Lecture 4
Socket Programming

George Nychis

Carnegie Mellon University

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http://www.cs.cmu.edu/~srini/15-441/F06/

Outline of Lecture

- Project 1 – Questions?
- Motivation for Sockets
- Introduction to Sockets
- Nitty Gritty of Sockets
- Break
  - Find a project partner!
- Concurrent Connections
- Select
- Roundup

Last Time

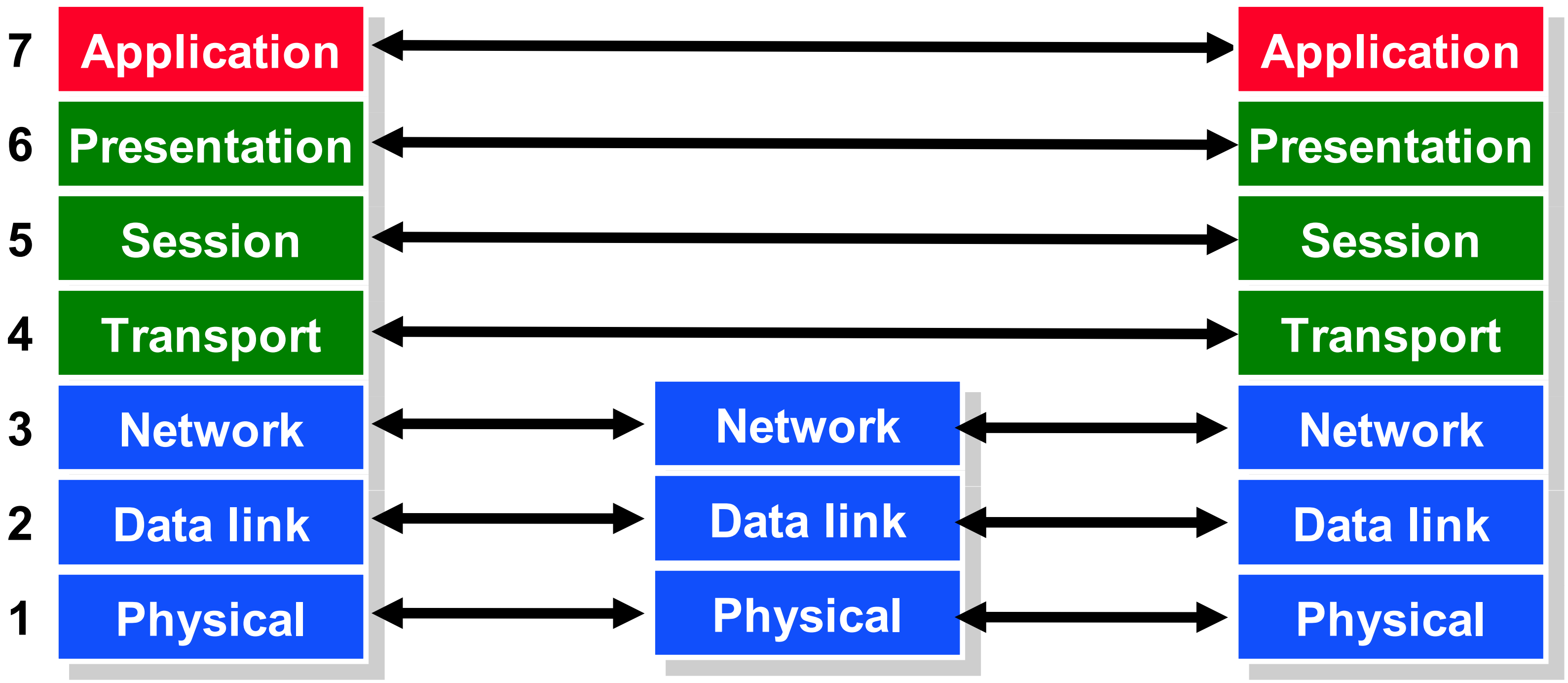
- What is a network?
- Lets start simple...
  - » What is a motivation of a computer network?
  - » What do we use networks for?
  - » How do we share data?

Let's Share Data!

- Suppose we have a 5MB file ...
  - » How can we transfer it?
  - » What type of applications and services can we use?
  - » Where do these services run?

Where do these processes exist?

- Lets take a step back:



IPC: Interprocess Communication

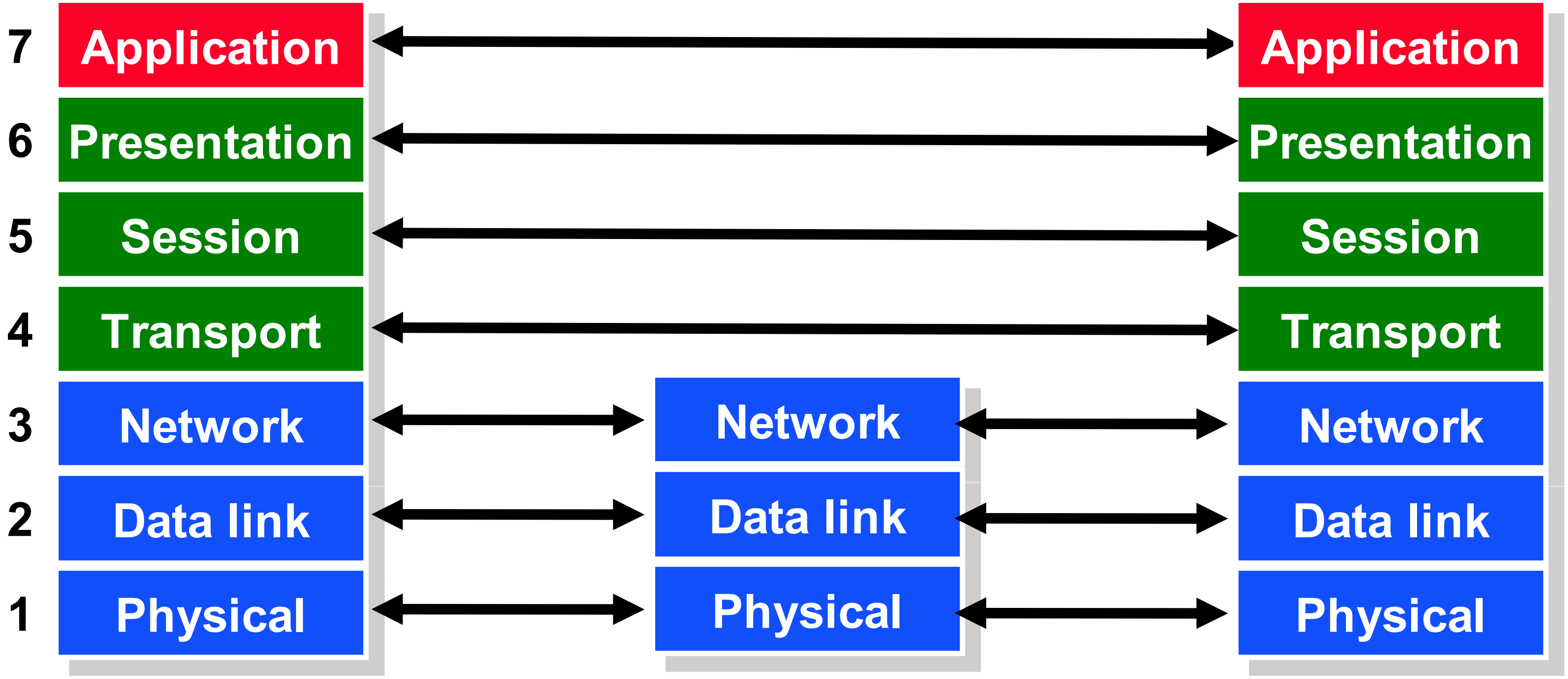
- **Overall Goal: Interprocess communication**
  - » **So what is the problem?**

- **No problem when both processes on a single machine...**

- **Network services such as FTP servers and HTTP servers typically run on seperate machines from the clients that access them**

Back to the Application Layer

- Lets revisit this one more time... why a layered abstraction again?



Just pass it down...

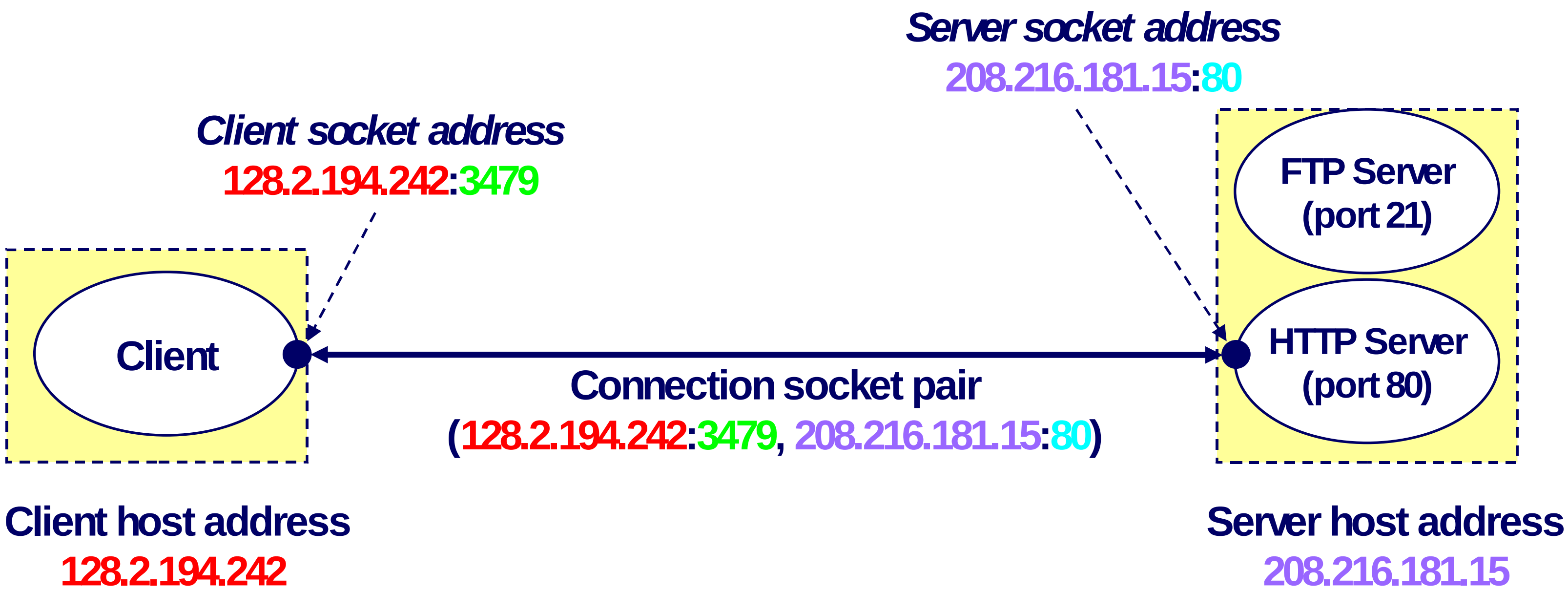
- Author of an FTP server does not need to worry about:
  - » How frames are formed
  - » How the data is routed through the network
  - » How reliability is ensured

- Author only needs a method of passing the data down to the next layer

Lower Layers Need Info

- OK, we pass the data down... what else do the lower layers need to know?
- Where does the data go?
- Once it gets there, where does it then go? What process gets the data?

Identifying the Destination



Why Should You Care?

- You've all read the project 1 description... *winking smiley face*
- You're going to be writing an application level service! (IRC server)
- You will need to do all of what we talked about:
  - Pass messages
  - Share data
- This is all done between the servers you write, and clients we will use to test them on seperate machines! (IPC)

Sockets

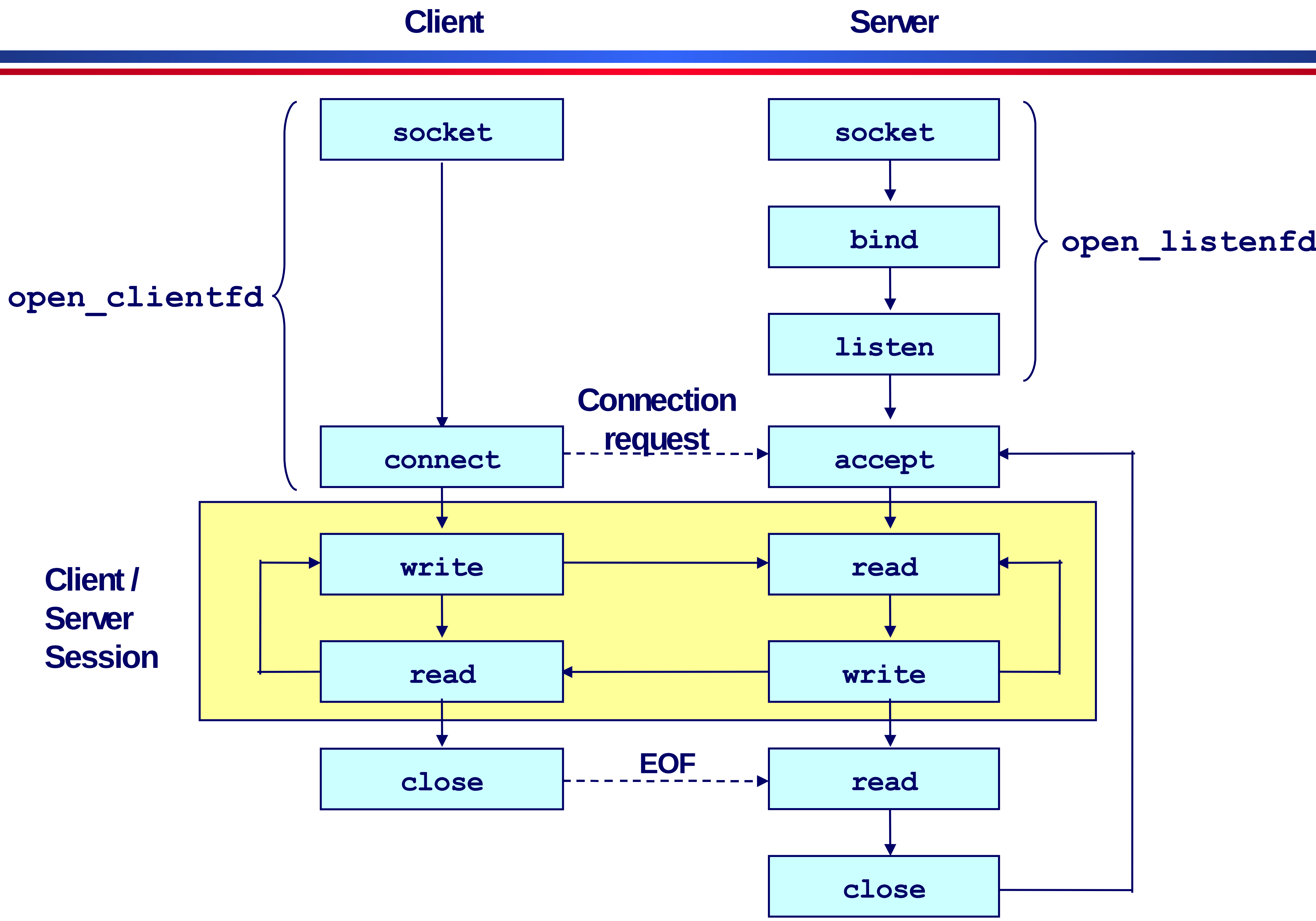
- Lucky for you, someone made it easy...

- Sockets!
  - » Set up the socket
    - – Where is the remote machine? (IP address)
    - – What service gets the data? (Port number)
  - » Send and Receive
    - – Designed to be simple, just like any other I/O in unix, read and write to the socket like a file
    - – Send -> write()
    - – Receive <- read()
  - » Close the socket

Client / Server

- **Socket setup depends on application**
- **Both client and server applications need to request a socket descriptor**
  - » Specify domain like IPv4 and then the type TCP/UDP
- **Server**
  - » Bind: assign a local address and port to the socket, like "127.0.0.1" and "80"
  - » Listen: ready to accept incoming connections
  - » Accept: take the first incoming connection out of a queue and get a new descriptor for communicating with it
- **Client**
  - » Connect: connect to a server in the listening state, specified by address and port

Overview


Client
Server
socket
socket
bind
listen
open_listenfd
open_clientfd
Connection
request
connect
accept
Client /
Server
Session
write
read
read
write
close
EOF
read
close

Step 1: Setup the Socket

- **Both client and server applications need to setup the socket (*man socket*)**
  - » int socket(int domain, int type, int protocol);
- **Domain:**
  - » “AF_INET” -- IPv4
- **Type:**
  - » “SOCK_STREAM” -- TCP (Your IRC server)
  - » “SOCK_DGRAM” -- UDP (Routing Daemon -> Routing Daemon)
- **Protocol:**
  - » “0”
- **For example...**
  - » int sock = socket(AF_INET, SOCK_STREAM, 0);

Step 2 (Server): Binding the Socket

- **Only the server needs to bind (*man bind*)**
  - » int bind(int sockfd, const struct sockaddr *my_addr, socklen_t addrlen);
- **sockfd:**
  - » Whatever socket() returned!
- **my_addr:**
  - » For Internet addresses, must cast (struct sockaddr_in *) to (struct sockaddr *)

```
struct sockaddr_in {
    short             sin_family;   // e.g. AF_INET
    unsigned short    sin_port;     // e.g. htons(3490)
    struct in_addr    sin_addr;     // see struct in_addr, below
    char              sin_zero[8];  // zero this if you want to
};
struct in_addr {
    unsigned long s_addr;  // load with inet_aton()
};
```

Step 2 (Server): Binding the Socket ... Continued

- **addrlen:**
  - » sizeof(your_sockaddr_in_struct)

- **For example...**

```
struct sockaddr_in saddr;
int sockfd;
unsigned short port = 80;

if((sockfd=socket(AF_INET, SOCK_STREAM, 0) < 0) {    // from back a couple
slides
     printf("Error creating socket\n");
     ...
}

memset(&saddr, '\0', sizeof(saddr));          // zero structure out
saddr.sin_family = AF_INET;                   // match the socket() call
saddr.sin_addr.s_addr = htonl(INADDR_ANY); // bind to any local address
saddr.sin_port = htons(port);                     // specify port to listen on

if((bind(sockfd, (struct sockaddr *) &saddr, sizeof(saddr)) < 0) { // bind!
     printf("Error binding\n");
     ...
}
```

Network Byte Ordering

- **Wait wait... what was that "htons()/htonl()" thing?**

- **Network Byte Ordering**
  - » Network is big-endian, host may be big- or little-endian
  - » Functions work on 16-bit (short) and 32-bit (long) values
  - » htons() / htonl() : convert host byte order to network byte order
  - » ntohs() / ntohl(): convert network byte order to host byte order
  - » Use these to convert network addresses, ports, …

Step 3 (Server): Listen

- **Now we have a socket descriptor and address/port associated with the socket**
- **Lets listen in! (*man listen*)**
  - » int listen(int sockfd, int backlog);
- **sockfd:**
  - » Again, whatever socket() returned
- **backlog:**
  - » Total number of hosts we want to queue
- **Example...**
  - » listen(sockfd, 5); // pass it sockfd, no more than a queue of 5

Step 4 (Server): Accept

- **Server must accept incoming connections (*man 2 accept*)**
  - » int accept(int sockfd, struct sockaddr *addr, socklen_t *addrlen)
- **sockfd:**
  - » The usual culprit, socket() return
- **addr:**
  - » A pointer to a struct sockaddr_in, cast as (struct sockaddr *)
- **addrlen:**
  - » Pointer to an integer to store the returned size of *addr*, should be initialized as original sizeof(*addr*);
- **Example:**
  - » int isock=accept(sockfd, (struct sockaddr_in *) &caddr, &clen);

Lets put the server together...

```
struct sockaddr_in saddr, caddr;
int sockfd, clen, isock;
unsigned short port = 80;

if((sockfd=socket(AF_INET, SOCK_STREAM, 0) < 0) {    // from back a couple
slides
     printf("Error creating socket\n");
     ...
}

memset(&saddr, '\0', sizeof(saddr));        // zero structure out
saddr.sin_family = AF_INET;                 // match the socket() call
saddr.sin_addr.s_addr = htonl(INADDR_ANY); // bind to any local address
saddr.sin_port = htons(port);                   // specify port to listen on

if((bind(sockfd, (struct sockaddr *) &saddr, sizeof(saddr)) < 0) { // bind!
     printf("Error binding\n");
     ...
}

if(listen(sockfd, 5) < 0) {        // listen for incoming connections
     printf("Error listening\n");
     ...
}

clen=sizeof(caddr)
if((isock=accept(sockfd, (struct sockaddr *) &caddr, &clen)) < 0) {// accept
one
     printf("Error accepting\n");
     ...
}
```

What happened to the client?

- **The last thing the client did was socket() !**
- **The client need not do bind, listen, and accept**
- **All the client does now is connect (*man connect*)**
  - » int connect(int sockfd, const struct sockaddr *saddr, socklen_t addrlen);
- **Example...**
  - » connect(sockfd, (struct sockaddr *) &saddr, sizeof(saddr));

Piecing the Client Together

```
struct sockaddr_in saddr;
struct hostent *h;
int sockfd, connfd;
unsigned short port = 80;

if((sockfd=socket(AF_INET, SOCK_STREAM, 0) < 0) {    // from back a couple slides
     printf("Error creating socket\n");
     ...
}

if((h=gethostbyname("www.slashdot.org")) == NULL) { // Lookup the hostname
     printf("Unknown host\n");
     ...
}

memset(&saddr, '\0', sizeof(saddr));        // zero structure out
saddr.sin_family = AF_INET;                 // match the socket() call
memcpy((char *) &saddr.sin_addr.s_addr, h->h_addr_list[0], h->h_length); // copy the
address
saddr.sin_port = htons(port);                         // specify port to connect to

if((connfd=connect(sockfd, (struct sockaddr *) &saddr, sizeof(saddr)) < 0) { // connect!
     printf("Cannot connect\n");
     ...
}
```

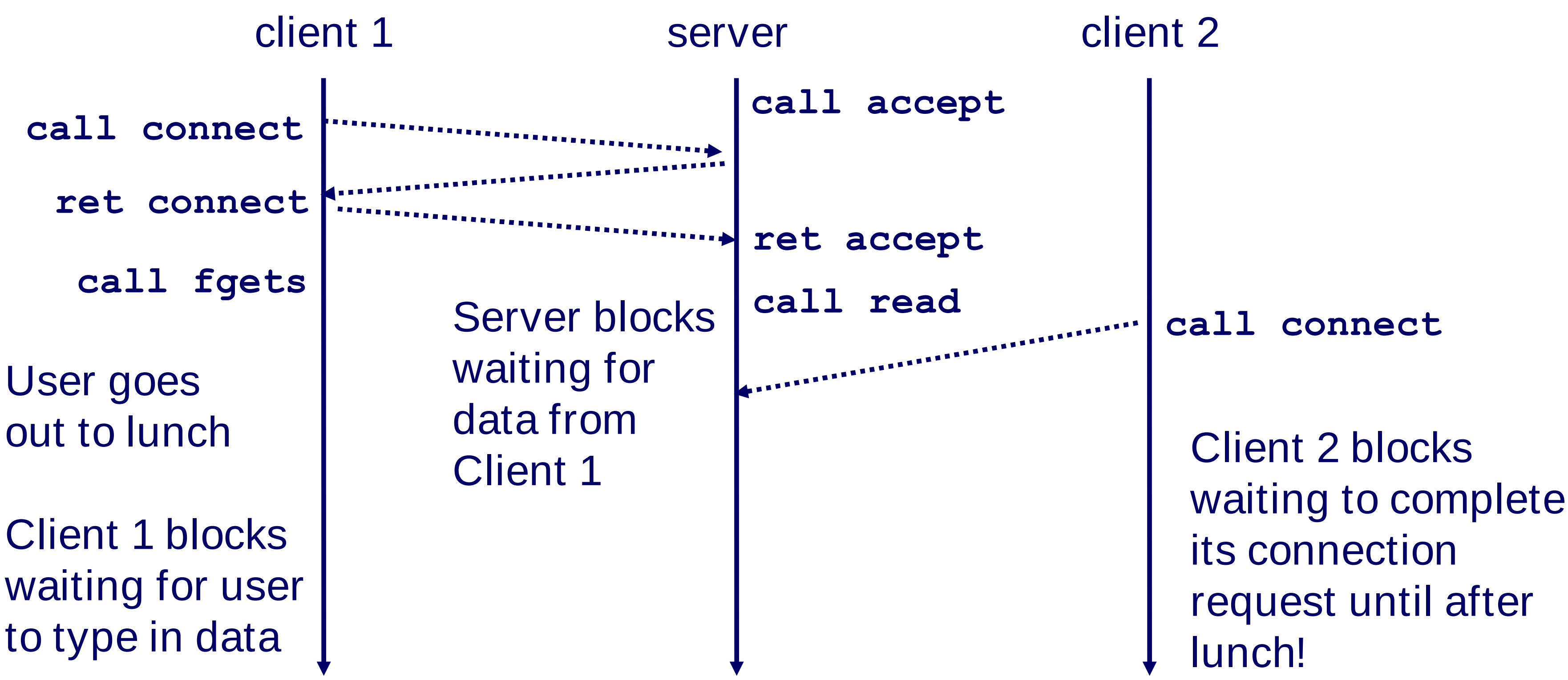
We're Connected!

- **Great, server accepting connections, and client connecting to servers.**
- **Now what? Lets send and receive data!**
  - » read()
  - » write()
- **Both functions are used by client and server:**
  - » ssize_t read(int fd, void *buf, size_t len);
  - » ssize_t write(int fd, const void *buf, size_t len);
- **Example...**
  - » read(sockfd, buffer, sizeof(buffer));
  - » write(sockfd, “hey\n”, strlen(“hey\n”));

Finally, Close Up Shop

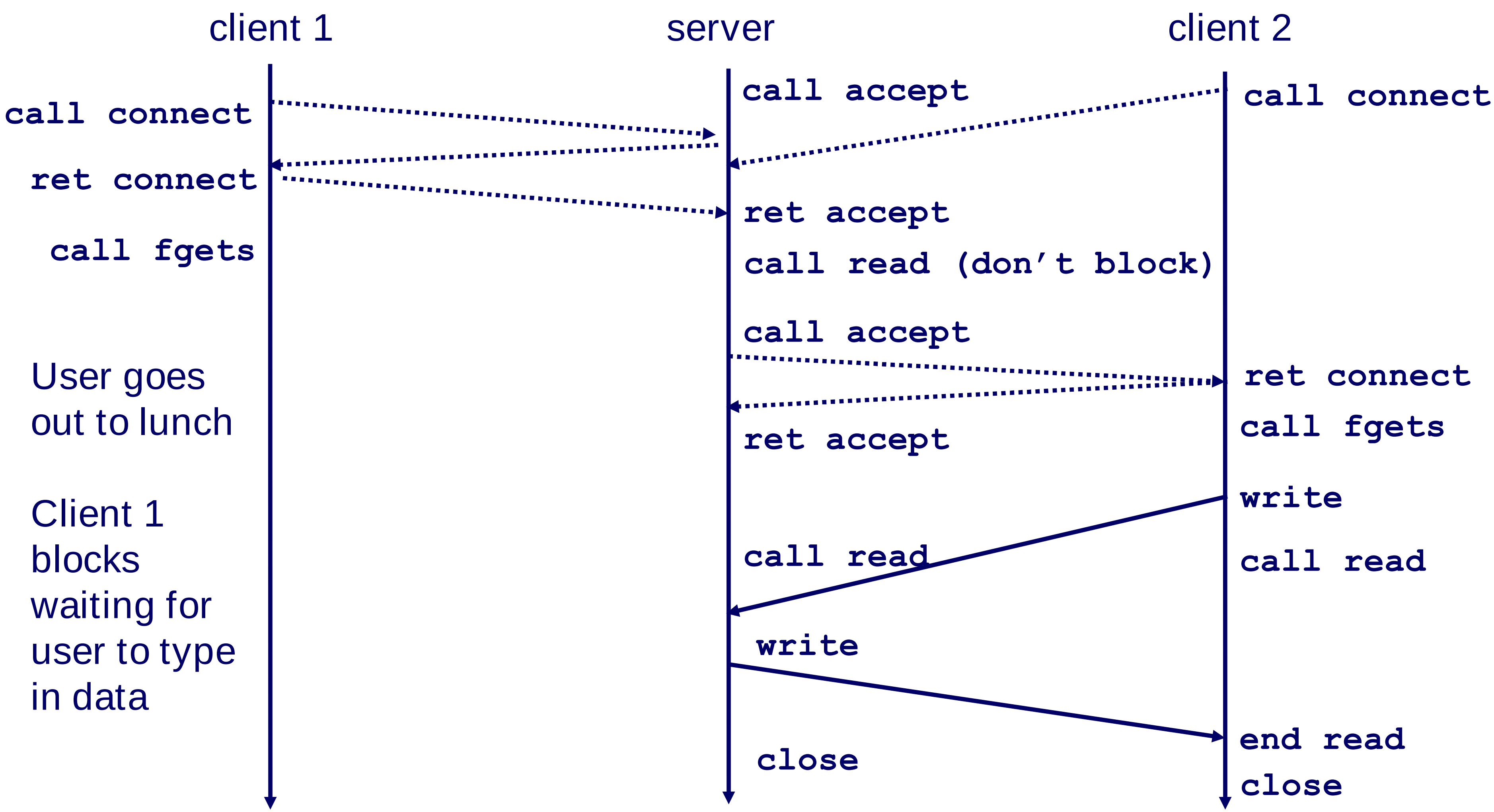
- **Don't forget, like a file, you must close it (*man close*)**
  - » int close(int sockfd);
- **That's it!**
- **Loop around the accept() on the server to accept a new connection once one has finished**
- **But what's wrong with this?**

Server Flaw



client 1
server
client 2
call accept
call connect
ret connect
ret accept
call fgets
call read
call connect
Server blocks waiting for data from Client 1
User goes out to lunch
Client 1 blocks waiting for user to type in data
Client 2 blocks waiting to complete its connection request until after lunch!

Concurrent Servers



Taken from D. Murray, R. Bryant, and G. Langale 15-441/213 slides

Solutions to Concurrency

- Threads – first thing that comes to mind
  - » (+) Threads allow concurrency
  - » (+) Easier methodology
  - » (-) Threads increase design complexity (race conditions)
  - » (-) Concurrency slightly more complicated
- Select()
  - » (+) Select allows concurrency
  - » (+) Does not introduce race conditions
  - » (-) Default control flow is more complicated
- Nobody has won the battle... but...
  .... you MUST you use select() !!

What Does Select Do?

- Allows you to monitor multiple file descriptors (straight from the “man”!)

- Why is this helpful?
  - » accept() returns a new file descriptor for the incoming connection
  - » set sockets to non-blocking... select does not specify how much we can write
  - » “collect” incoming file descriptors and monitor all of them!

Setting Socket to Not Block

- **Before we even get to use select, we need to set all sockets to non-blocking**
- **Also need to allow reuse of the socket**

```
int sock, opts=1;

sock = socket(...);  // To give you an idea of where the new code goes

setsockopt(sock, SOL_SOCKET, SO_REUSEADDR, &opts, sizeof(opts));

if((opts = fcntl(sock, F_GETFL)) < 0) { // Get current options
     printf("Error...\n");
     ...
}
opts = (opts | O_NONBLOCK);  // Don't clobber your old settings
if(fcntl(sock, F_SETFL, opts) < 0) {
     printf("Error...\n");
     ...
}

bind(...);  // To again give you an idea where the new code goes
```

Select()

- int select(int maxfdp1, fd_set *readset, fd_set *writeset, NULL, struct timeval *timeout);
- fd_set – bit vector with max FD_SETSIZE bits
  - » bit k is set to 1 if descriptor k is a member of the set
- readset – bit vector for read descriptors
- writeset – bit vector for write descriptors
- maxfdp1 – max file descriptor + 1

How does this change things?

```
// socket() call and non-blocking code is above this point

if((bind(sockfd, (struct sockaddr *) &saddr, sizeof(saddr)) < 0) { // bind!
     printf("Error binding\n");
     ...
}

if(listen(sockfd, 5) < 0) {           // listen for incoming connections
     printf("Error listening\n");
     ...
}

clen=sizeof(caddr);

// Setup pool.read_set with an FD_ZERO() and FD_SET() for
//    your server socket file descriptor.  (whatever socket() returned)

while(1) {
     pool.ready_set = &pool.read_set;  // Save the current state
     pool.nready = select(pool.maxfd+1, &pool.ready_set, &pool.write_set, NULL, NULL);

     if(FD_ISSET(sockfd, &pool.ready_set)) {  // Check if there is an incoming conn
          isock=accept(sockfd, (struct sockaddr *) &caddr, &clen); // accept it
          add_client(isock, &pool);  // add the client by the incoming socket fd
     }

     check_clients(&pool);  // check if any data needs to be sent/received from clients
}

...

close(sockfd);
```

How to Set Your Bit Vectors

- void FD_ZERO(fd_set *fdset);
  - Clear out all the bits in the set *fdset*
- void FD_SET(int fd, fd_set *fdset);
  - Set the bit for *fd* to 1 in the set *fdset*
- void FD_CLR(int fd, fd_set *fdset);
  - Set the bit for *fd* to 0 in the set *fdset*
- int FD_ISSET(int fd, fd_set *fdset);
  - Test whether the bit for *fd* is set to 1 in *fdset*

Use a Structure of Sets

```
typedef struct { /* represents a pool of connected descriptors */
    int maxfd;          /* largest descriptor in read_set */
    fd_set read_set;    /* set of all active read descriptors */
    fd_set write_set;    /* set of all active read descriptors */
    fd_set ready_set; /* subset of descriptors ready for reading  */
    int nready;         /* number of ready descriptors from select */

    int maxi;           /* highwater index into client array */
    int clientfd[FD_SETSIZE];    /* set of active descriptors */
    rio_t clientrio[FD_SETSIZE]; /* set of active read buffers */
    ...    // ADD WHAT WOULD BE HELPFUL FOR PJ1
} pool;
```

What Was check_clients() ?

- The main loop tests for incoming connections with FD_ISSET() only
  - » But we have so many other file descriptors to test!
- Store your client file descriptors in pool.clientfd[ ] and test all of them with FD_ISSET()
  - » Clients may be trying to send us data
  - » We may have pending data to send to clients

Suggestions

- Woah, all this code... now what?
- Start simple, get yourself familiar (a first revision!)
  - Code a server to accept a single connection
  - Use a telnet client to connect and send data
  - Have the server read the message and display it
- Write a simple client to send messages instead of telnet
- Take it to the next level... modify it a bit (a new revision!)
  - Add the non-blocking socket code
  - Add select() functionality
  - Have server echo back to the clients

Routines for Line by Line

- a read() won't always give you everything you want!
- IRC is on a line by line basis
- If you get half a line from a read() (aka. no \n in what you read), then buffer what you have so far and wait to process the line

Roundup

- **Sockets**
  1. Setup -- <DMACHINE,DSERVICE> -- <IP,PORT>
  2. I/O – read() / write()
  3. Close – close()
- **Client:** socket() -------------------------> connect() -> I/O -> close()
- **Server:** socket() -> bind() -> listen() -> accept() -> I/O -> close()

- **Concurrency:** select()
- **Bit Vectors:** fd_set, FD_ZERO(), FD_SET(), FD_CLR(), FD_ISSET()

Confusion?

- The more organized you keep your file descriptors, the better off you'll be
- Keep your while(1){ } thin, have functions check the bit vectors
- Questions?

Get Started Early

- Find your partner if you have not done so already
- Share your schedules and share what days and times you are free to meet

- Lots of c0d3 ...
  - » "Official Solution" -> ~5,000 lines of code by: | wc

- Work ahead of the checkpoints!