Introduction to Unix Network Programming

Reference: Stevens Unix Network Programming

Network Programming

- As an Internet user… you already know a lot about the Internet!

Terminology

- `google.com`
- `facebook.com`
- `illinois.edu`

Domain Names

Terminology

- `http://google.com/`
- `http://facebook.com/`
- `http://illinois.edu/`

Uniform Resource Locators (URLs)

Terminology

- `http://google.com/`
- `http://facebook.com/`
- `http://illinois.edu/`

Protocol:
Hypertext Transfer Protocol (HTTP)

Terminology

- `google.com` → `74.125.225.70`
- `facebook.com` → `66.220.158.11`
- `illinois.edu` → `128.174.4.87`

Internet Protocol (IP) Addresses

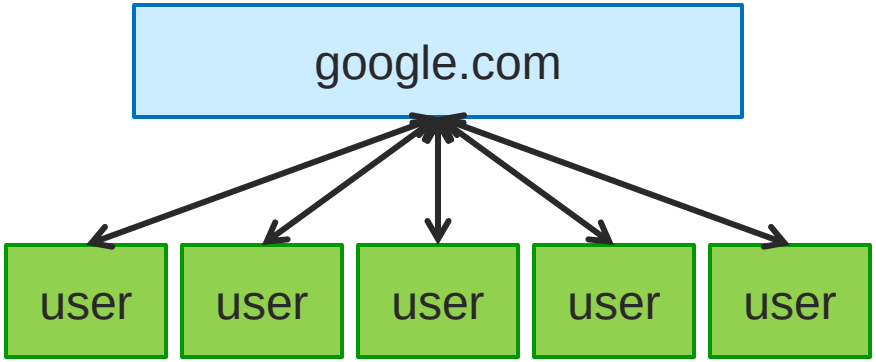
Terminology

- `google.com` → `74.125.225.70`
- `facebook.com` → `66.220.158.11`
- `illinois.edu` → `128.174.4.87`

How are these address translated?

Domain Name System (DNS) via Domain Name Servers

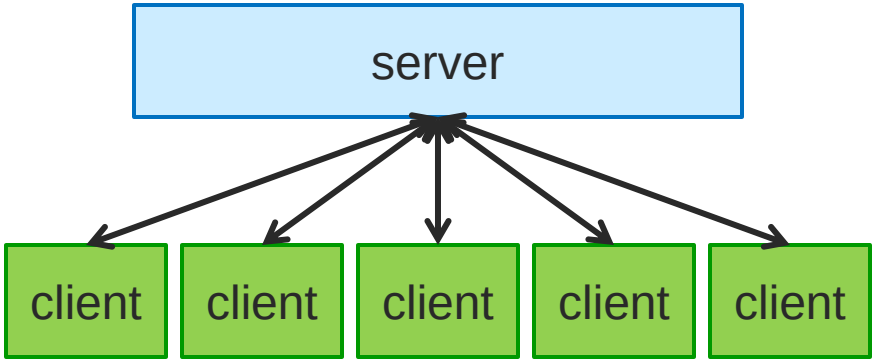
Client-Server Model



- Server: google
- Client: you

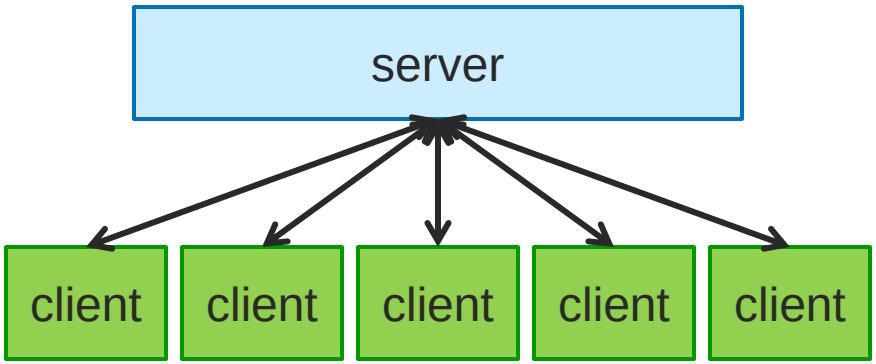
  (and everyone else)

Client-Server Model



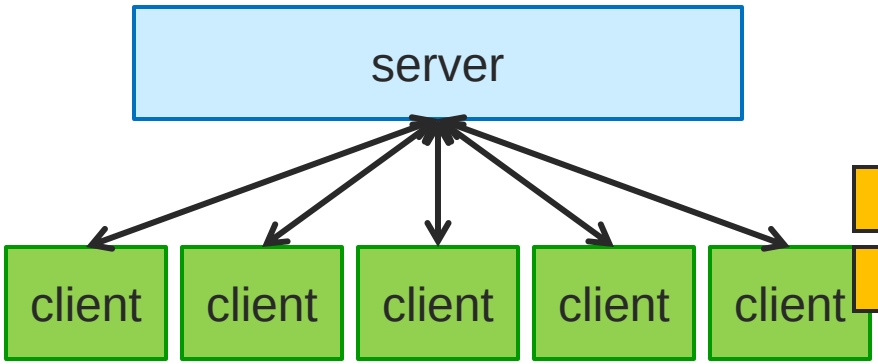
- Properties?

Client-Server Model



- Properties?
  - Client
    - Initiates contact
    - Waits for server's response
  - Server
    - Well-known name
    - Waits for contact
    - Processes requests, sends replies

Client-Server Model



- Properties?
  - Client
    - Initiates contact
    - Waits for server's response
  - Server
    - Well-known name
    - Waits for contact
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How?

How?

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How?

Network Socket

- All communications across a network happen over a ***network socket***
- Properties

Network Socket

- All communications across a network happen over a ***network socket***

- Properties
  - A form of Inter-Process Communications
  - Bi-directional
  - Connection made via a ***socket address***

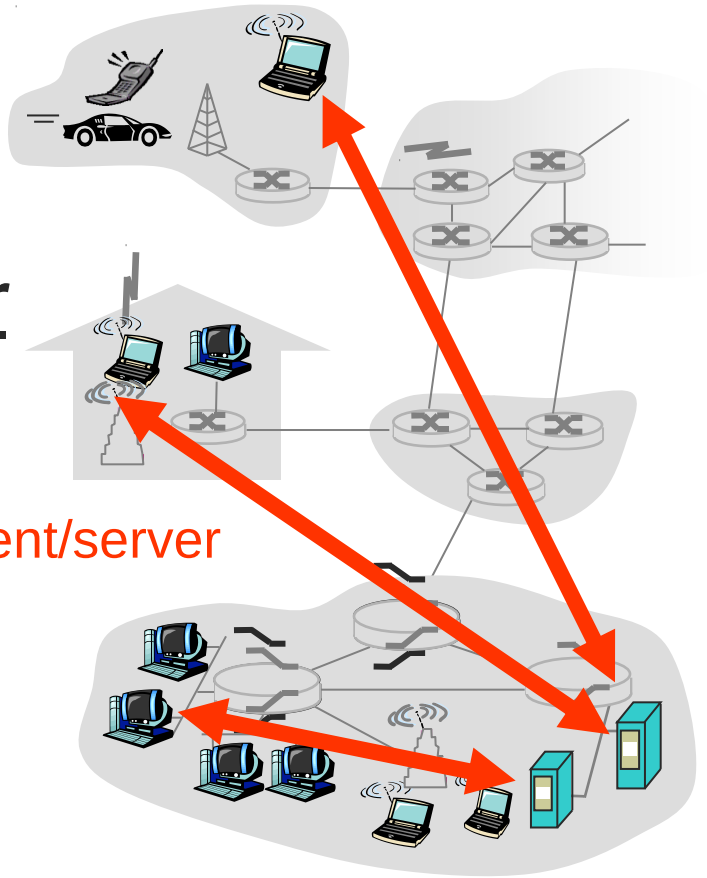
Socket Address

- A ***socket address*** is a pair:
  - IP Address
  - Port Number

- A socket must also bind to a specific transport-layer protocol
  - TCP
  - UDP

Port Number?

- IP Addresses
  - Get a packet to the destination ***computer***
- Port Numbers
  - Get a packet to the destination ***process***



Port Numbers

- A port number is…
  - An 16-bit unsigned integer
    - 0 - 65535
  - A unique resource shared across the entire system
    - Two processes cannot both use port 80
  - Ports below 1024 are reserved
    - Requires elevated privileges on many OSs
    - Widely used applications have their own port number

Application Port Numbers

- When we connect to google.com, what port on google.com are we connecting to?

We are connected to an HTTP server

Public HTTP servers always listen for new connections on port 80

Initializing a socket…

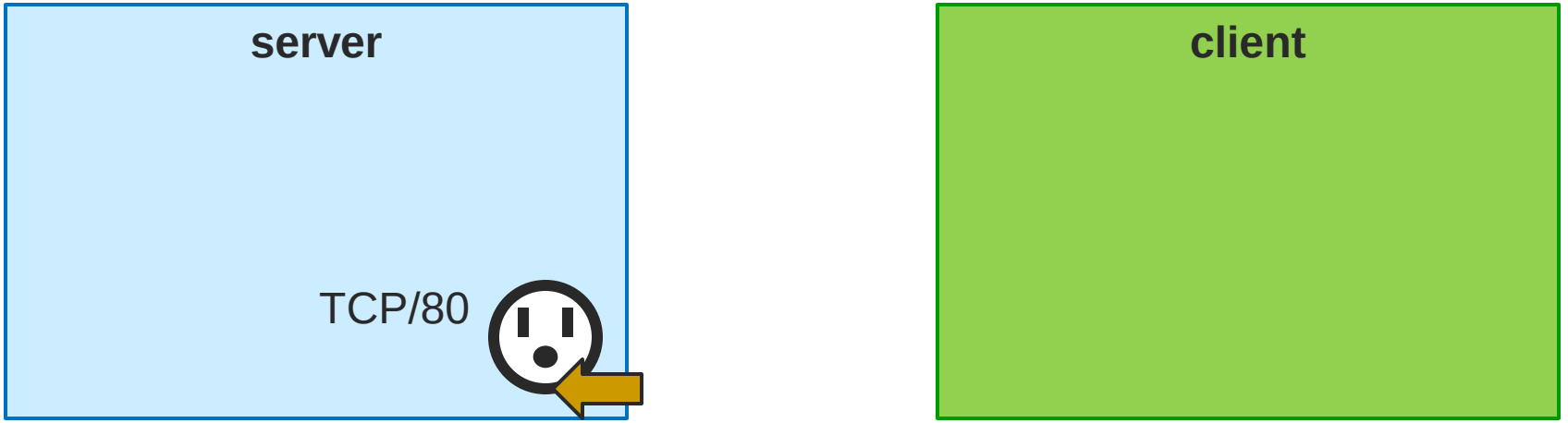
- Two ways to initialize a socket:

1. Listen for an incoming connection
   - Often called a “Server Socket”

2. Connect to a “server socket”

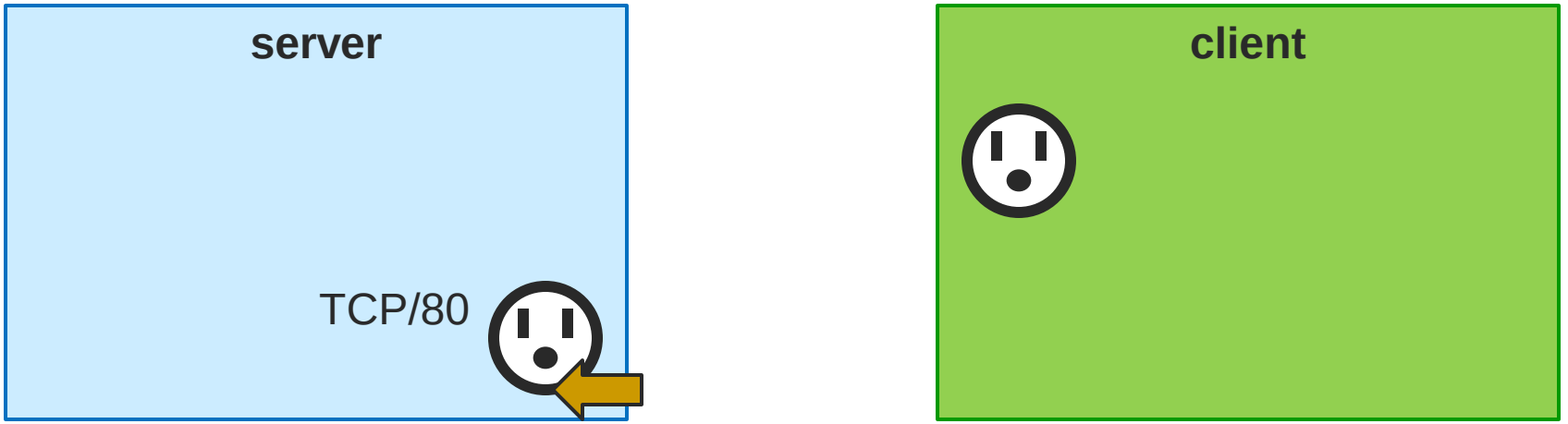
Client-Server Model

- Server
  - Creates a socket to listen for incoming connections
  - Must listen on a specific protocol/port



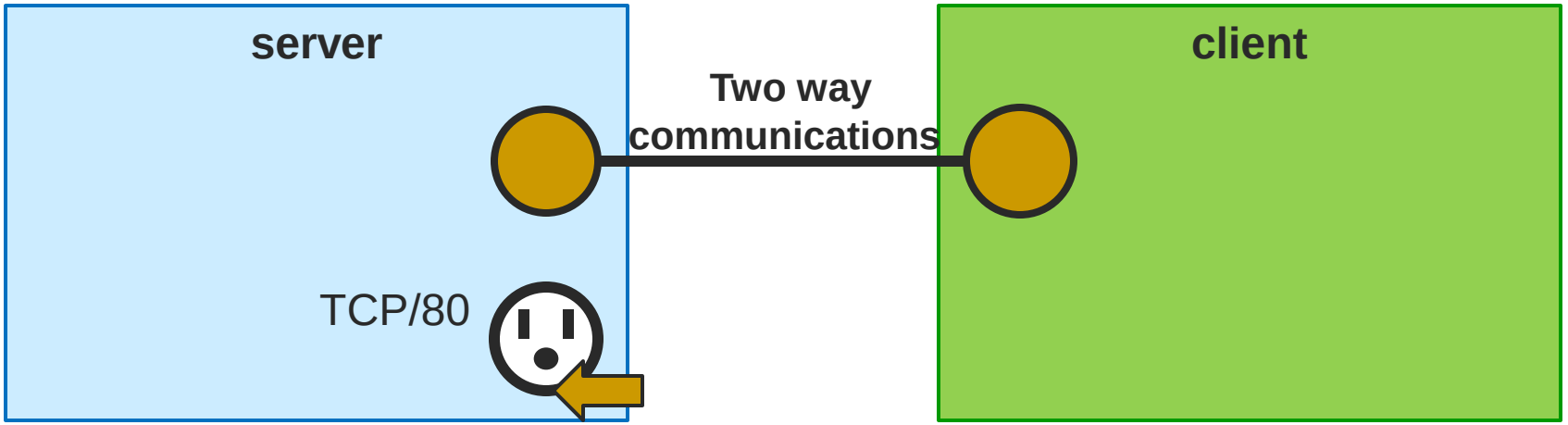
Client-Server Model

- Client
  - Creates a socket to connect to a remote computer

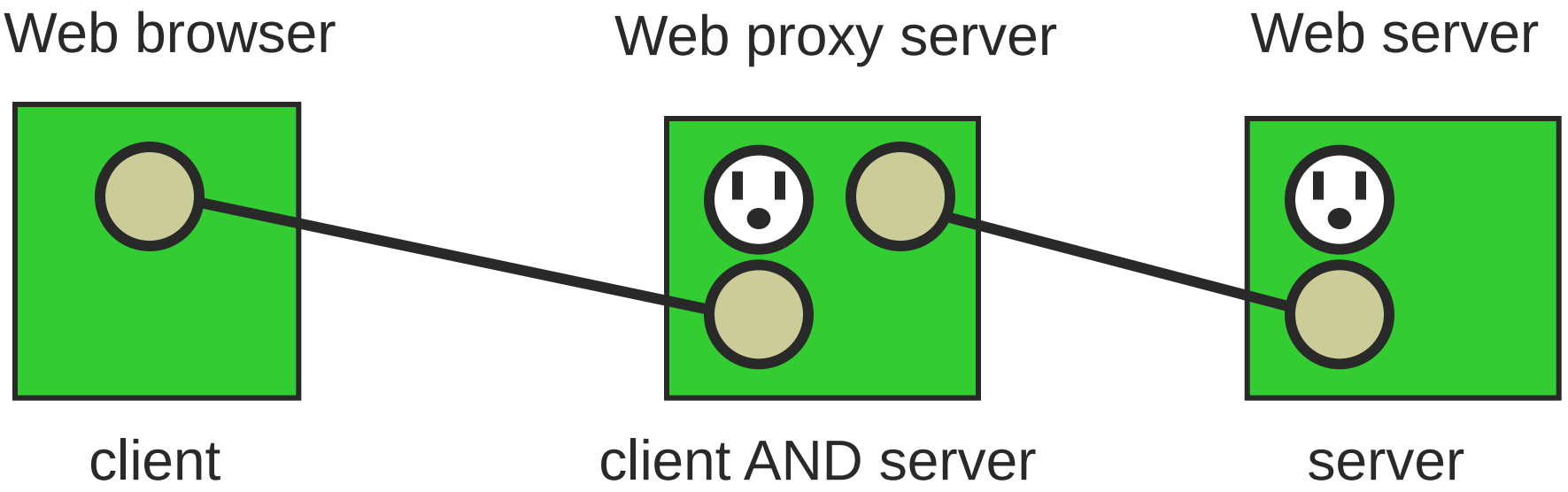


Client-Server Model

- Server
  - Spawns a new socket to communicate directly with the newly connected client
  - Allows other clients to connect



Server Can Be A Client! (And Vice-Versa)



- Server: Process that listens and accepts requests
- Client: Process that connects to a listening process

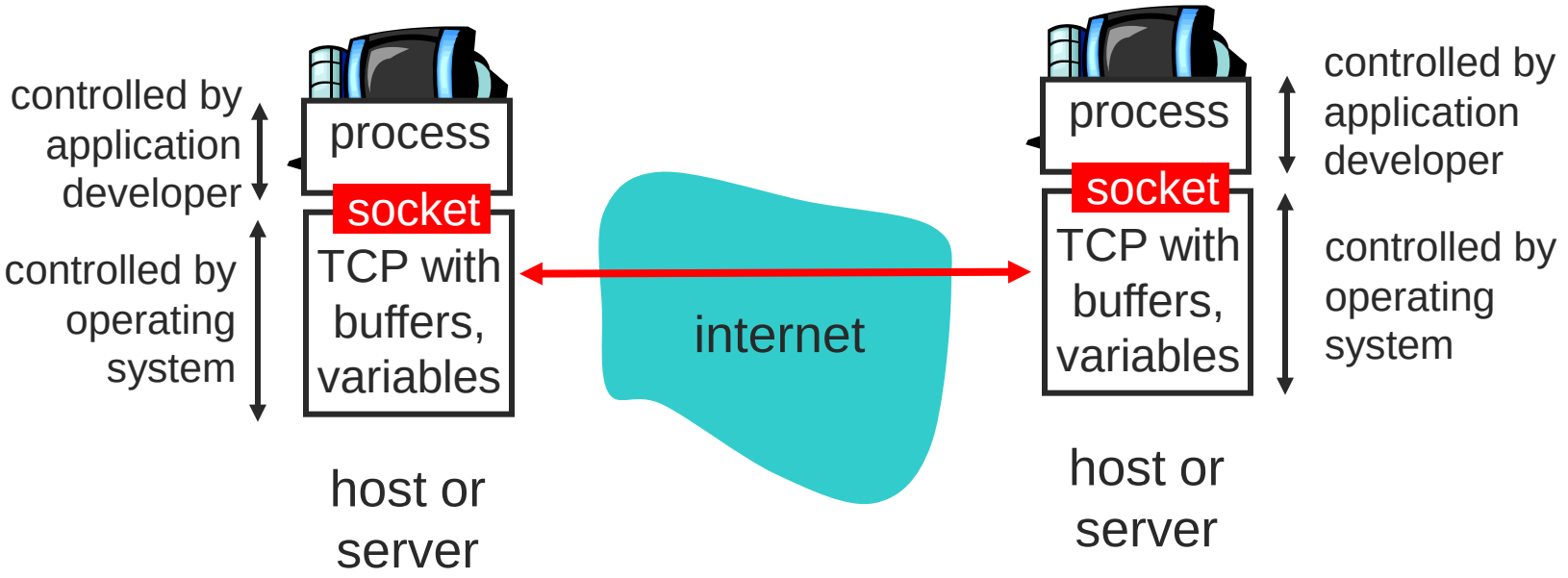
Beej's Guide

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

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

TCP Connections

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



TCP Connections

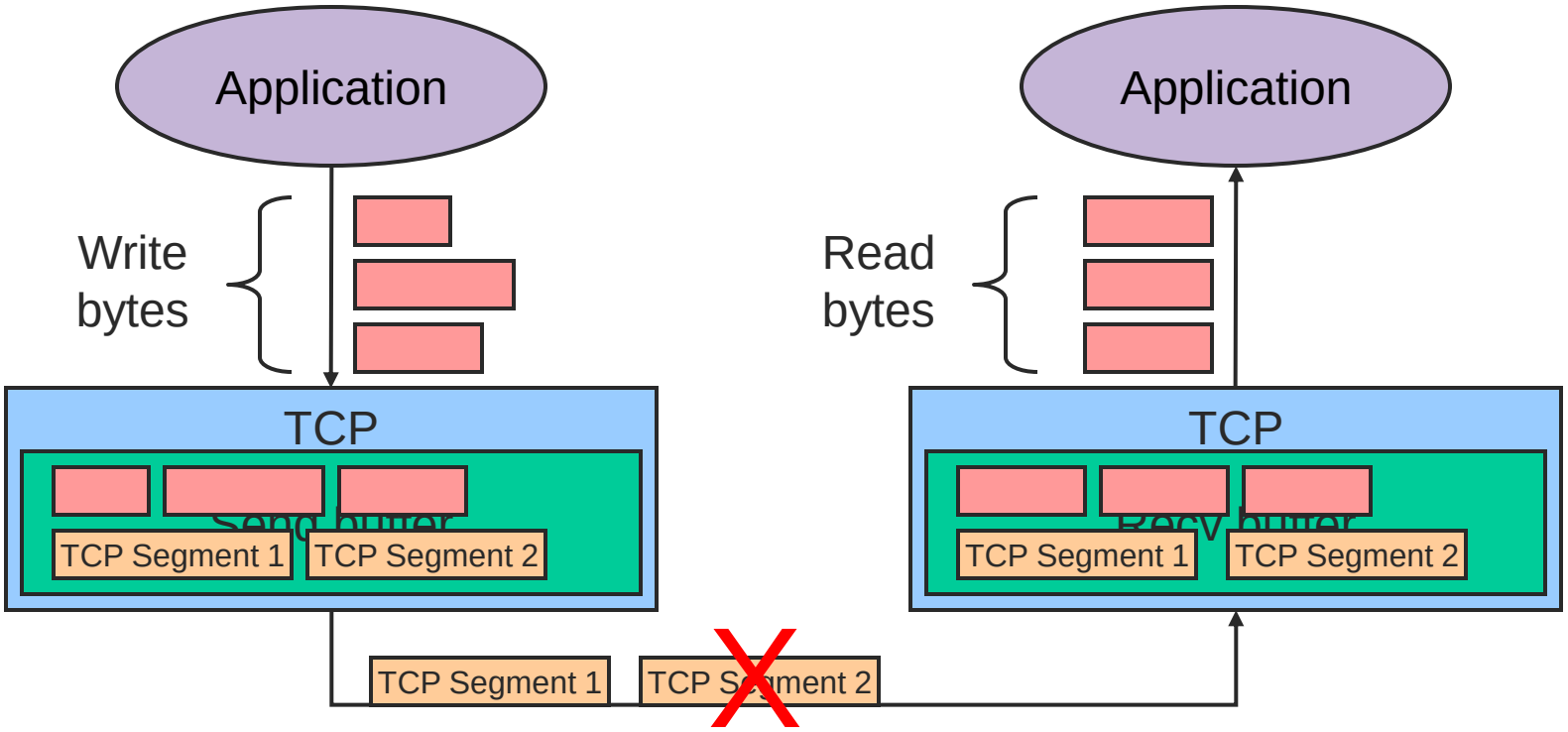
- Transmission Control Protocol (TCP) Service
  - OSI Transport Layer
  - Service Model
    - Byte stream (interpreted by application)
    - 16-bit port space allows multiple connections on a single host
    - Connection-oriented
      - Set up connection before communicating
      - Tear down connection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

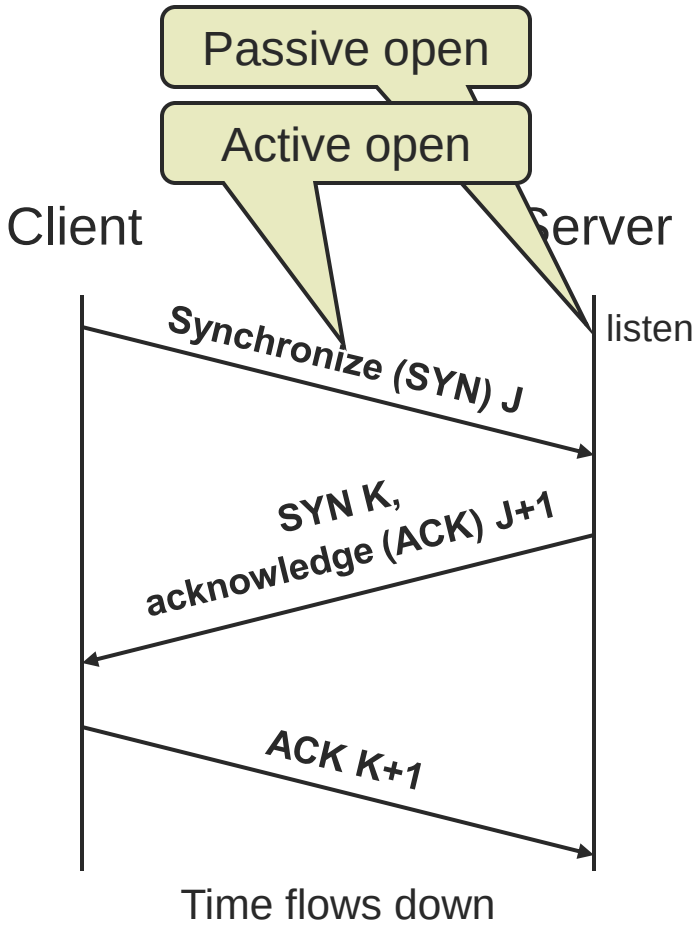
- Telephone Call
  - Guaranteed delivery
  - In-order delivery
  - Connection-oriented
  - Setup connection followed by conversation

TCP Byte Stream



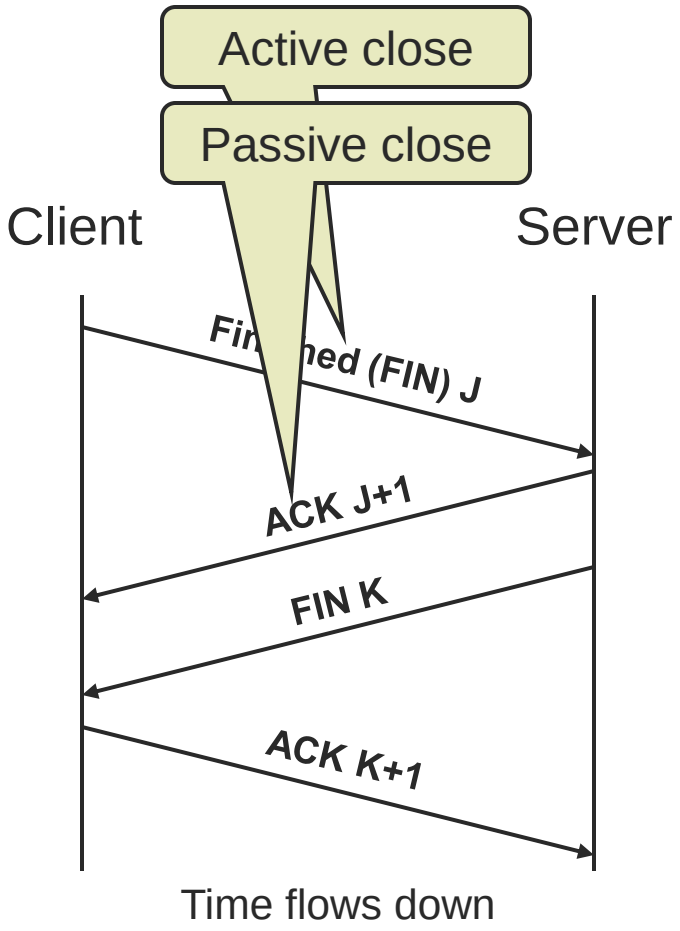
TCP Connection Establishment

- 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

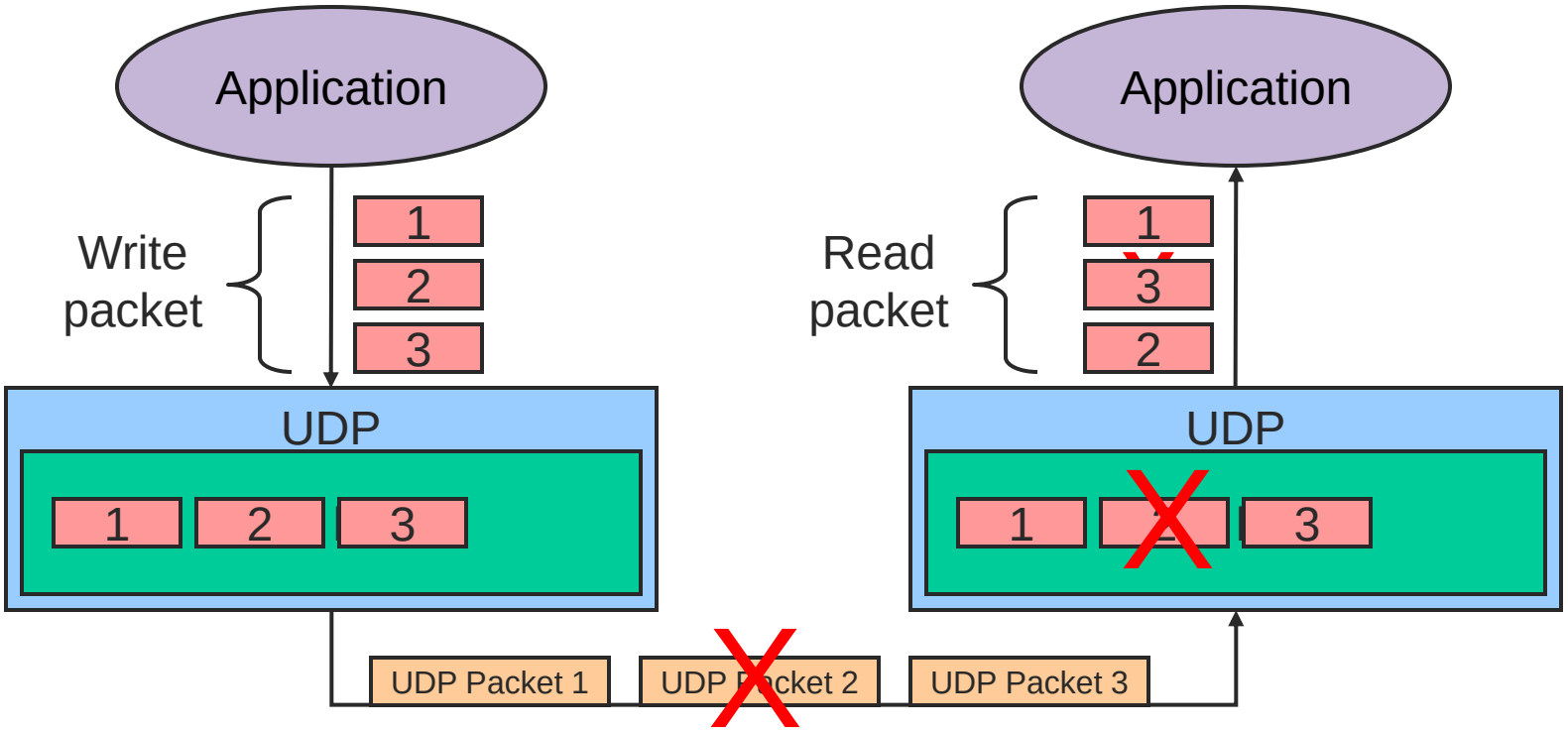
- User Datagram Protocol Service
  - OSI Transport Layer
  - Provides a thin layer over IP
  - 16-bit port space (distinct from TCP ports) allows multiple recipients on a single host

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

UDP Packet Stream



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.
```


Address Functions

- All binary values are network byte ordered

```
int gethostname(char *hostname, size_t size);
```

  - Returns the name of your machine

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

  - Returns the name of the machine at the other end of the socket!

Address Access/Conversion Functions

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

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

```
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

Sockets API

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

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);
```

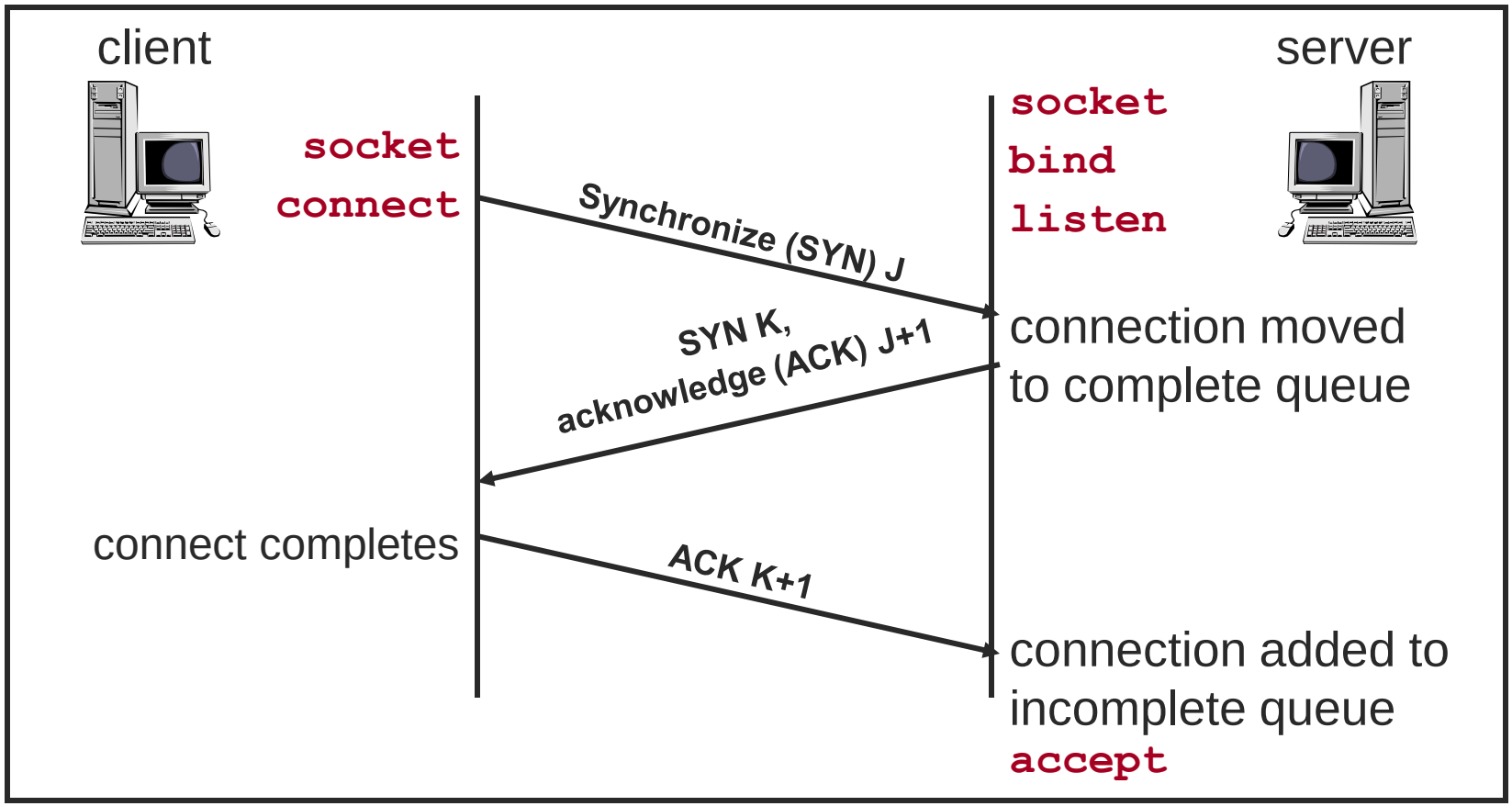
- Force termination of communication across a socket in one or both directions
  - Returns 0 on success, -1 and sets **`errno`** on failure
  - **`sockfd`**: socket file descriptor (returned from **`socket`**)
  - **`howto`**:
    - **`SHUT_RD`** to stop reading
    - **`SHUT_WR`** to stop writing
 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

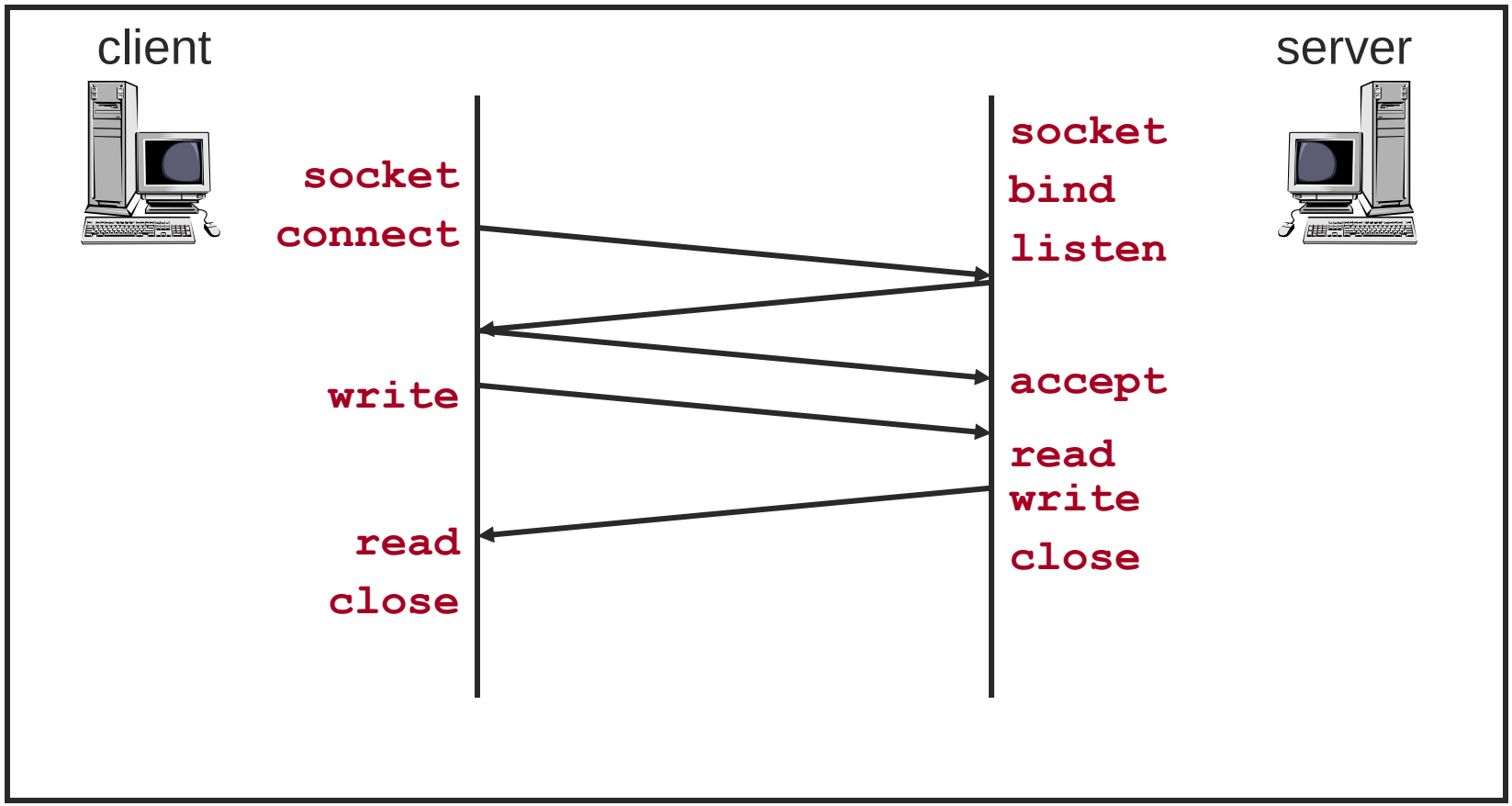
Note on `close` vs. `shutdown`

- `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

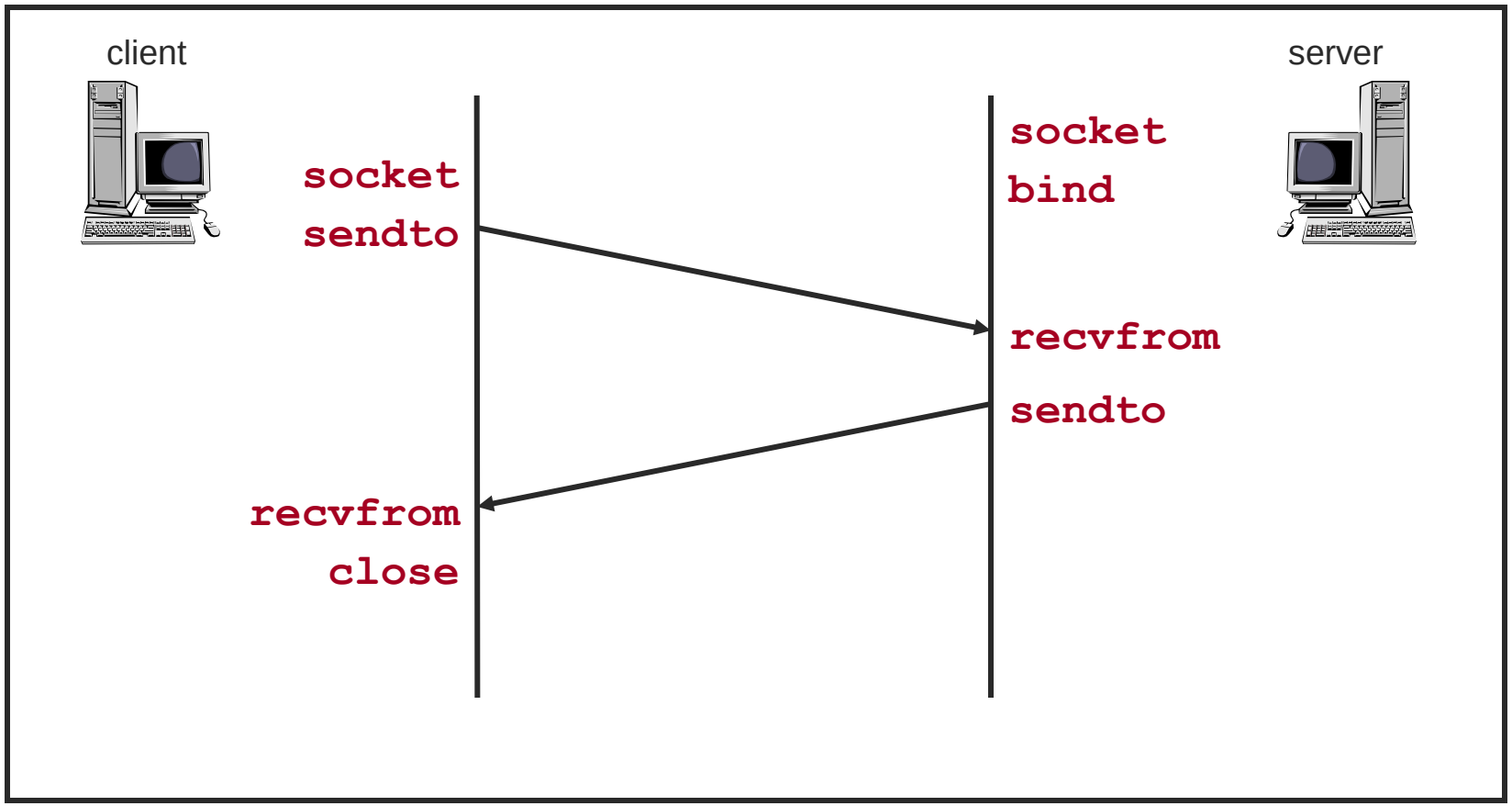
TCP Connection Setup



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

```
#define PORT "3490"  // port to connect to
#define BACKLOG 10   // Max pending connections

// get sockaddr
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);
}
```


server

```
int main(void) {
    // listen on sock_fd, new connection on new_fd
    int sockfd, new_fd;

    struct addrinfo hints, *serv, *p;

    // connector's address information
    struct sockaddr_storage their_addr;

    socklen_t sin_size;
    int yes=1;
    char s[INET6_ADDRSTRLEN];
    int rv;
```


server

```
memset(&hints, 0, sizeof hints);
hints.ai_family = AF_UNSPEC;
hints.ai_socktype = SOCK_STREAM;
hints.ai_flags = AI_PASSIVE; // use my IP

if ((rv = getaddrinfo(NULL, PORT, &hints, &serv)) != 0)
{
    fprintf(stderr, "getaddrinfo: %s\n",
            gai_strerror(rv));
    return 1;
}
```


server

```
// loop through all the 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("server: socket");
            continue;
    }
```


server

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

        break;
}
```


server

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

freeaddrinfo(servinfo); // all done with this

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


server

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


server

```
        if (!fork()) { // this is the child process
                close(sockfd); // child doesn't need this
                if (send(new_fd, "Hello, world!", 13, 0)
                                == -1)
                        perror("send");
                close(new_fd);
                exit(0);
        }
        close(new_fd);  // parent doesn't need this
    }

    return 0;
}
```


client

```
#define PORT "3490" // the port client will be connecting to

#define MAXDATASIZE 100 // max bytes can get at once

// 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);
}
```


client

```
int main(int argc, char *argv[])
{
    int sockfd, numbytes;
    char buf[MAXDATASIZE];
    struct addrinfo hints, *servinfo, *p;
    int rv;
    char s[INET6_ADDRSTRLEN];

    if (argc != 2) {
        fprintf(stderr,"usage: client hostname\n");
        exit(1);
    }
```


client

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

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


client

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

    break;
}
```


client

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

inet_ntop(p->ai_family, get_in_addr((struct sockaddr *)
            p->ai_addr), s, sizeof s);
printf("client: connecting to %s\n", s);

freeaddrinfo(servinfo); // all done with this structure

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


client

```
    buf[numbytes] = '\0';

    printf("client: received '%s'\n",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

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

#define MAXBUFLEN 100

// 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;
    struct addrinfo hints, *servinfo, *p;
    int rv;
    int numbytes;
    struct sockaddr_storage their_addr;
    char buf[MAXBUFLEN];
    socklen_t addr_len;
    char s[INET6_ADDRSTRLEN];
```


listener

```
memset(&hints, 0, sizeof hints);
hints.ai_family = AF_UNSPEC; // set to AF_INET to force IPv4
hints.ai_socktype = SOCK_DGRAM;
hints.ai_flags = AI_PASSIVE; // use my IP

if ((rv = getaddrinfo(NULL, MYPORT, &hints, &servinfo)) != 0)
{
    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

```
#define SERVERPORT "4950"     // the port to connect to

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

    if (argc != 3) {
        fprintf(stderr,"usage: talker hostname message\n");
        exit(1);
    }
```


talker

```
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