file descriptor”
- Error Model
  - Return value
    - 0 on success
    - -1 on failure
    - NULL on failure for routines returning pointers
  - `errno` variable

Socket Creation and Setup

- Include file **`<sys/socket.h>`**
- Create a socket
  - **`int socket (int family, int type, int protocol);`**
  - Returns file descriptor or -1.
- Bind a socket to a local IP address and port number
  - **`int bind (int sockfd, struct sockaddr* myaddr, int addrlen);`**
- Put socket into passive state (wait for connections rather than initiate a connection).
  - **`int listen (int sockfd, int backlog);`**

Functions: socket

```
int socket (int family, int type, int
   protocol);
```

- Create a socket.
  - Returns file descriptor or -1. Also sets **`errno`** on failure.
  - **`family`**: address family (namespace)
    - **`AF_INET`** for IPv4
    - other possibilities: **`AF_INET6`** (IPv6), **`AF_UNIX`** or **`AF_LOCAL`** (Unix socket), **`AF_ROUTE`** (routing)
  - **`type`**: style of communication
    - **`SOCK_STREAM`** for TCP (with **`AF_INET`**)
    - **`SOCK_DGRAM`** for UDP (with **`AF_INET`**)
  - **`protocol`**: protocol within family
    - typically 0

Example: socket

```
int sockfd, new_fd; /* listen on sock_fd, new
                       connection on new_fd */
struct sockaddr_in my_addr;        /* my address     */
struct sockaddr_in their_addr; /* connector addr */
int sin_size;

if ((sockfd = socket(AF_INET, SOCK_STREAM, 0))==-1){
    perror("socket");
    exit(1);
}
```


Function: bind

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

- Bind a socket to a local IP address and port number
  - Returns 0 on success, -1 and sets **errno** on failure
  - **sockfd**: socket file descriptor (returned from **socket**)
  - **myaddr**: includes IP address and port number
    - IP address: set by kernel if value passed is **INADDR_ANY**, else set by caller
    - port number: set by kernel if value passed is 0, else set by caller
  - **addrlen**: length of address structure
    - **= sizeof (struct sockaddr_in)**

Example: bind

```
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 = htonl(INADDR_ANY);
/* automatically fill with my IP                   */
bzero(&(my_addr.sin_zero), 8);    /* zero struct */

if (bind(sockfd, (struct sockaddr *)&my_addr,
         sizeof(struct sockaddr)) == -1) {
    perror("bind");
    exit(1);
}
```


TCP and UDP Ports

- Allocated and assigned by the Internet Assigned Numbers Authority
  - see **`RFC 1700`** (for historical purposes only)

1-512	▪ standard services (see **`/etc/services`**) ▪ super-user only
513-1023	▪ registered and controlled, also used for identity verification ▪ super-user only
1024-49151	▪ registered services/ephemeral ports
49152-65535	▪ private/ephemeral ports

Reserved Ports

Keyword	Decimal	Description	Keyword	Decimal	Description
	0/tcp	Reserved	time	37/tcp	Time
	0/udp	Reserved	time	37/udp	Time
tcpmux	1/tcp	TCP Port Service	name	42/tcp	Host Name Server
tcpmux	1/udp	TCP Port Service	name	42/udp	Host Name Server
echo	7/tcp	Echo	nameserver	42/tcp	Host Name Server
echo	7/udp	Echo	nameserver	42/udp	Host Name Server
systat	11/tcp	Active Users	nicname	43/tcp	Who Is
systat	11/udp	Active Users	nicname	43/udp	Who Is
daytime	13/tcp	Daytime (RFC 867)	domain	53/tcp	Domain Name Server
daytime	13/udp	Daytime (RFC 867)	domain	53/udp	Domain Name Server
qotd	17/tcp	Quote of the Day	whois++	63/tcp	whois++
qotd	17/udp	Quote of the Day	whois++	63/udp	whois++
chargen	19/tcp	Character Generator	gopher	70/tcp	Gopher
chargen	19/udp	Character Generator	gopher	70/udp	Gopher
ftp-data	20/tcp	File Transfer Data	finger	79/tcp	Finger
ftp-data	20/udp	File Transfer Data	finger	79/udp	Finger
ftp	21/tcp	File Transfer Ctl	http	80/tcp	World Wide Web HTTP
ftp	21/udp	File Transfer Ctl	http	80/udp	World Wide Web HTTP
ssh	22/tcp	SSH Remote Login	www	80/tcp	World Wide Web HTTP
ssh	22/udp	SSH Remote Login	www	80/udp	World Wide Web HTTP
telnet	23/tcp	Telnet	www-http	80/tcp	World Wide Web HTTP
telnet	23/udp	Telnet	www-http	80/udp	World Wide Web HTTP
smtp	25/tcp	Simple Mail Transfer	kerberos	88/tcp	Kerberos
smtp	25/udp	Simple Mail Transfer	kerberos	88/udp	Kerberos

Functions: listen

```
int listen (int sockfd, int backlog);
```

- Put socket into passive state (wait for connections rather than initiate a connection)
  - Returns 0 on success, -1 and sets **errno** on failure
  - **sockfd**: socket file descriptor (returned from **socket**)
  - **backlog**: bound on length of unaccepted connection queue (connection backlog); kernel will cap, thus better to set high
  - Example:

```
if (listen(sockfd, BACKLOG) == -1) {
        perror("listen");
        exit(1);
}
```


Establishing a Connection

- Include file **<sys/socket.h>**

```
int connect (int sockfd, struct
   sockaddr* servaddr, int addrlen);
```

  - Connect to another socket.

```
int accept (int sockfd, struct sockaddr*
   cliaddr, int* addrlen);
```

  - Accept a new connection. Returns file descriptor or -1.

Functions: connect

```
int connect (int sockfd, struct
   sockaddr* servaddr, int addrlen);
```

- Connect to another socket.
  - Returns 0 on success, -1 and sets **`errno`** on failure
  - **`sockfd`**: socket file descriptor (returned from **`socket`**)
  - **`servaddr`**: IP address and port number of server
  - **`addrlen`**: length of address structure
    - **`= sizeof (struct sockaddr_in)`**
- Can use with UDP to restrict incoming datagrams and to obtain asynchronous errors

Example: connect

```
their_addr.sin_family = AF_INET; /* interp'd by host */
their_addr.sin_port = htons (PORT);
their_addr.sin_addr = *((struct in_addr*)he->h_addr);

bzero (&(their_addr.sin_zero), 8);
/* zero rest of struct */

if (connect (sockfd, (struct sockaddr*)&their_addr,
             sizeof (struct sockaddr)) == -1) {
    perror ("connect");
    exit (1);
}
```


Functions: accept

```
int accept (int sockfd, struct sockaddr* cliaddr,
    int* addrlen);
```

- Block waiting for a new connection
  - Returns file descriptor or -1 and sets **`errno`** on failure
  - **`sockfd`**: socket file descriptor (returned from **`socket`**)
  - **`cliaddr`**: IP address and port number of client (returned from call)
  - **`addrlen`**: length of address structure = pointer to **`int`** set to **`sizeof (struct sockaddr_in)`**

- **`addrlen`** is a **value-result** argument
  - the caller passes the size of the address structure, the kernel returns the size of the client's address (the number of bytes written)

Example: accept

```
sin_size = sizeof(struct sockaddr_in);
if ((new_fd = accept(sockfd, (struct sockaddr*)
                &their_addr, &sin_size)) == -1) {
    perror("accept");
    continue;
}
```

- How does the server know which client it is?
  - **their_addr.sin_addr** contains the client's IP address
  - **their_addr.port** contains the client's port number

```
printf("server: got connection from %s\n",
        inet_ntoa(their_addr.sin_addr));
```


Functions: accept

- Notes
  - After **`accept()`** returns a new socket descriptor, I/O can be done using **`read()`** and **`write()`**
  - Why does **`accept()`** need to return a new descriptor?

Sending and Receiving Data

```
int write (int sockfd, char* buf, size_t
   nbytes);
```

- Write data to a stream (TCP) or "connected" datagram (UDP) socket.
  - Returns number of bytes written or -1.

```
int read (int sockfd, char* buf, size_t
   nbytes);
```

- Read data from a stream (TCP) or "connected" datagram (UDP) socket.
  - Returns number of bytes read or -1.

Functions: write

```
int write (int sockfd, char* buf, size_t nbytes);
```

- Write data to a stream (TCP) or "connected" datagram (UDP) socket
  - Returns number of bytes written or -1 and sets **errno** on failure
  - **sockfd**: socket file descriptor (returned from **socket**)
  - **buf**: data buffer
  - **nbytes**: number of bytes to try to write
  - Example:

```
if((w = write(fd, buf, sizeof(buf))) < 0) {
   perror("write");
   exit(1);
}
```


Functions: write

```
int write (int sockfd, char* buf, size_t nbytes);
```

- Notes
  - **`write`** blocks waiting for data from the client
  - **`write`** may not write all bytes asked for
    - Does not guarantee that **`sizeof(buf)`** is written
    - This is not an error
    - Simply continue writing to the device
  - Some reasons for failure or partial writes
    - Process received interrupt or signal
    - Kernel resources unavailable *(e.g.*, buffers)

Example: writen

```
/* Write "n" bytes to a descriptor */
ssize_t writen(int fd, const void *ptr, size_t n) {
    size_t nleft;
    ssize_t nwritten;
    nleft = n;
    while (nleft > 0) {
        if ((nwritten = write(fd, ptr, nleft)) < 0) {
            if (nleft == n)
                return(-1); /* error, return -1 */
            else
                break; /* error, return amount written so far */
        }
        else
            if (nwritten == 0)
                break;
        nleft -= nwritten;
        ptr += nwritten;
    }
    return(n - nleft); /* return >= 0 */
}
```

`write` returned a potential error

0 bytes were written

Update number of bytes left to write and pointer into buffer

Functions: read

```
int read (int sockfd, char* buf, size_t nbytes);
```

- Read data from a stream (TCP) or "connected" datagram (UDP) socket
  - Returns number of bytes read or -1, sets **errno** on failure
  - Returns 0 if socket closed
  - **sockfd**: socket file descriptor (returned from **socket**)
  - **buf**: data buffer
  - **nbytes**: number of bytes to try to read
  - Example

```
if((r = read(newfd, buf, sizeof(buf))) < 0) {
    perror("read"); exit(1);
}
```


Functions: read

```
int read (int sockfd, char* buf, size_t nbytes);
```

- Notes
  - **`read`** blocks waiting for data from the client
  - **`read`** may return less than asked for
    - Does not guarantee that **`sizeof(buf)`** is read
    - This is not an error
    - Simply continue reading from the device

Example: readn

```
/* Read "n" bytes from a descriptor */
ssize_t readn(int fd, void *ptr, size_t n) {
    size_t nleft;
    ssize_t nread;
    nleft = n;
    while (nleft > 0) {
        if ((nread = read(fd, ptr, nleft)) < 0) {
            if (nleft == n)
                return(-1); /* error, return -1 */
            else
                break; /* error, return amt read */
        }
        else
            if (nread == 0)
                break; /* EOF */
            nleft -= nread;
            ptr += nread;
        }
    return(n - nleft); /* return >= 0 */
}
```

`read` returned a potential error

0 bytes were read

Update number of bytes left to read and pointer into buffer

Sending and Receiving Data

```
int send(int sockfd, const void * buf,
   size_t nbytes, int flags);
```

- Write data to a stream (TCP) or "connected" datagram (UDP) socket.
  - Returns number of bytes written or -1.

```
int recv(int sockfd, void *buf, size_t
   nbytes, int flags);
```

- Read data from a stream (TCP) or "connected" datagram (UDP) socket.
  - Returns number of bytes read or -1.

Functions: send

```
int send(int sockfd, const void * buf, size_t
   nbytes, int flags);
```

- Send data un a stream (TCP) or “connected” datagram (UDP) socket
  - Returns number of bytes written or -1 and sets **`errno`** on failure
  - **`sockfd`**: socket file descriptor (returned from **`socket`**)
  - **`buf`**: data buffer
  - **`nbytes`**: number of bytes to try to write
  - **`flags`**: control flags
    - MSG_PEEK: get data from the beginning of the receive queue without removing that data from the queue

Functions: send

```
int send(int sockfd, const void * buf, size_t
   nbytes, int flags);
```

- Example

```
len = strlen(msg);
bytes_sent = send(sockfd, msg, len, 0);
```


Functions: recv

```
int recv(int sockfd, void *buf, size_t nbytes,
    int flags);
```

- Read data from a stream (TCP) or "connected" datagram (UDP) socket
  - Returns number of bytes read or -1, sets **`errno`** on failure
  - Returns 0 if socket closed
  - **`sockfd`**: socket file descriptor (returned from **`socket`**)
  - **`buf`**: data buffer
  - **`nbytes`**: number of bytes to try to read
  - **`flags`**: see man page for details; typically use 0

Functions: recv

```
int read (int sockfd, char* buf, size_t nbytes);
```

- Notes
  - **`read`** blocks waiting for data from the client but does not guarantee that **`sizeof(buf)`** is read
  - Example

```
if((r = read(newfd, buf, sizeof(buf))) < 0) {
   perror("read"); exit(1);
}
```


Sending and Receiving Data

- Datagram sockets aren't connected to a remote host
  - What piece of information do we need to give before we send a packet?
  - The destination/source address!

Sending and Receiving Data

```
int sendto (int sockfd, char* buf,
   size_t nbytes, int flags, struct
   sockaddr* destaddr, int addrlen);
```

- Send a datagram to another UDP socket.
  - Returns number of bytes written or -1.

```
int recvfrom (int sockfd, char* buf,
   size_t nbytes, int flags, struct
   sockaddr* srcaddr, int* addrlen);
```

- Read a datagram from a UDP socket.
  - Returns number of bytes read or -1.

Functions: sendto

```
int sendto (int sockfd, char* buf, size_t nbytes,
    int flags, struct sockaddr* destaddr, int
    addrlen);
```

- Send a datagram to another UDP socket
  - Returns number of bytes written or -1 and sets **errno** on failure
  - **sockfd**: socket file descriptor (returned from **socket**)
  - **buf**: data buffer
  - **nbytes**: number of bytes to try to read
  - **flags**: see man page for details; typically use 0
  - **destaddr**: IP address and port number of destination socket
  - **addrlen**: length of address structure
    - **= sizeof (struct sockaddr_in)**

Functions: sendto

```
int sendto (int sockfd, char* buf, size_t nbytes,
    int flags, struct sockaddr* destaddr, int
    addrlen);
```

- Example

```
n = sendto(sock, buf, sizeof(buf), 0,(struct
    sockaddr *) &from,fromlen);
if (n < 0)
    perror("sendto");
    exit(1);
}
```


Functions: recvfrom

```
int recvfrom (int sockfd, char* buf, size_t
   nbytes, int flags, struct sockaddr* srcaddr,
   int* addrlen);
```

- Read a datagram from a UDP socket.
  - Returns number of bytes read (0 is valid) or -1 and sets **`errno`** on failure
  - **`sockfd`**: socket file descriptor (returned from **`socket`**)
  - **`buf`**: data buffer
  - **`nbytes`**: number of bytes to try to read
  - **`flags`**: see man page for details; typically use 0
  - **`srcaddr`**: IP address and port number of sending socket (returned from call)
  - **`addrlen`**: length of address structure = pointer to **`int`** set to **`sizeof (struct sockaddr_in)`**

Functions: recvfrom

```
int recvfrom (int sockfd, char* buf, size_t
   nbytes, int flags, struct sockaddr* srcaddr,
   int* addrlen);
```

- Example

```
n = recvfrom(sock, buf, 1024, 0, (struct sockaddr
    *)&from,&fromlen);
if (n < 0) {
    perror("recvfrom");
    exit(1);
}
```


Tearing Down a Connection

```
int close (int sockfd);
```

- Close a socket.
  - Returns 0 on success, -1 and sets `errno` on failure.

```
int shutdown (int sockfd, int howto);
```

- Force termination of communication across a socket in one or both directions.
  - Returns 0 on success, -1 and sets `errno` on failure.

Functions: close

```
int close (int sockfd);
```

- Close a socket
  - Returns 0 on success, -1 and sets **`errno`** on failure
  - **`sockfd`**: socket file descriptor (returned from **`socket`**)
- Closes communication on socket in both directions
  - All data sent before **`close`** are delivered to other side (although this aspect can be overridden)
- After **`close`**, **`sockfd`** is not valid for reading or writing

Functions: shutdown

```
int shutdown (int sockfd, int howto);
```

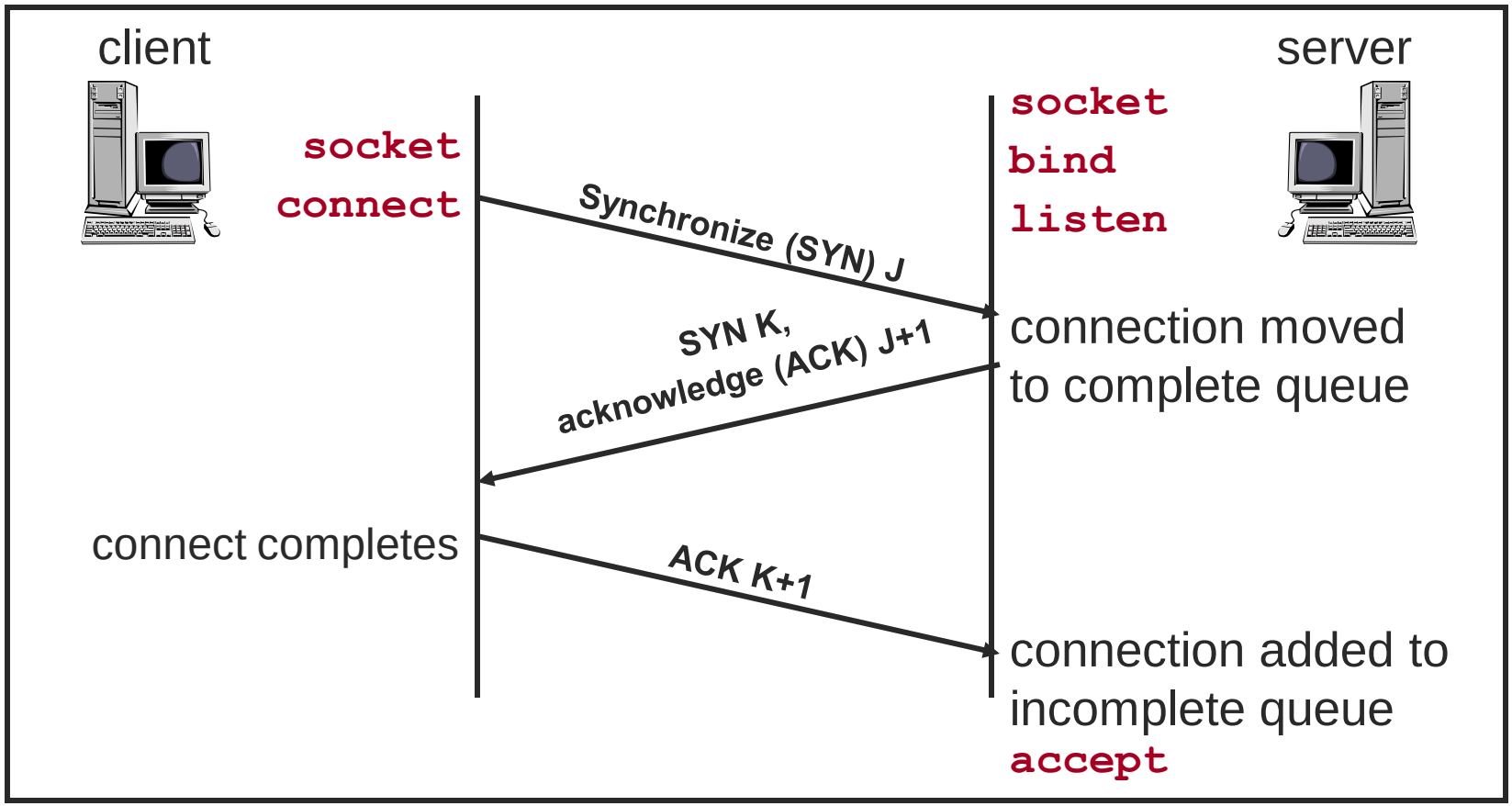
- Force termination of communication across a socket in one or both directions
  - Returns 0 on success, -1 and sets **errno** on failure
  - **sockfd**: socket file descriptor (returned from **socket**)
  - **howto**:
    - **SHUT_RD** to stop reading
    - **SHUT_WR** to stop writing
    - **SHUT_RDWR** to stop both

- **shutdown** overrides the usual rules regarding duplicated sockets, in which TCP teardown does not occur until all copies have closed the socket

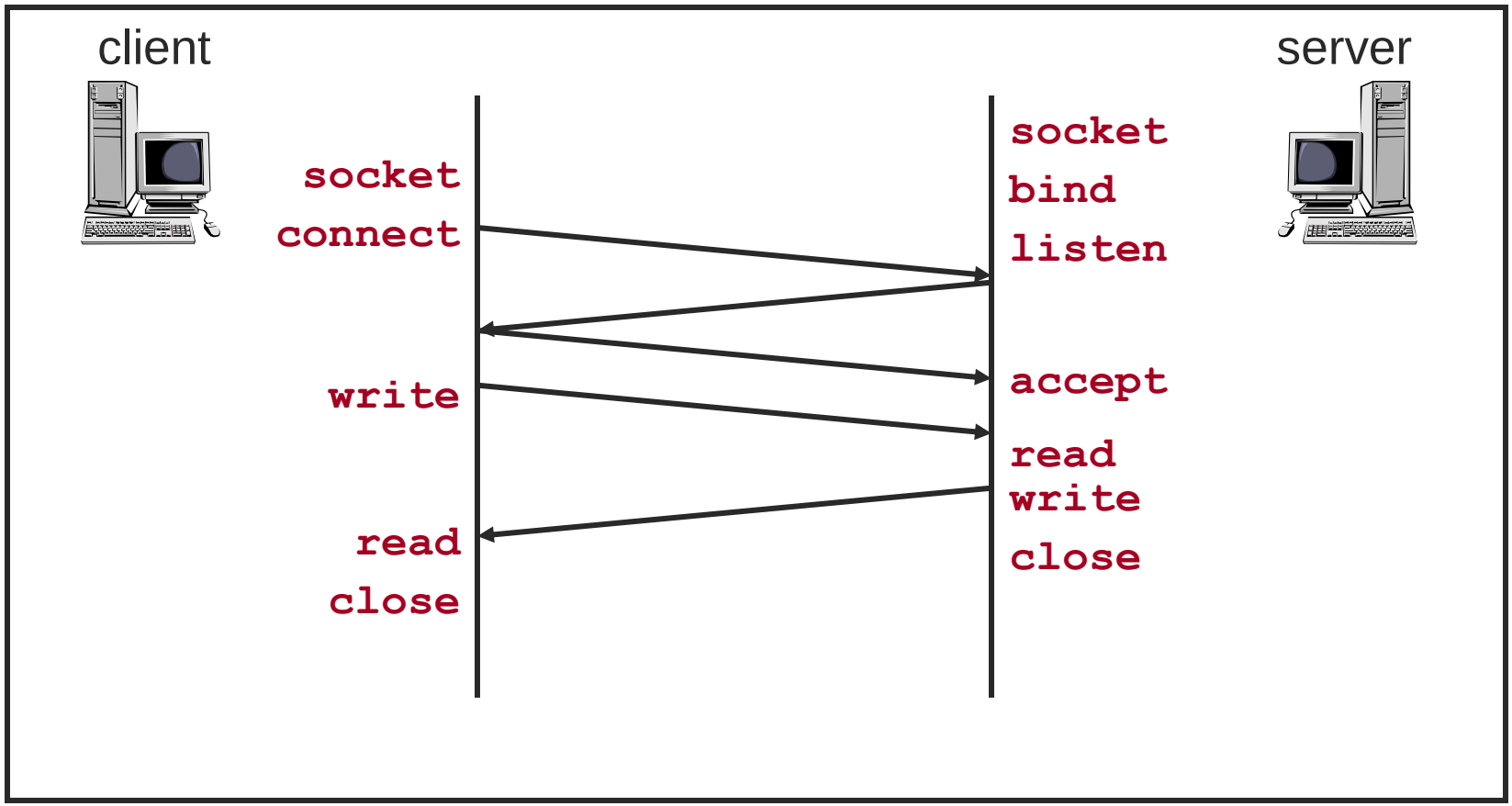
Note on `close` vs. `shutdown`

- `close()`: closes the socket but the connection is still open for processes that shares this socket
  - The connection stays opened both for read and write
- `shutdown()`: breaks the connection for all processes sharing the socket
  - A read will detect `EOF`, and a write will receive `SIGPIPE`
  - `shutdown()` has a second argument how to close the connection:
    - 0 means to disable further reading
    - 1 to disable writing
    - 2 disables both

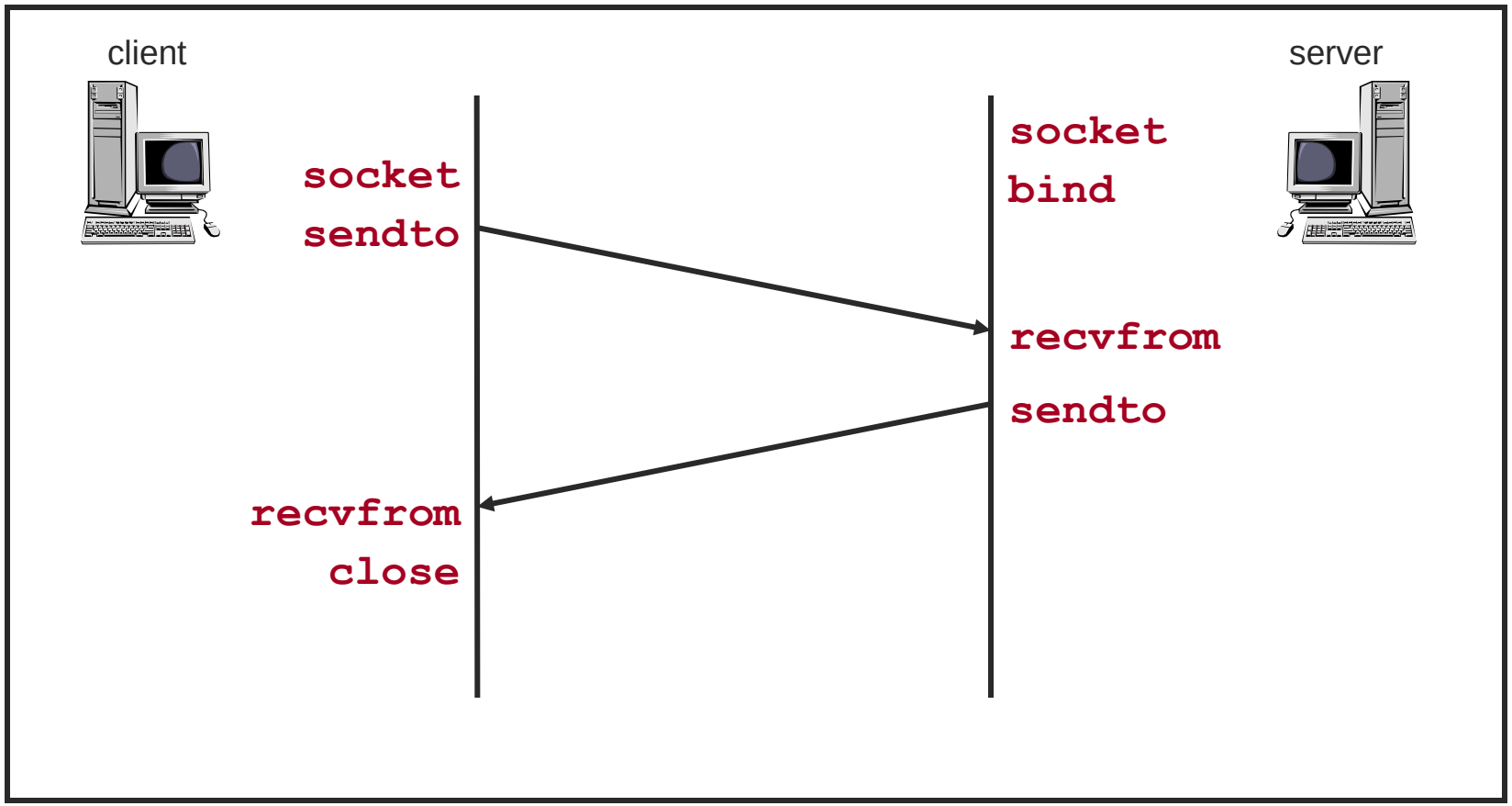
TCP Connection Setup



TCP Connection Example



UDP Connection Example



Examples

- Taken from Beej's Guide to Network Programming:
  `http://beej.us/guide/bgnet/`
- Structure
  - One server on a machine
  - Server handles multiple clients using **`fork()`**
- Basic routine
  - Server waits for a connection
  - **`accept()`**s the connection
  - **`fork()`**s a child process to handle the client

Example: TCP

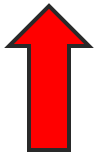
- Client-Server example using TCP
  - For each client
    - server forks new process to handle connection
    - sends "`Hello, world`"

server

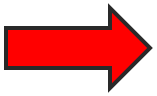
```
#include <stdio.h>
#include <stdlib.h>
#include <errno.h>
#include <string.h>
#include <sys/types.h>
#include <netinet/in.h>
#include <sys/socket.h>
#include <sys/wait.h>
#define PORT 3490   /* well-known port */
#define BACKLOG 10  /* how many pending
                       connections queue
                       will hold */
```


server

```
main()
{
    int sockfd, new_fd;     /* listen on sock_fd, new
                               connection on new_fd */
    struct sockaddr_in my_addr;     /* my address     */
    struct sockaddr_in their_addr; /* connector addr */
    int sin_size;

    if ((sockfd = socket(AF_INET, SOCK_STREAM, 0))==-
    1){
        perror("socket");
        exit(1);
    }
```



server



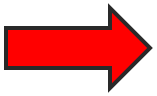
```
my_addr.sin_family = AF_INET; /* host byte order */
my_addr.sin_port = htons(MYPORT); /* short, network
                                     byte order   */
my_addr.sin_addr.s_addr = htonl(INADDR_ANY);
/* automatically fill with my IP                  */
bzero(&(my_addr.sin_zero), 8);    /* zero struct */

if (bind(sockfd, (struct sockaddr *)&my_addr,
         sizeof(struct sockaddr)) == -1) {
    perror("bind");
    exit(1);
}
```

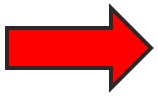

server

```
if (listen(sockfd, BACKLOG) == -1) {
    perror("listen");
    exit(1);
}

while(1) { /* main accept() loop */
    sin_size = sizeof(struct sockaddr_in);
    if ((new_fd = accept(sockfd, (struct sockaddr*)
                    &their_addr,&sin_size)) == -1) {
            perror("accept");
            continue;
    }
    printf("server: got connection from %s\n",
    inet_ntoa(their_addr.sin_addr));
```

server

```
        if (!fork()) { /* this is the child process */
                if (send(new_fd,"Hello, world!\n", 14, 0)
                                == -1)
                        perror("send");
                close(new_fd);
                exit(0);
        }
        close(new_fd); /* parent doesn't need this */
        /* clean up all child processes */
        while(waitpid(-1,NULL,WNOHANG) > 0);
    }
}
```



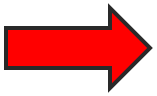


client

```
#include <stdlib.h>
#include <errno.h>
#include <string.h>
#include <netdb.h>
#include <sys/types.h>
#include <netinet/in.h>
#include <sys/socket.h>
#define PORT 3490                /* well-known port */
#define MAXDATASIZE 100          /* max number of bytes we
                                    can get at once */
```


client

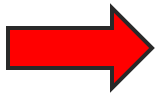
```
int main (int argc, char* argv[]){
    int sockfd, numbytes;
    char buf[MAXDATASIZE + 1];
    struct hostent* he;
    struct sockaddr_in their_addr;
    /* connector's address information */
    if (argc != 2) {
        fprintf (stderr, "usage: client hostname\n");
    exit (1);
    }
    if ((he = gethostbyname (argv[1])) == NULL) {
        /* get the host info */
    perror ("gethostbyname");
    exit (1);
    }
```



client

```
if ((sockfd = socket (AF_INET, SOCK_STREAM, 0)) == -1) {
    perror ("socket");
    exit (1);
}

their_addr.sin_family = AF_INET; /* interp'd by host */
their_addr.sin_port = htons (PORT);
their_addr.sin_addr = *((struct in_addr*)he->h_addr);
bzero (&(their_addr.sin_zero), 8);
/* zero rest of struct */
if (connect (sockfd, (struct sockaddr*)&their_addr,
             sizeof (struct sockaddr)) == -1) {
    perror ("connect");
    exit (1);
}
```


client



```
    if ((numbytes = recv (sockfd, buf, MAXDATASIZE, 0))
                == -1) {
        perror ("recv");
        exit (1);
    }

    buf[numbytes] = '\0';
    printf ("Received: %s", buf);
    close (sockfd);
    return 0;
}
```


Example: UDP

- Client-Server example using UDP
  - For each client
    - **`listener`** sits on a machine waiting for an incoming packet on port 4950
    - **`talker`** sends a packet to that port, on the specified machine, that contains whatever the user enters on the command line

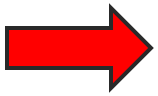
listener

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <errno.h>
#include <string.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>
#include <netdb.h>

#define MYPORT "4950"  // the port users will be connecting to
#define MAXBUFLEN 100
```


listener

```
// get sockaddr, IPv4 or IPv6:
void *get_in_addr(struct sockaddr *sa) {
    if (sa->sa_family == AF_INET) {
        return &(((struct sockaddr_in*)sa)->sin_addr);
    }
    return &(((struct sockaddr_in6*)sa)->sin6_addr);
}
```


listener

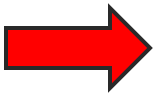


```
int main(void) {
    int sockfd, rv, numbytes;
    struct addrinfo hints, *servinfo, *p;
    struct sockaddr_storage their_addr;
    char buf[MAXBUFLEN], s[INET6_ADDRSTRLEN];
    size_t addr_len;
    memset(&hints, 0, sizeof hints);
    hints.ai_family = AF_UNSPEC;
    hints.ai_socktype = SOCK_DGRAM;
    hints.ai_flags = AI_PASSIVE; // use my IP

    if ((rv = getaddrinfo(NULL,MYPORT,&hints,&servinfo)) == -1) {
        fprintf(stderr, "getaddrinfo: %s\n", gai_strerror(rv));
        return 1;
    }
```


listener

```
// loop through all results and bind to the first we can
for(p = servinfo; p != NULL; p = p->ai_next) {
    if ((sockfd = socket(p->ai_family, p->ai_socktype,
                    p->ai_protocol)) == -1) {
            perror("listener: socket");
            continue;
    }

    if (bind(sockfd, p->ai_addr, p->ai_addrlen) == -1) {
            close(sockfd);
            perror("listener: bind");
            continue;
    }
    break;
}
```


listener



```
if (p == NULL) {
    fprintf(stderr, "listener: failed to bind socket\n");
    return 2;
}
freeaddrinfo(servinfo);
printf("listener: waiting to recvfrom...\n");

addr_len = sizeof their_addr;
if ((numbytes = recvfrom(sockfd, buf, MAXBUFLEN-1 , 0,
    (struct sockaddr *)&their_addr, &addr_len)) == -1) {
    perror("recvfrom");
    exit(1);
}
```

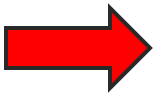

listener

```
        printf("listener: got packet from %s\n",
        inet_ntop(their_addr.ss_family,
                get_in_addr((struct sockaddr *)&their_addr),
                s, sizeof s));
    printf("listener: packet is %d bytes long\n", numbytes);
    buf[numbytes] = '\0';
    printf("listener: packet contains \"%s\"\n", buf);

    close(sockfd);

    return 0;
}
```


talker

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <errno.h>
#include <string.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <arpa/inet.h>
#include <netdb.h>

#define SERVERPORT "4950"     // port users will connect to
```


talker

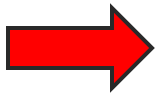


```
int main(int argc, char *argv[]) {
    int sockfd, rv, numbytes;
    struct addrinfo hints, *servinfo, *p;

    memset(&hints, 0, sizeof hints);
    hints.ai_family = AF_UNSPEC;
    hints.ai_socktype = SOCK_DGRAM;

    if ((rv = getaddrinfo(argv[1], SERVERPORT, &hints,
                          &servinfo)) != 0) {
        fprintf(stderr, "getaddrinfo: %s\n", gai_strerror(rv));
        return 1;
    }
```


talker

```
// loop through all the results and make a socket
for(p = servinfo; p != NULL; p = p->ai_next) {
    if ((sockfd = socket(p->ai_family, p->ai_socktype,
                         p->ai_protocol)) == -1) {
            perror("talker: socket");
            continue;
    }
    break;
}

if (p == NULL) {
    fprintf(stderr, "talker: failed to bind socket\n");
    return 2;
}
```


talker



```
    if ((numbytes = sendto(sockfd, argv[2], strlen(argv[2]), 0,
                           p->ai_addr, p->ai_addrlen)) == -1) {
        perror("talker: sendto");
        exit(1);
    }

    freeaddrinfo(servinfo);

    printf("talker: sent %d bytes to %s\n", numbytes, argv[1]);
    close(sockfd);

    return 0;
}
```


Connected Datagram Sockets

- **`talker`** calls **`connect()`** and specifies **`listener`**'s address
  - **`talker`** may only send to and receive from the address specified by **`connect()`**
  - Don't have to use **`sendto()`** and **`recvfrom()`**
  - Simply use **`send()`** and **`recv()`**

Framing

- Goal
  - Framing messages on a byte stream
- Given a TCP message stream, how can we pass logical messages?
  - Note:
    - read may return partial or multiple messages
  - Questions:
    - How can we determine the end of a message?
- Hint
  - string storage in C and Pascal
  - format strings with printf

Framing Problem

- Approach
  - Think about the problem for a minute or two
  - Introduce yourself to 2-3 people near you (form groups of 3-4)
  - Discuss the problem and agree on a solution