Introduction to Unix Network Programming

References:

Stevens Unix Network Programming

Ch. 1-6 or 1st ed., Ch. 1-3, 6

Beej's guide: http://beej.us/guide/bgnet/

Network Programming with Sockets

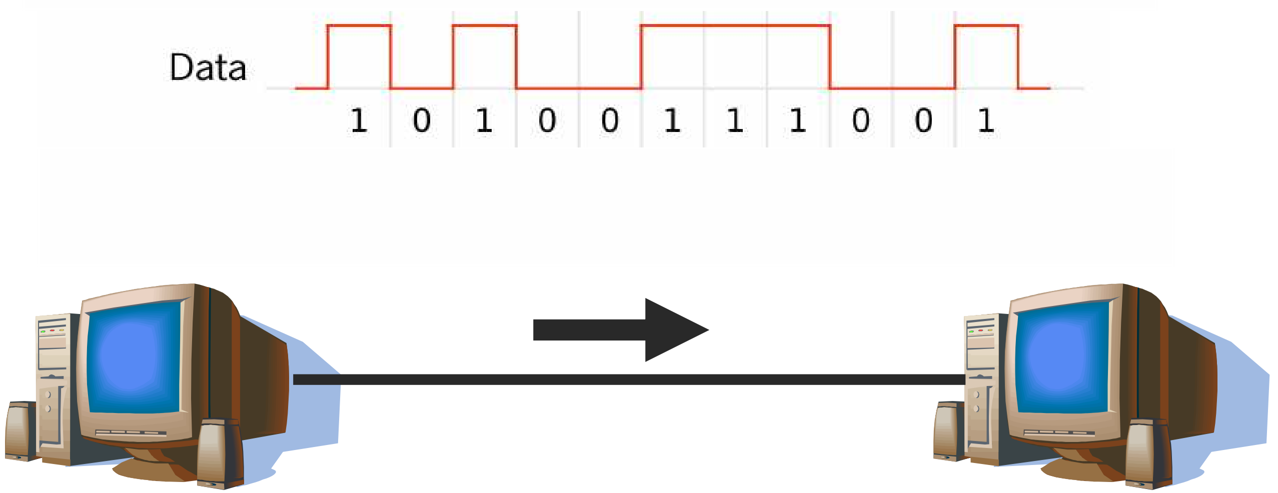
- Sockets API:
  - An interface to the transport layer
    - Introduced in 1981 by BSD 4.1
    - Implemented as library and/or system calls
    - Similar interfaces to TCP and UDP
    - Can also serve as interface to IP (for super-user); known as “raw sockets”

Network Programming

- How should two hosts communicate with each other over the Internet?
  - The “Internet Protocol” (IP)
  - Transport protocols: TCP, UDP

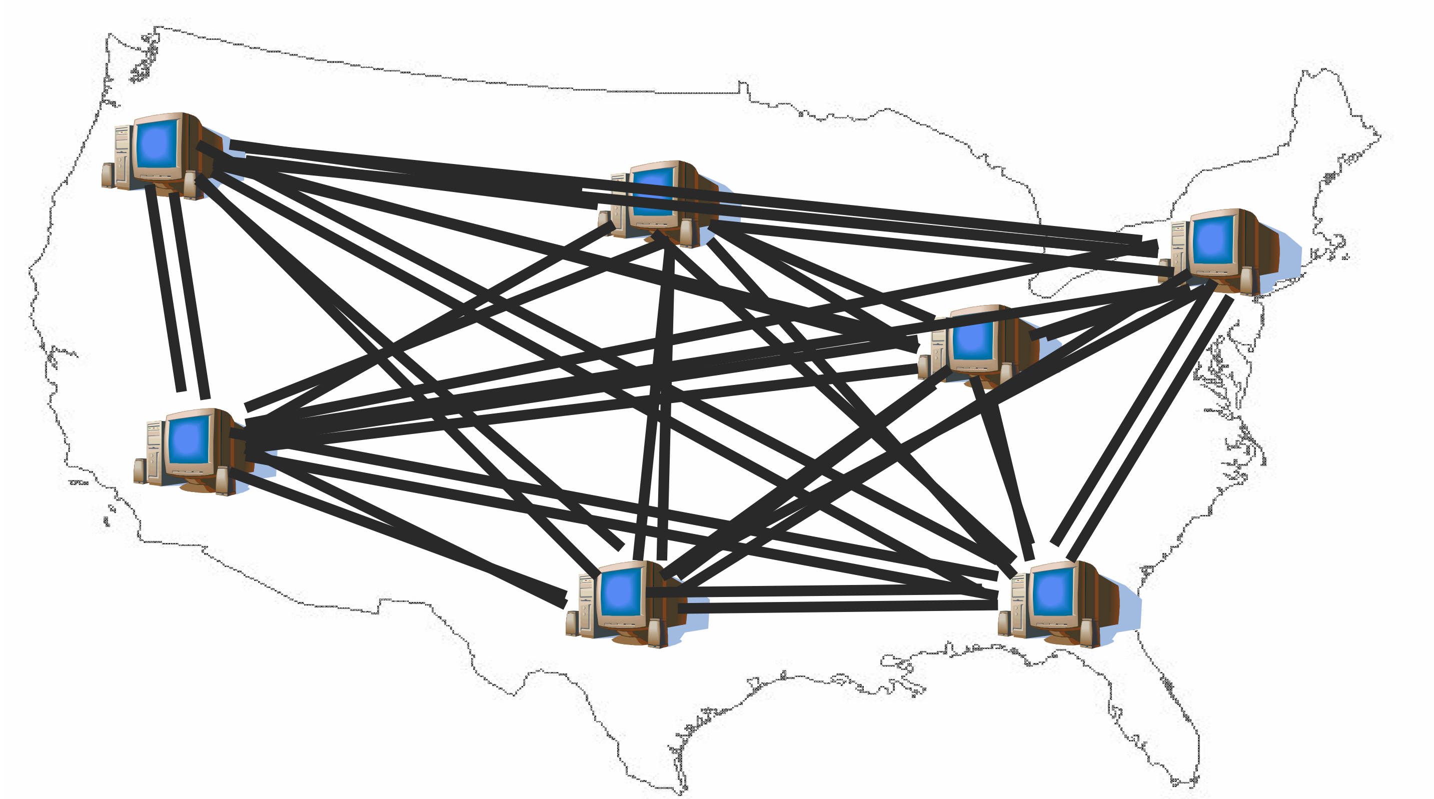
- How should programmers interact with the protocols?
  - Sockets API – application programming interface
  - De facto standard for network programming

How can two hosts communicate?



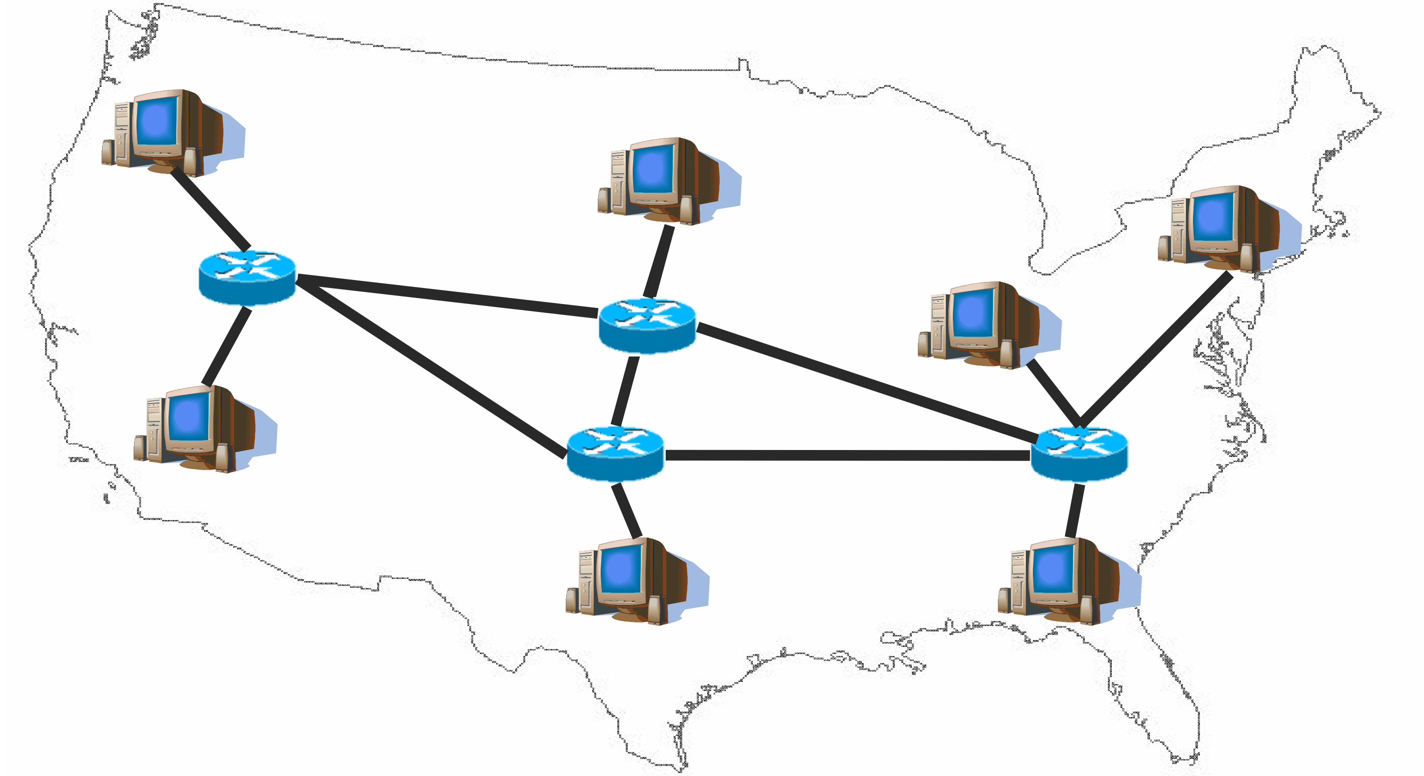
- Encode information on modulated “Carrier signal”
  - Phase, frequency, and amplitude modulation, and combinations thereof
  - Technologies: copper, optical, wireless

How can many hosts communicate?



- Naïve approach: full mesh
- Problem: doesn't scale to the 570,937,778 hosts in the Internet (estimated, Aug 2008)

How can many hosts communicate?

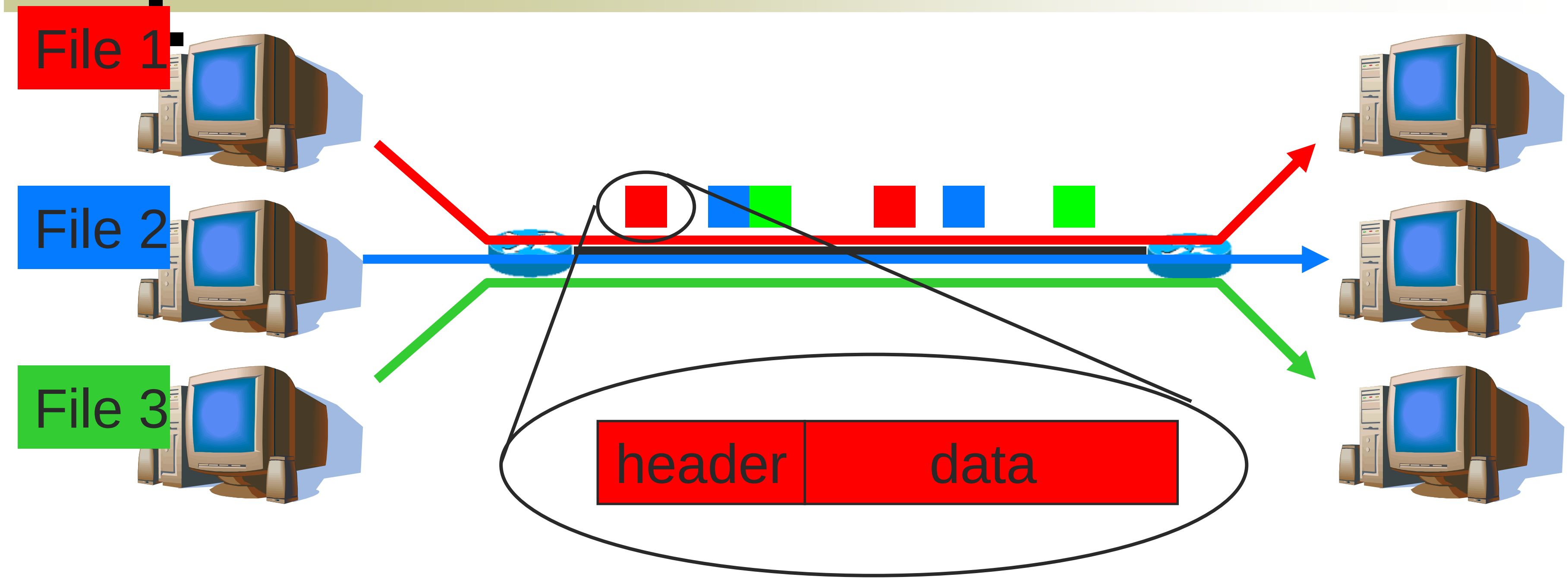


- Multiplex traffic with routers
- Question: How to identify the destination?
- Question: How to share bandwidth across different flows?

Identifying hosts with *Addresses* and *Names*

- IP addresses
  - Easily handled by routers/computers
  - Fixed length
  - E.g.: **`128.121.146.100`**
- But how do you know the IP address?
- Internet domain names
  - Human readable, variable length
  - E.g.: **`twitter.com`**
- But how do you get the IP address from the domain name?
  - Domain Name System (DNS) maps between them

How can many hosts share network resources?



- Solution: divide traffic into “IP packets”
  - At each router, the entire packet is received, stored, and then forwarded to the next router
  - Use packet “headers” to denote which connection the packet belongs to
    - Contains src/dst address/port, length, checksum, time-to-live, protocol, flags, type-of-service, etc

Is IP enough?

- What if host runs multiple applications? Or if contents get corrupted?
- Solution: User Datagram Protocol (UDP)
  - 16-bit “Port numbers” in header distinguishes traffic from different applications
  - “Checksum” covering data, UDP header, and IP header detects flipped bits
  - Unit of Transfer is “datagram” (a variable length packet)
  - Properties:
    - *Unreliable* (no guaranteed delivery)
    - *Unordered* (no guarantee of maintained order of delivery)
    - *Unlimited Transmission* (no flow control)

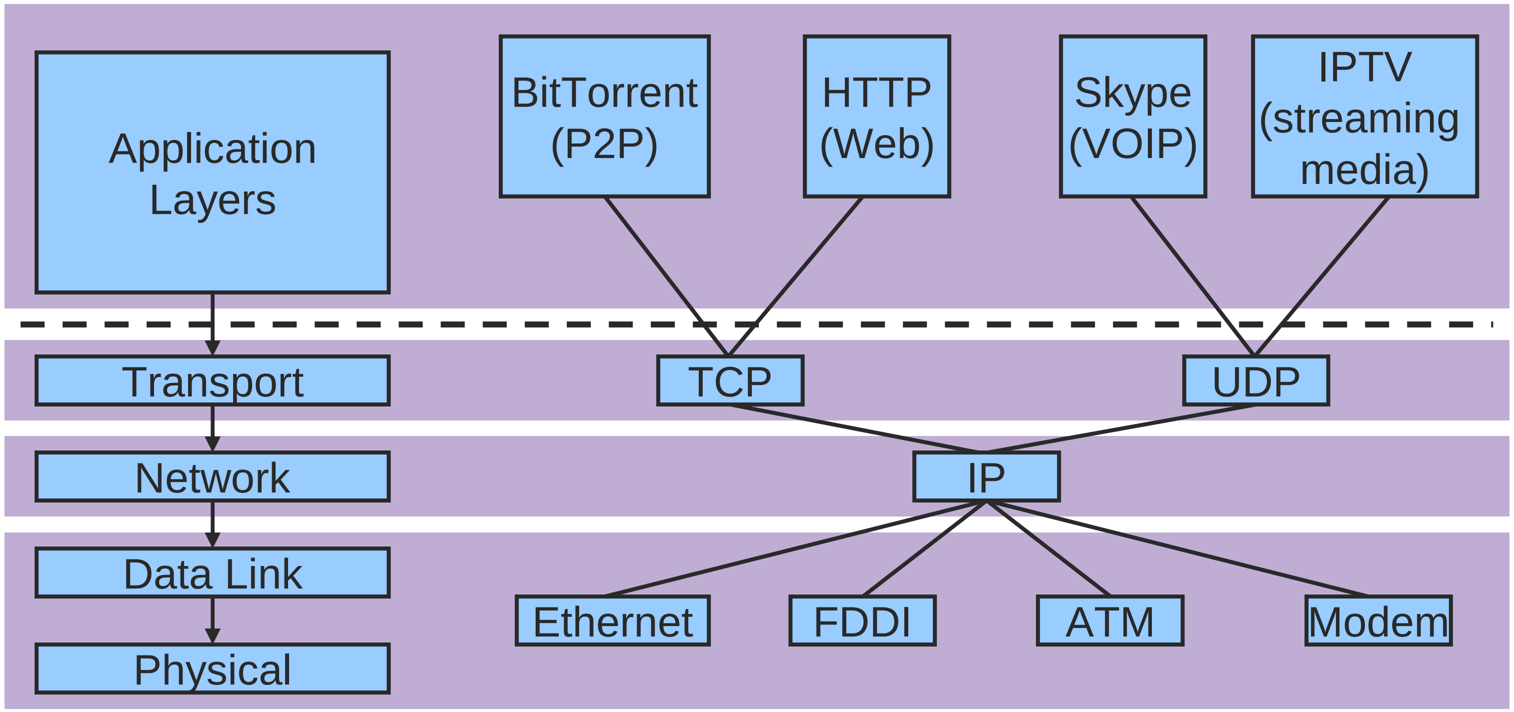
Is UDP enough?

- What if network gets congested? Or packets get lost/reordered/duplicated?
- Solution: Transport Control Protocol (TCP)
  - Uses “sequence numbers” and guarantees reliability, ordering, and integrity
  - Backs off when there is congestion
  - Connection-oriented (Set up connection before communicating, Tear down connection when done)
  - Gives ‘byte-stream” abstraction to application
  - Also has ports, but different namespace from UDP
- Which one is better, TCP or UDP?
- Why not other hybrid design points?

TCP Service

- Reliable Data Transfer
  - Guarantees delivery of all data
  - Exactly once if no catastrophic failures
- Sequenced Data Transfer
  - Guarantees in-order delivery of data
  - If A sends M1 followed by M2 to B, B never receives M2 before M1
- Regulated Data Flow
  - Monitors network and adjusts transmission appropriately
  - Prevents senders from wasting bandwidth
  - Reduces global congestion problems
- Data Transmission
  - Full-Duplex byte stream

Internet Protocols

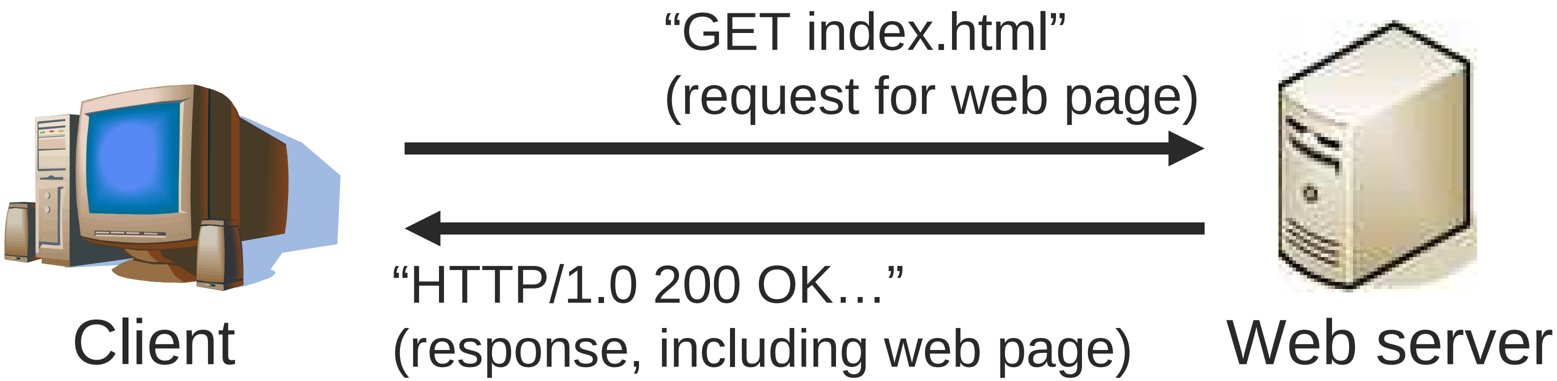


Next question: How should people program networked apps?

- How can we compose together programs running on different machines?
  - Client-server model
- What sort of interfaces should we reveal to the programmer?
  - Sockets API

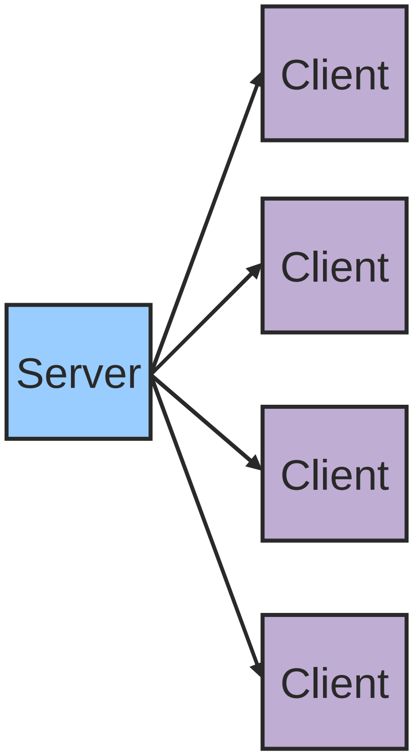
Client-Server Model

- A client initiates a request to a well-known server
- Example: the web



- Other examples: FTP, SSH/Telnet, SMTP (email), Print servers, File servers

Client-Server Model



- Asymmetric Communication
  - Client sends requests
  - Server sends replies
- Server/Daemon
  - Well-known name and port
  - Waits for contact
  - Processes requests, sends replies
- Client
  - Initiates contact
  - Waits for response
- Can you think of any network apps that are not client/server?

Server-side service models

- 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
- Which one is best?

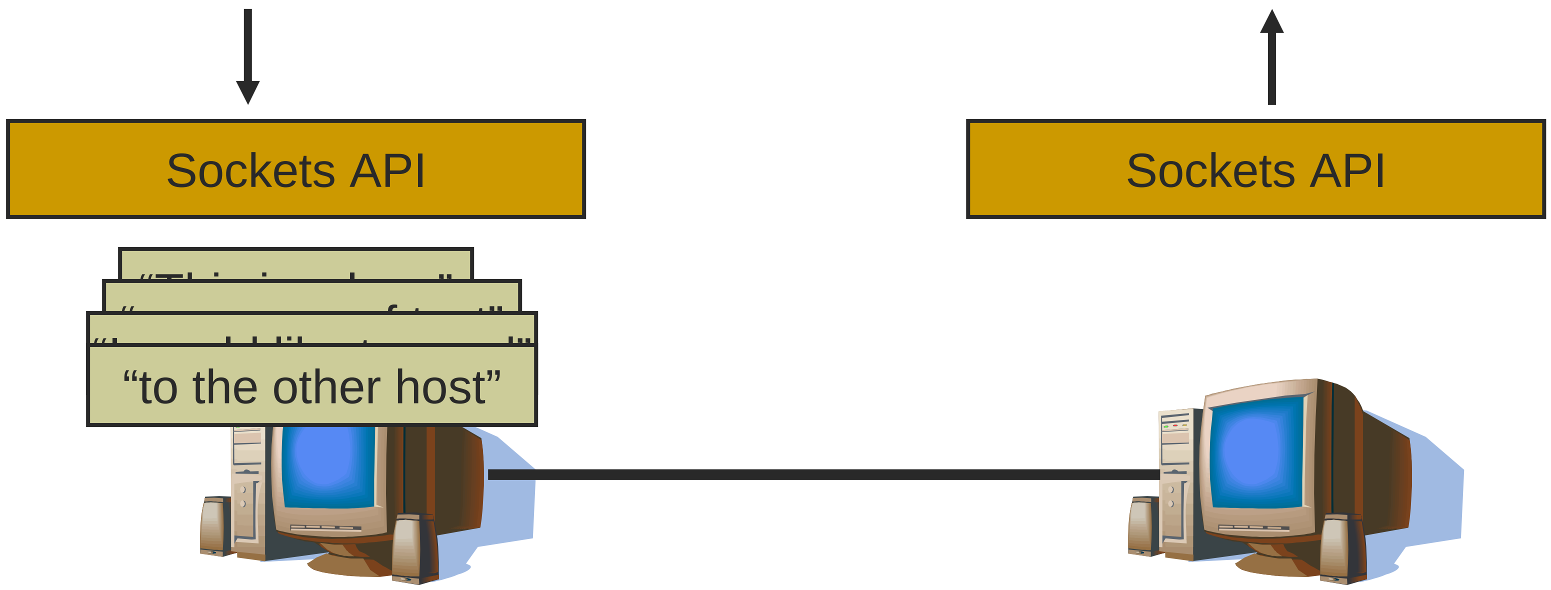
What interfaces to expose to programmer?

- Stream vs. Datagram sockets
- Stream sockets
  - Abstraction: send a long stream of characters
  - Typically implemented on top of TCP
- Datagram sockets
  - Abstraction: send a single packet
  - Typically implemented on top of UDP

Stream sockets

send(“This is a long sequence of text I would like to send to the other host”)

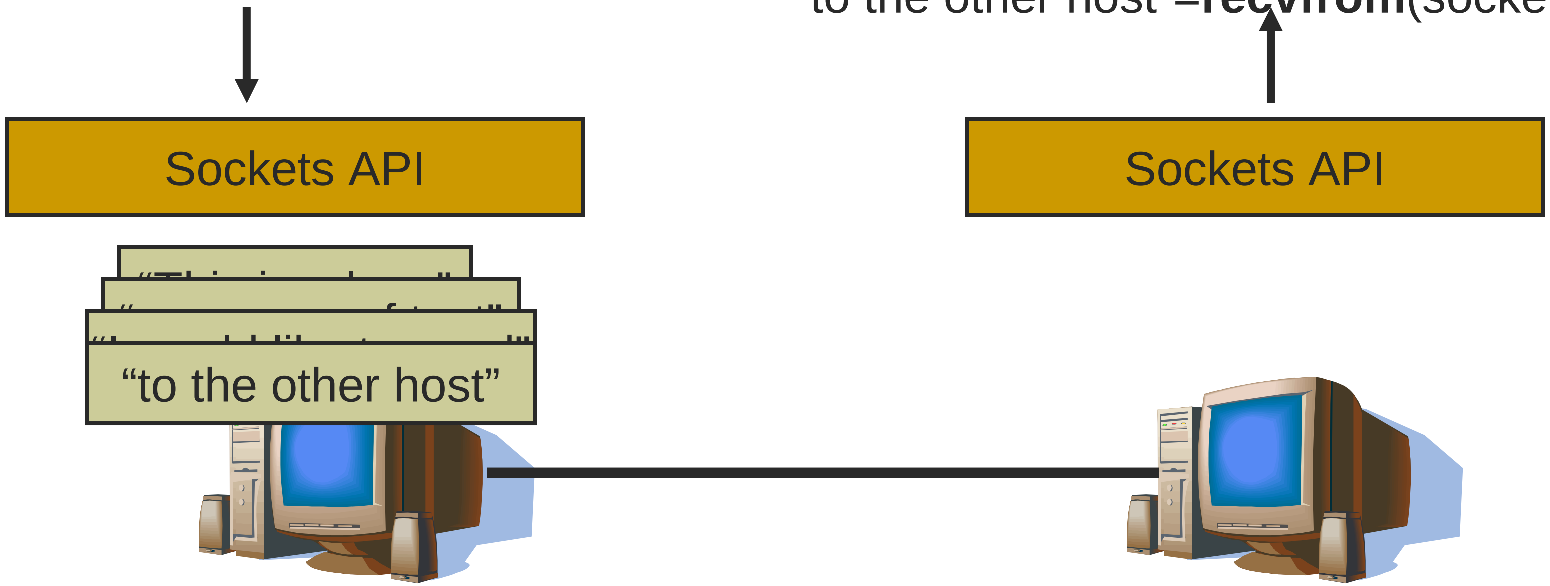
“This is a long sequence of text I would like to send to the other host”=**recv**(socket)



Datagram sockets

sendto(“This is a long”)
sendto(“sequence of text”)
sendto(“I would like to send”)
sendto(“to the other host”)

“This is a long”=**recvfrom**(socket)
“sequence of text”=**recvfrom**(socket)
“I would like to send”=**recvfrom**(socket)
“to the other host”=**recvfrom**(socket)



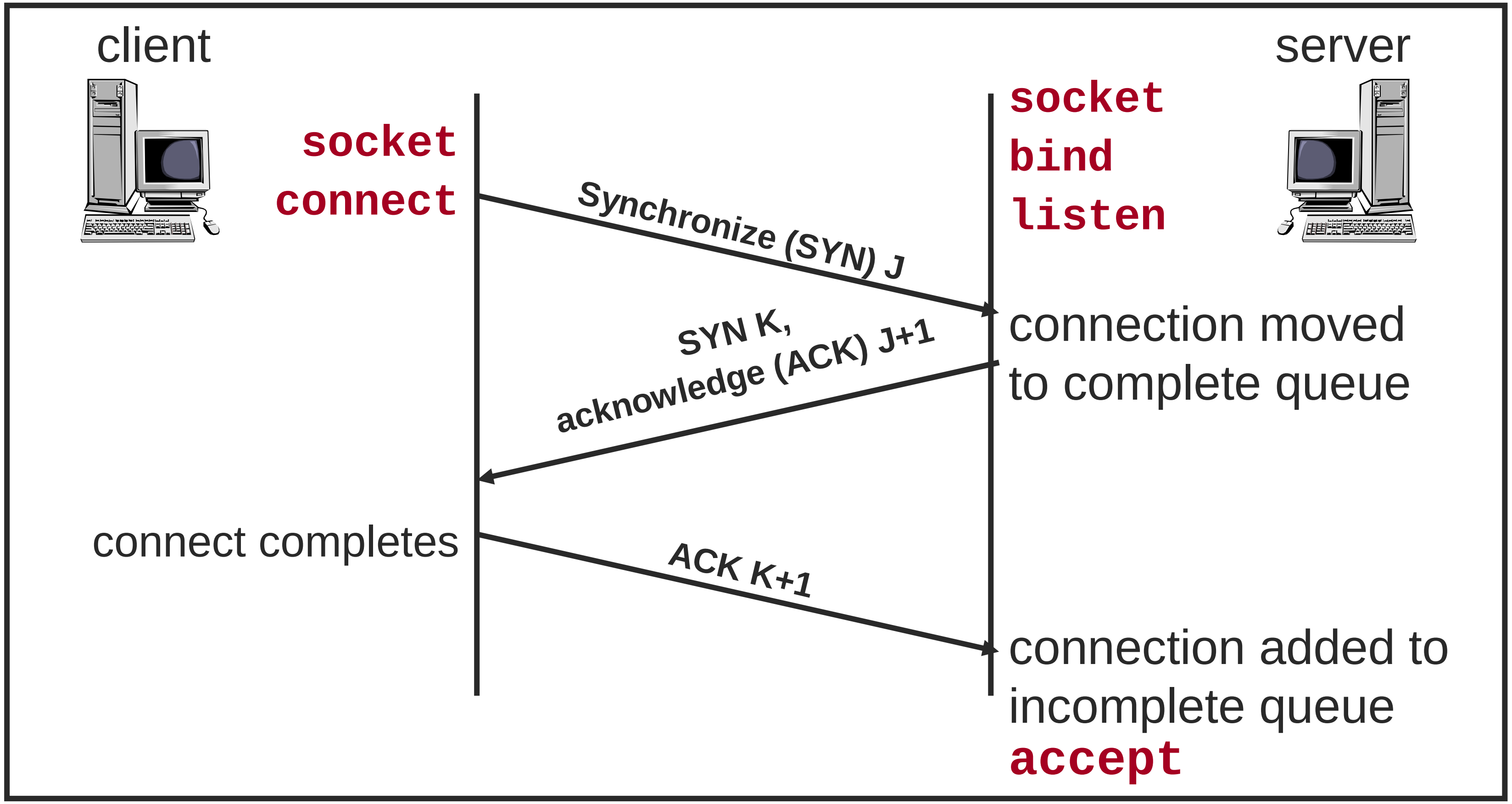
What specific functions to expose?

- Data structures to *store information about connections and hosts*
- Functions to *create and bind "socket descriptors"*
- Functions to *establish and teardown connections*
- Functions to *send and receive data over connections*

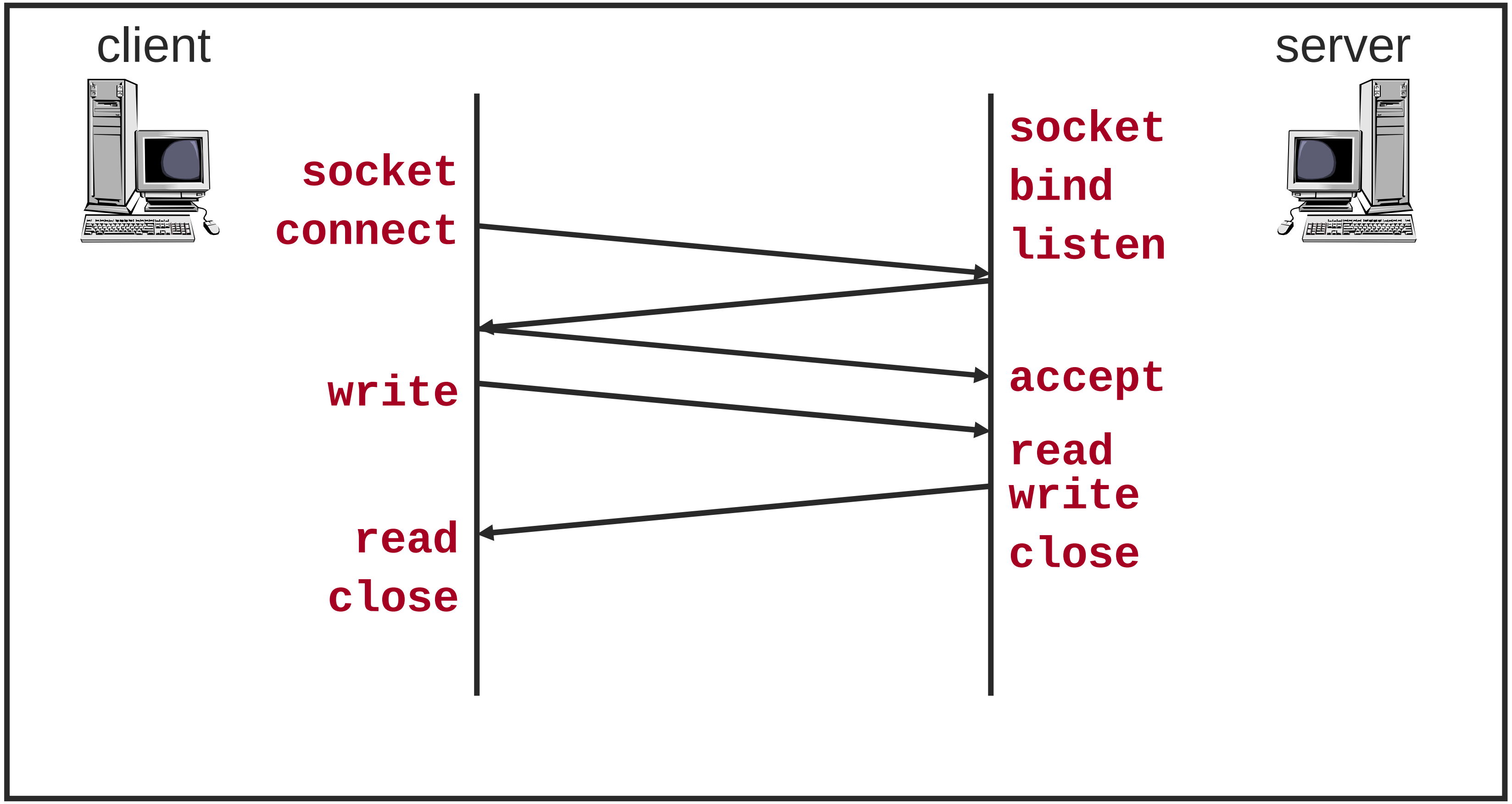
Example: TCP streaming client

1. Client specifies an IP address and port it wants to connect to.
2. The sockets library takes care of the connection setup details, and returns back a unique integer (a "socket").
3. When the application wants to send data, it specifies the socket number, and a pointer to the data it wants to send.
4. The library looks up in a table the IP/port information corresponding to that socket number, constructs a packet, puts that IP/port in the header, and sends the packet.

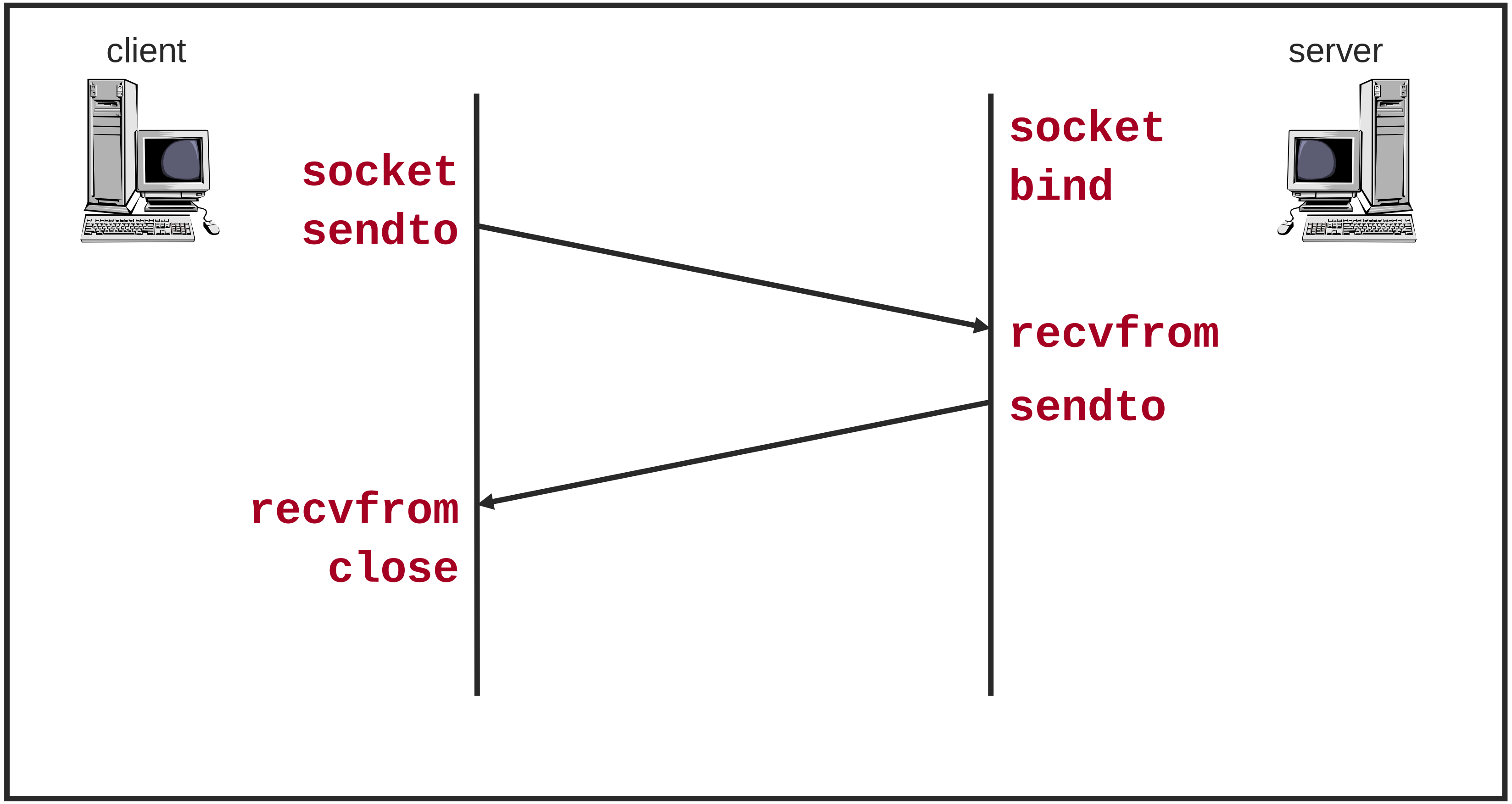
TCP Connection Setup



TCP Connection Example



UDP Connection Example



```
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);
    }
    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);
```

Socket descriptor (used to identify connections)

Information about a host (domain name, list of addresses associated with machine, type of address, etc

Gets IP address and other info for specified hostname via DNS lookup

Returns an available socket descriptor

Specifies identity of server we will connect to

```
    if (connect (sockfd, (struct sockaddr*)&their_addr,
                    sizeof (struct sockaddr)) == -1) {
        perror (“connect”);
        exit (1);
    }
    if ((numbytes = recv (sockfd, buf, MAXDATASIZE, 0))
                == -1) {
        perror (“recv”);
        exit (1);
    }

    buf[numbytes] = ‘\0’;
    printf (“Received: %s”, buf);
    close (sockfd);
    return 0;
}
```

Returns an available socket descriptor

Receive data from server, put it into buf

Tell OS we are done with this socket, Which will clean up state and tear down the connection

```
// SERVER CODE
main()
{
    int sockfd, 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);
    }
    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);
    }
```

Socket descriptors (used to identify connections)

Returns an available socket descriptor

Specifies identity of server's end of the connection

Associates that identity to the socket

```
// SERVER CODE (continued)

    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));
        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);
    }
}
```

Tell OS that we are we are willing To accept connections on this socket

Associate “new_fd” with the next client that connects (block until one does)

Send “hello world” to the client connected to new_fd

Tell OS we are done with this socket, which will clean up state and tear down the connection

Sockets API details

- Data structures to store/convert information about hosts/connections
  - **`inet_ntoa, inet_aton, gethostbyname,`**
- Functions to create and bind socket descriptors
  - **`socket, bind, listen`**
- Functions to establish and teardown connections
  - **`connect, accept, close, shutdown`**
- Functions to send and receive data
  - **`send, sendto, write, recv, recvfrom, read`**

One tricky issue…

- Different processor architectures store data in different “byte orderings”
  - What is 200 in binary? `1100 1001`? Or `1001 1100`?

- **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, PowerPC):
    - Most significant byte of word is stored in the lowest memory address
  - Host Byte Order can be Big or Little Endian
  - Network Byte Order = Big Endian
    - Allows both sides to communicate
    - Must be used for some data (i.e. IP Addresses)

Converting byte orderings

Solution: use byte ordering functions to convert. E.g.:

```
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
```

How to handle concurrency?

- Process requests serially
  - Slow – what if you're processing another request? What if you're blocked on accept()?

- Multiple threads/processes (e.g. Apache web server)
  - Each thread handles one request
  - fork(), pthreads

- Synchronous I/O (e.g. Squid web proxy cache)
  - Maintain a "set" of file descriptors, whenever one has an "event", process it and put it back onto the set
  - select(), poll()

Select

```
int select (int num_fds, fd_set* read_set, fd_set*
    write_set, fd_set* except_set, struct timeval*
    timeout);
```

- Wait for readable/writable file descriptors.
- Return:
  - Number of descriptors ready
  - -1 on error, sets **`errno`**
- Parameters:
  - **`num_fds`**:
    - number of file descriptors to check, numbered from 0
  - **`read_set, write_set, except_set`**:
    - Sets (bit vectors) of file descriptors to check for the specific condition
  - **`timeout`**:
    - Time to wait for a descriptor to become ready

File Descriptor Sets

```
int select (int num_fds, fd_set* read_set,
   fd_set* write_set, fd_set* except_set, struct
   timeval* timeout);
```

- Bit vectors
  - Only first **num_fds** checked
  - Macros to create and check sets

```
fds_set myset;
void FD_ZERO (&myset);     /* clear all bits */
void FD_SET (n, &myset);   /* set bits n to 1 */
void FD_CLEAR (n, &myset); /* clear bit n */
int FD_ISSET (n, &myset);  /* is bit n set? */
```

File Descriptor Sets

- Three conditions to check for
  - Readable:
    - Data available for reading
  - Writable:
    - Buffer space available for writing
  - Exception:
    - Out-of-band data available (TCP)

Timeout

- Structure

```
struct timeval {
   long tv_sec;        /* seconds */
   long tv_usec;       /* microseconds */
};
```

Select

- High-resolution sleep function
  - All descriptor sets **NULL**
  - Positive **timeout**
- Wait until descriptor(s) become ready
  - At least one descriptor in set
  - **timeout NULL**
- Wait until descriptor(s) become ready or timeout occurs
  - At least one descriptor in set
  - Positive **timeout**
- Check descriptors immediately (poll)
  - At least one descriptor in set
  - 0 **timeout**

Select: Example

```
fd_set my_read;
FD_ZERO(&my_read);
FD_SET(0, &my_read);

if (select(1, &my_read, NULL, NULL) == 1) {
   ASSERT(FD_ISSET(0, &my_read);
   /* data ready on stdin */
}
```

- Question: which is better, pthreads or select?

Advanced Sockets

```
int yes = 1;
setsockopt (fd, SOL_SOCKET,
   SO_REUSEADDR, (char *) &yes, sizeof
   (yes));
```

- Call just before bind
- Allows bind to succeed despite the existence of existing connections in the requested TCP port
- Connections in limbo (e.g. lost final ACK) will cause bind to fail

Concurrent programming with Posix Threads (pthreads)

- When coding
  - Include **<pthread.h>** first in all source files
- When compiling
  - Use compiler flag **–D_REENTRANT**
- When linking
  - Link library **-lpthread**

```
// PTHREADS EXAMPLE

void main(int argc, char* argv[]) {
    int n,i;
    pthread_t *threads;
    pthread_attr_t pthread_custom_attr;
    parm *p;

    if (argc != 2)
    {
        printf ("Usage: %s n\n  where n is no. of threads\n",argv[0]);
        exit(1);
    }

    n=atoi(argv[1]);

    if ((n < 1) || (n > MAX_THREAD))
    {
        printf ("The no of thread should between 1 and
                        %d.\n",MAX_THREAD);
        exit(1);
    }

    threads=(pthread_t *)malloc(n*sizeof(*threads));
    pthread_attr_init(&pthread_custom_attr);

    p=(parm *)malloc(sizeof(parm)*n);
```

Contains thread information, acts as handle for thread

Specifies "attributes" for thread, like Scheduling policy/priority and stack size

Initializes attributes to default values (NULL)

```
    /* Start up threads */
    for (i=0; i<n; i++)
    {
       p[i].id=i;
       pthread_create(&threads[i], &pthread_custom_attr, hello,
             (void *)(p+i));
    }

    /* Synchronize the completion of each thread. */

    for (i=0; i<n; i++)
    {
       pthread_join(threads[i],NULL);
    }
    free(p);
}

void *hello(void *arg)
{
    parm *p=(parm *)arg;
    printf("Hello from node %d\n", p->id);
    return (NULL);
}
```

Creates a pthread, assigns it attributes, triggers it to run function pointer

Wait on termination of thread threads[i]

Thread function (passed in during pthread_create)

pthread Creation

```
int pthread_create (pthread_t* tid, pthread_attr_t*
    attr, void*(child_main), void* arg);
```

- Spawn a new posix thread
- Parameters:
  - **`tid`**:
    - Unique thread identifier returned from call
  - **`attr`**:
    - Attributes structure used to define new thread
    - Use **`NULL`** for default values
  - **`child_main`**:
    - Main routine for child thread
    - Takes a pointer **`(void*)`**, returns a pointer **`(void*)`**
  - **`arg`**:
    - Argument passed to child thread

Sockets API details

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Socket Address Structure

- IP address:

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

- TCP or UDP address+port:

```
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

Address Access/Conversion Functions

- All binary values are network byte ordered

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

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

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

- Translate IP address to DNS 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)

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

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)`**

TCP and UDP Ports

- Allocated and assigned by the Internet Assigned Numbers Authority
  - see **RFC 1700** or

ftp://ftp.isi.edu/in-notes/iana/assignments/port-numbers

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

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

Functions: accept

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

- Accept 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)

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.

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: 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

- Some reasons for failure or partial writes
  - process received interrupt or signal
  - kernel resources unavailable (*e.g.*, buffers)

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 and 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

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: 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)`**

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

Summary

- Transport protocols
  - TCP, UDP
- Network programming
  - Sockets API, pthreads