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

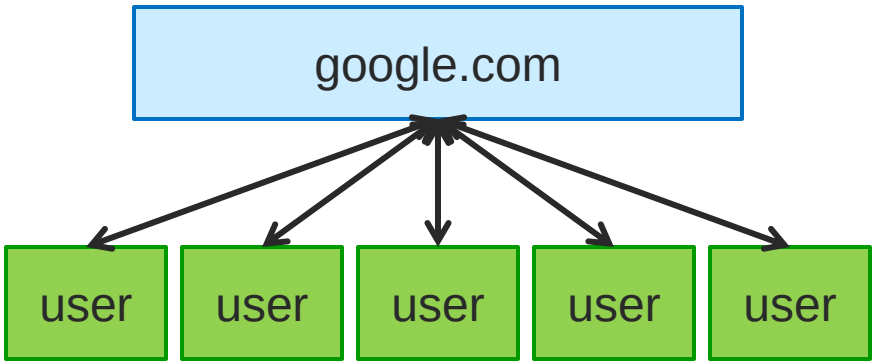
Terminology

- google.com ➔ 74.125.225.70
- facebook.com ➔ 66.220.158.11
- illinois.edu ➔ 128.174.4.87

- How are these addresses translated?

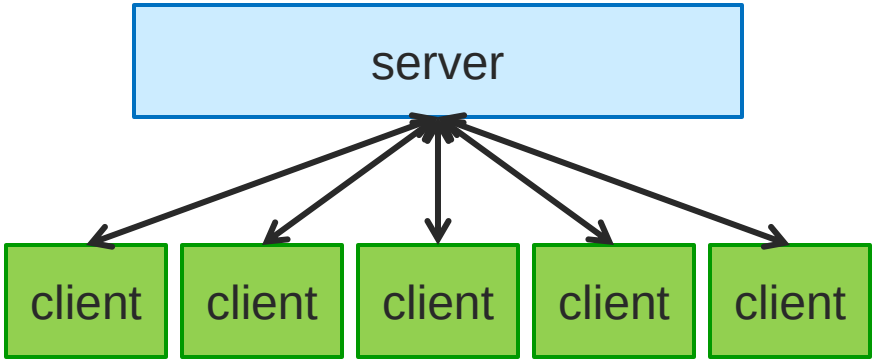
Domain Name System (DNS) via Domain Name Servers

Client-Server Model



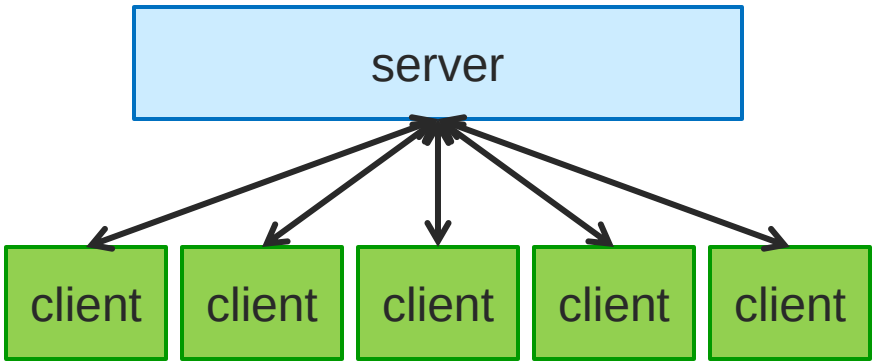
- Server: google
- Client: you
  (and everyone else)

Client-Server Model



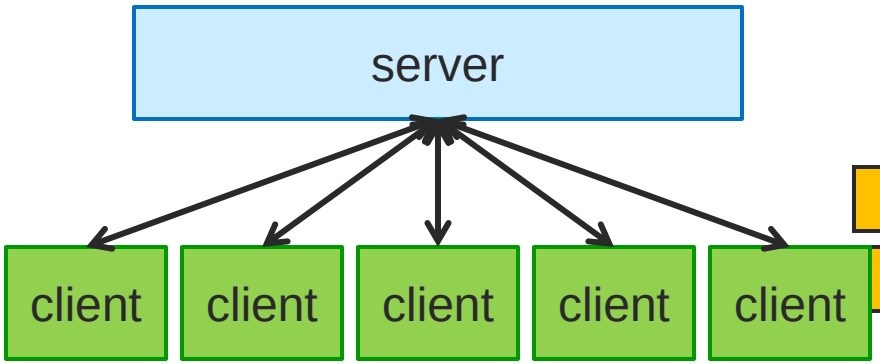
- Properties?
  - **Client:**
  - **Server:**

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** — How?
    - **Waits for server's response** — How?
  - **Server:**
    - **Well-known name**
    - **Waits for contact** — How?
    - **Processes requests, sends replies** — 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 Inner-Process Communications
  - Bi-directional
  - Connection made via a ***socket address***

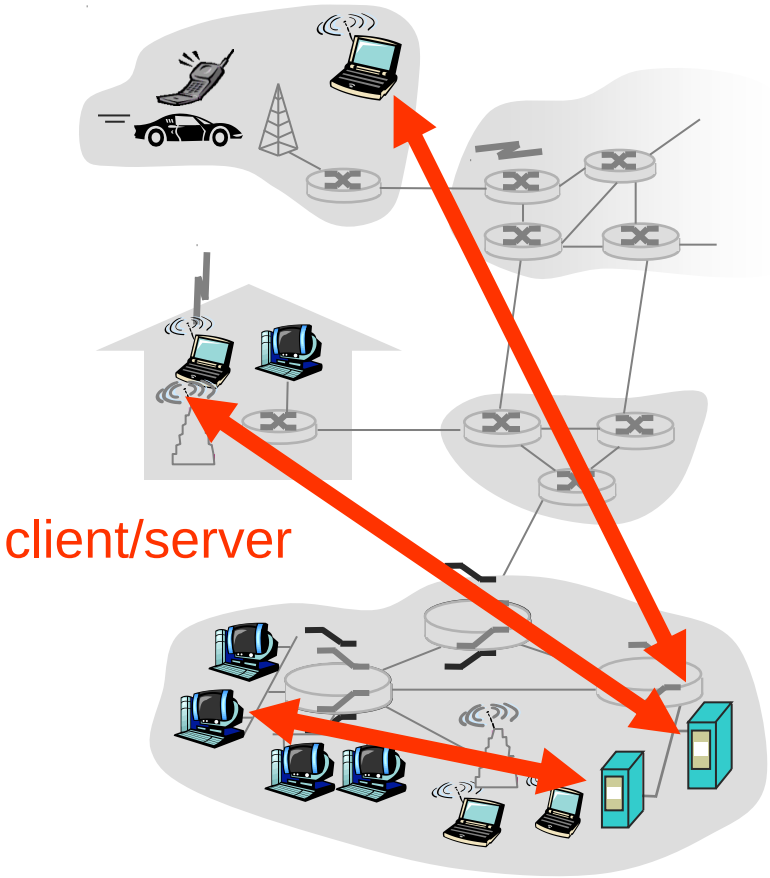
Socket Address

- A ***socket address*** is:
  - 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 utilize 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…

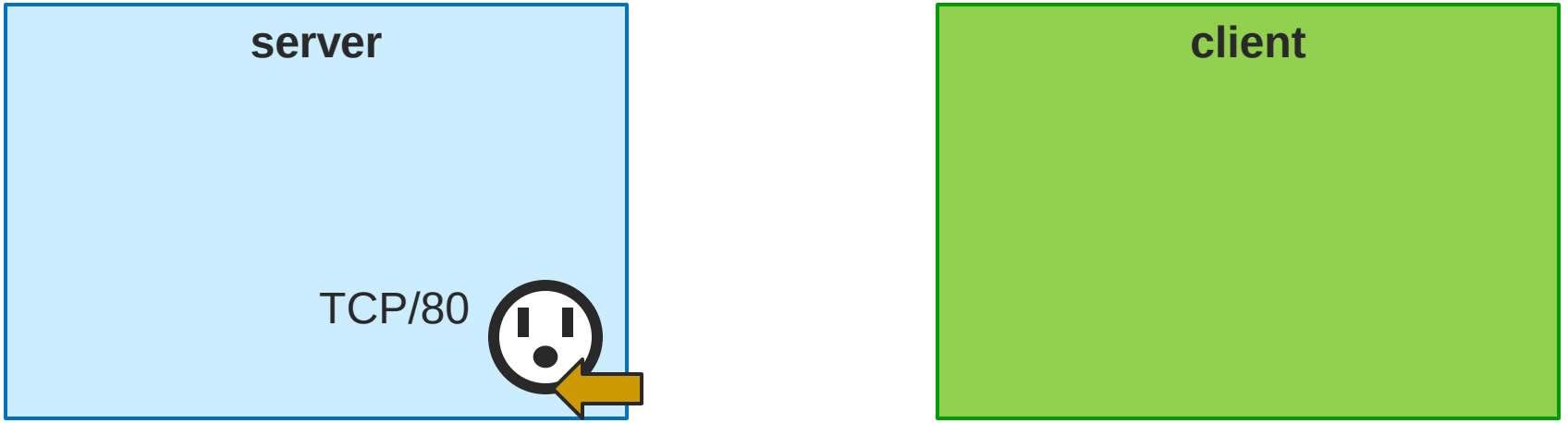
- Two ways to initialize a socket:

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

2. To connect to a “server socket”

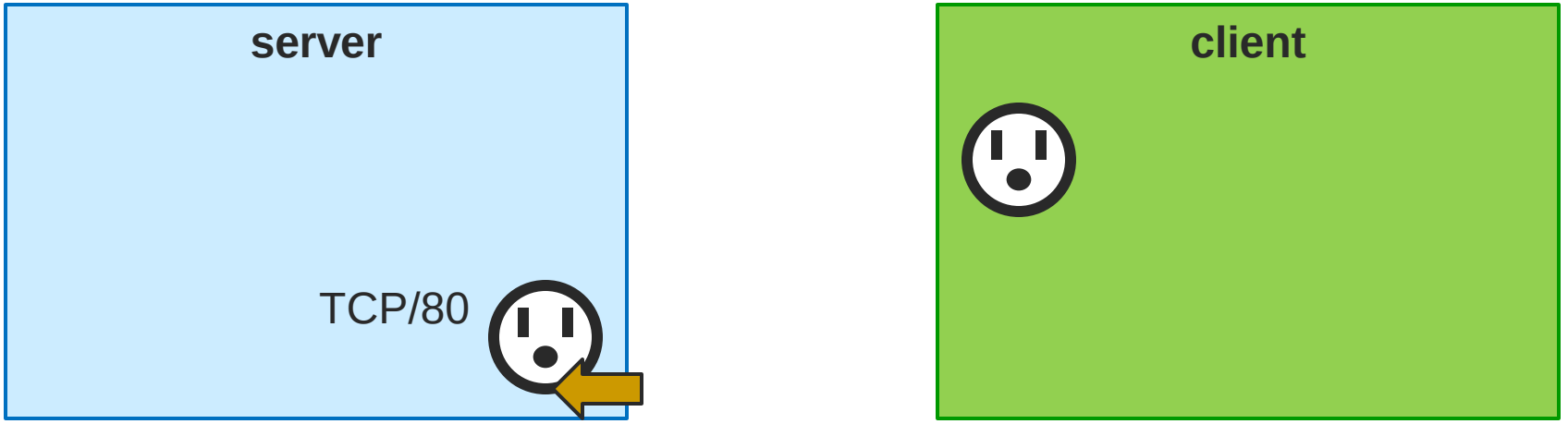
Client-Server Model

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



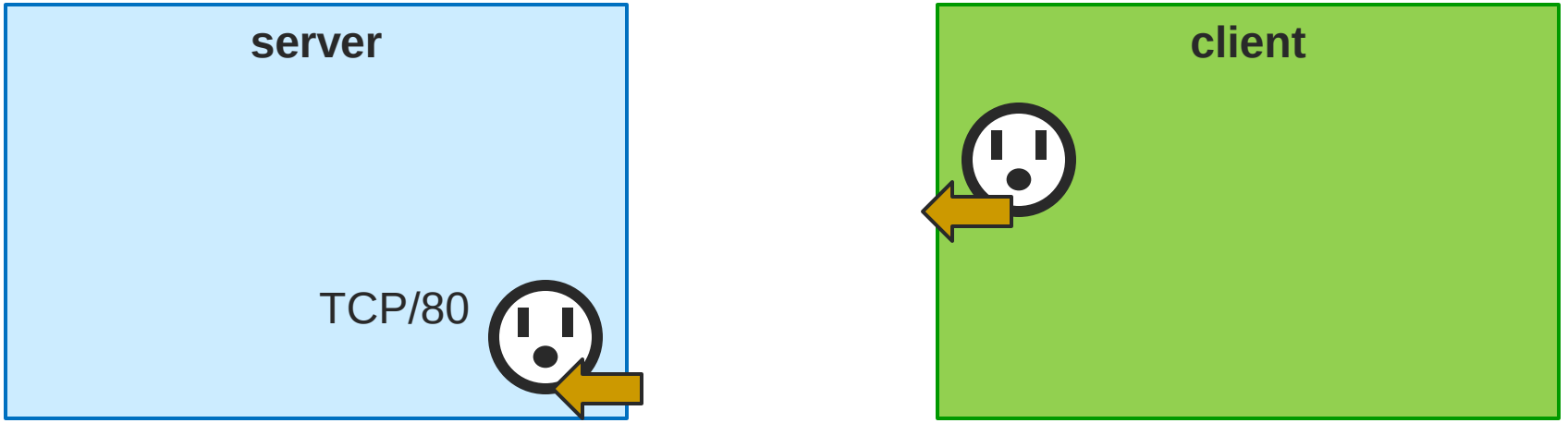
Client-Server Model

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



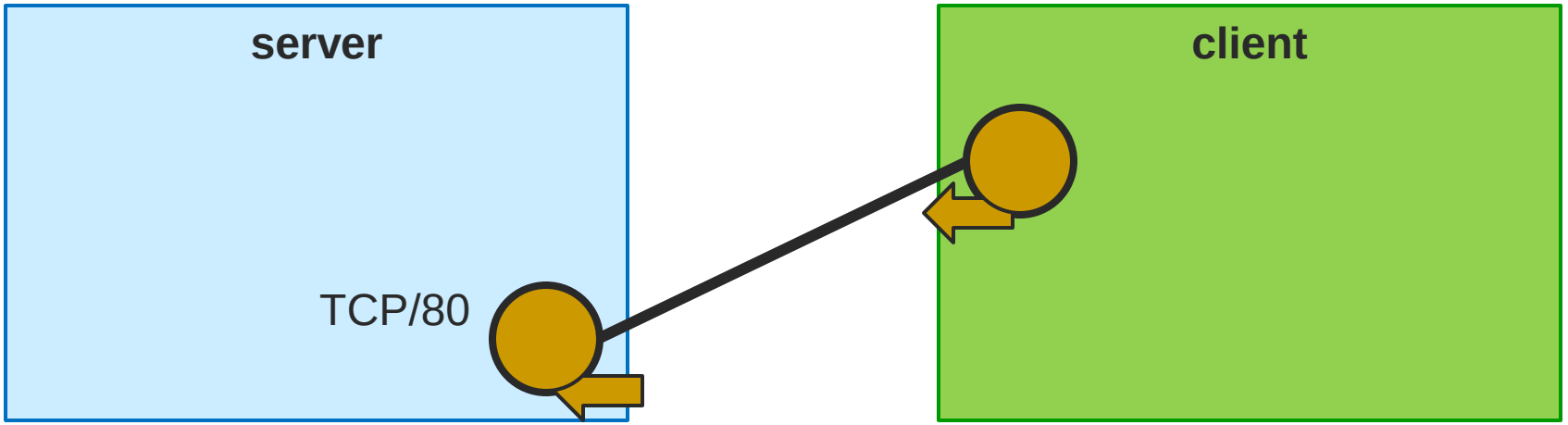
Client-Server Model

- Client:
  - Requests a connection to TCP port 80 on 74.125.225.70.



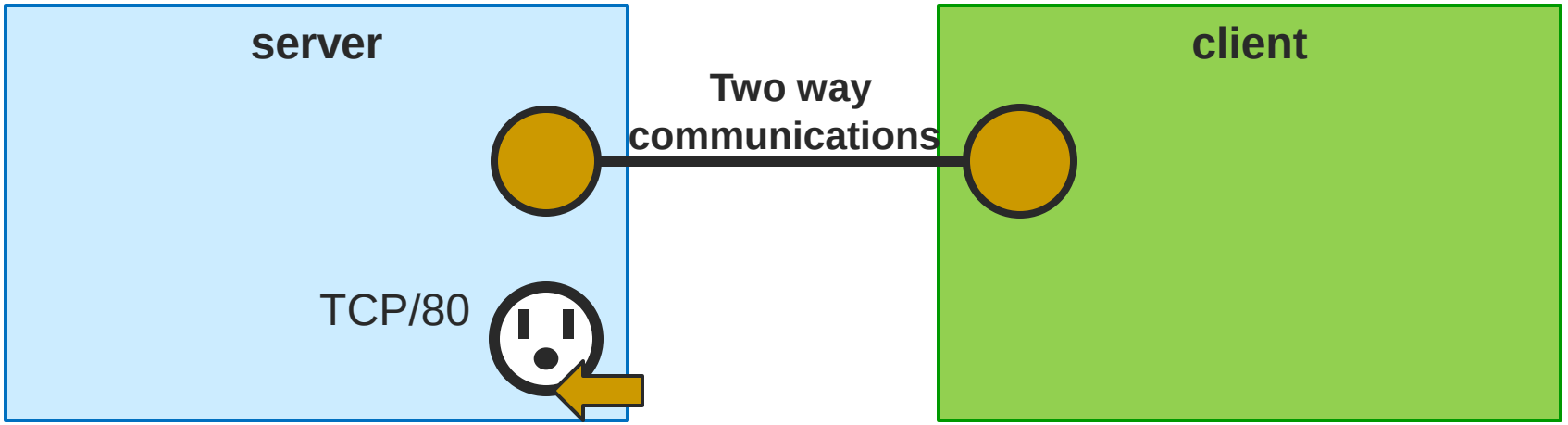
Client-Server Model

- Server:
  - Accepts the connection.



Client-Server Model

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



The `sockaddr` structure

- ***Earlier…*** *a* ***socket address*** is:
  - IP Address
  - Port Number

- This is represented in a special struct in C called a **`sockaddr`**.

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.
```


Creating a “Server Socket”

socket(): Creates a new socket for a specific protocol (eg: TCP)

bind(): Binds the socket to a specific port (eg: 80)

listen(): Moves the socket into a state of listening for incoming connections.

accept(): Accepts an incoming connection.

Creating a “Client Socket”

socket(): Creates a new socket for a specific protocol (eg: TCP)

connect():

Makes a network connection to a specified IP address and port.

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);
}
```


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 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 recv(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