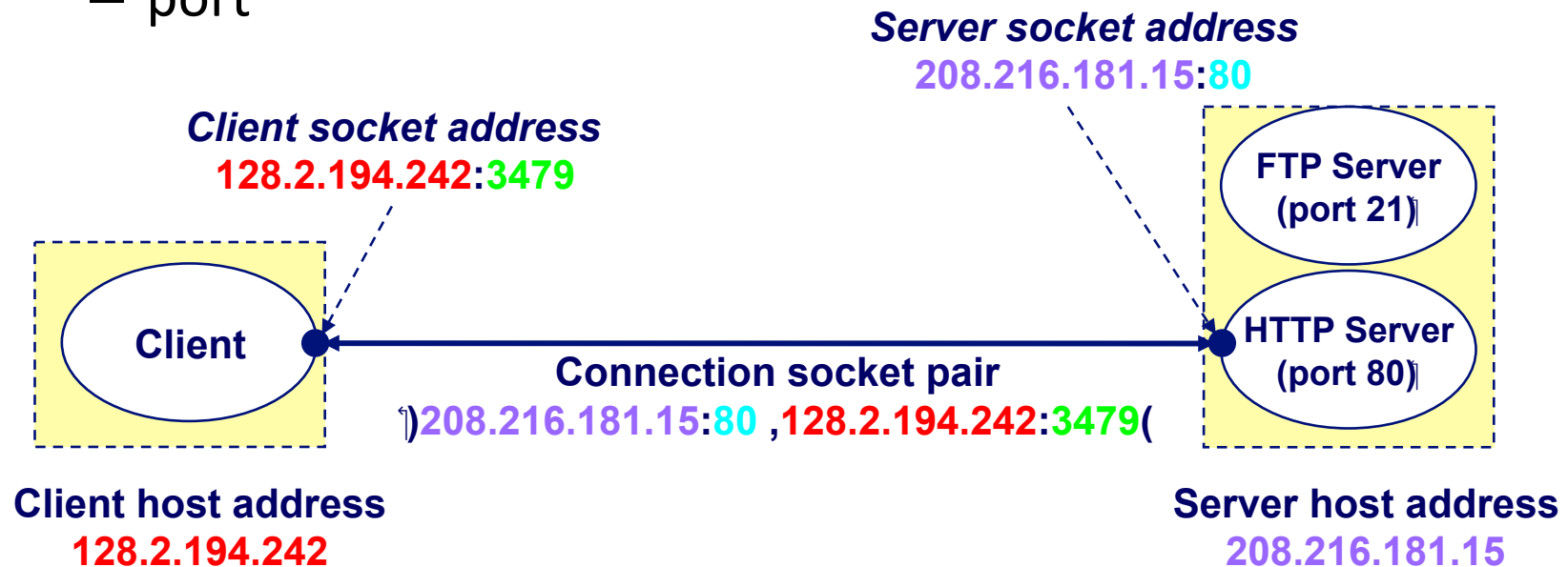


Why Socket?

- How can I program a network application?
 - Share data
 - Send messages
 - Finish course projects...
- IPC - Interprocess Communication

Identify the Destination

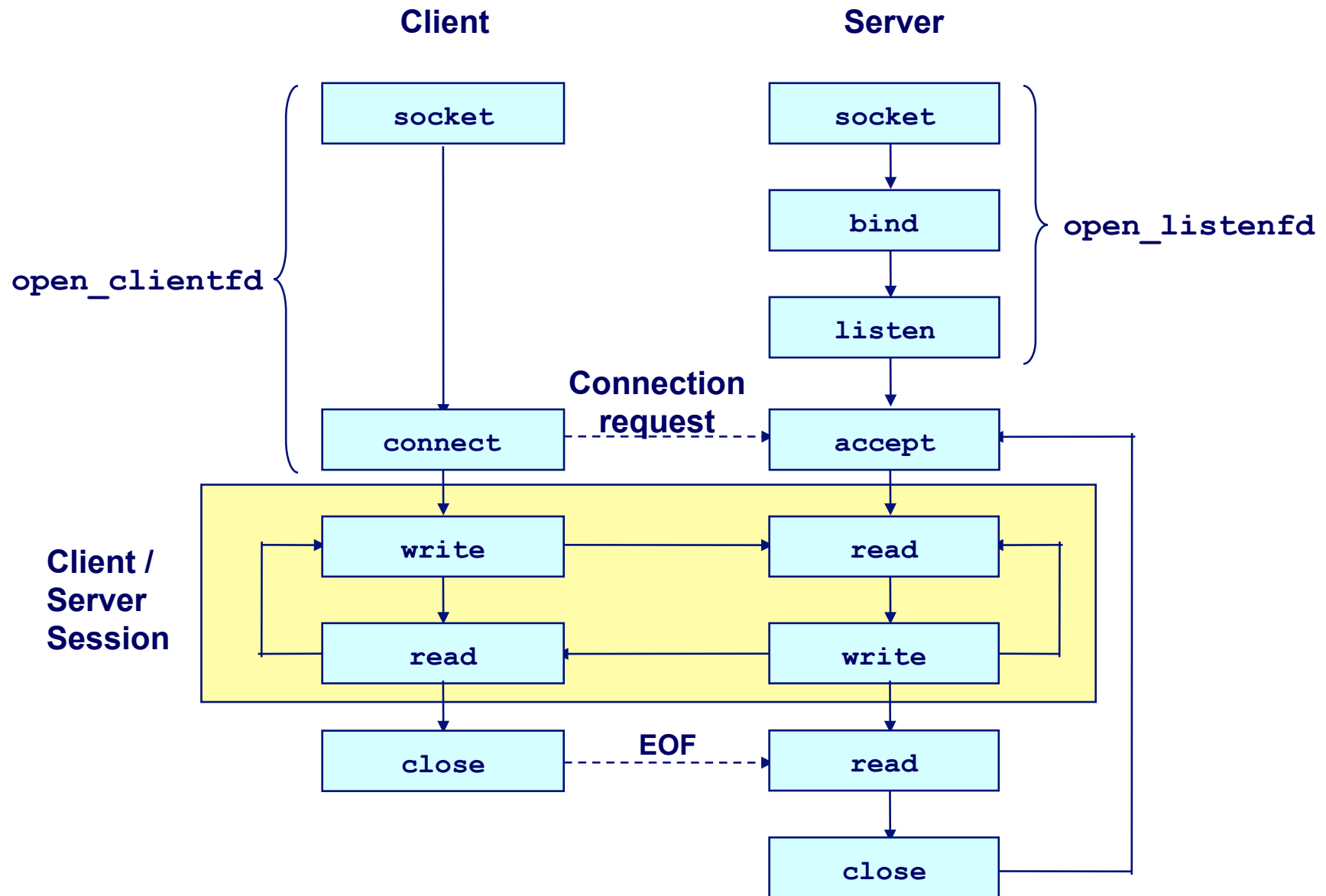
- Addressing
 - IP address
 - hostname (resolve to IP address via DNS)
- Multiplexing
 - port



Sockets

- How to use sockets
 - Setup socket
 - Where is the remote machine (IP address, hostname)
 - What service gets the data (port)
 - Send and Receive
 - Designed just like any other I/O in unix
 - send -- write
 - recv -- read
 - Close the socket

Overview



Step 1 – Setup Socket

- **Both client and server need to setup the socket**
 - *int socket(int domain, int type, int protocol);*
- *domain*
 - AF_INET -- IPv4 (AF_INET6 for IPv6)
- *type*
 - SOCK_STREAM -- TCP
 - SOCK_DGRAM -- UDP
- *protocol*
 - 0
- For example,
 - *int sockfd = socket(AF_INET, SOCK_STREAM, 0);*

Step 2 (Server) - Binding

- **Only server need to bind**
 - *int bind(int sockfd, const struct sockaddr *my_addr, socklen_t addrlen);*
- *sockfd*
 - file descriptor socket() returned
- *my_addr*
 - struct sockaddr_in for IPv4
 - 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()
};
```

What is that Cast?

- bind() takes in protocol-independent (struct sockaddr*)

```
struct sockaddr {  
    unsigned short  sa_family; // address family  
    char            sa_data[14]; // protocol address  
};
```

- C's polymorphism
- There are structs for IPv6, etc.

Step 2 (Server) - Binding contd.

- *addrlen*
 - size of the `sockaddr_in`

```
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");  
    ...  
}
```


What is htonl(), htons()?

- Byte ordering
 - Network order is big-endian
 - Host order can be big- or little-endian
 - x86 is little-endian
 - SPARC is big-endian
- Conversion
 - *htons()*, *htonl()*: host to network short/long
 - *ntohs()*, *ntohl()*: network order to host short/long
- What need to be converted?
 - Addresses
 - Port
 - etc.

Step 3 (Server) - Listen

- **Now we can listen**
 - *int listen(int sockfd, int backlog);*
- *sockfd*
 - again, file descriptor socket() returned
- *backlog*
 - number of pending connections to queue
- For example,
 - *listen(sockfd, 5);*

Step 4 (Server) - Accept

- **Server must explicitly accept incoming connections**
 - *int accept(int sockfd, struct sockaddr *addr, socklen_t *addrlen)*
- *sockfd*
 - again... file descriptor socket() returned
- *addr*
 - pointer to store client address, (struct sockaddr_in *) cast to (struct sockaddr *)
- *addrlen*
 - pointer to store the returned size of addr, should be sizeof (*addr)
- For example
 - *int isock=accept(sockfd, (struct sockaddr_in *) &caddr, &crlen);*

Put 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 about client?

- Client need not bind, listen, and accept
- **All client need to do is to connect**
 - *int connect(int sockfd, const struct sockaddr *saddr, socklen_t addrlen);*
- For example,
 - *connect(sockfd, (struct sockaddr *) &saddr, sizeof(saddr));*

Domain Name System (DNS)

- What if I want to send data to “www.slashdot.org”?
 - DNS: Conceptually, DNS is a database collection of host entries

```
struct hostent {  
    char      *h_name;    // official hostname  
    char      **h_aliases; // vector of alternative hostnames  
    int       h_addrtype; // address type, e.g. AF_INET  
    int       h_length;   // length of address in bytes, e.g. 4 for IPv4  
    char      **h_addr_list; // vector of addresses  
    char      *h_addr;     // first host address, synonym for h_addr_list[0]  
};
```

- hostname -> IP address
 - *struct hostent *gethostbyname(const char *name);*
- IP address -> hostname
 - *struct hostent *gethostbyaddr(const char *addr, int len, int type);*

Put 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");
    ...
}
```

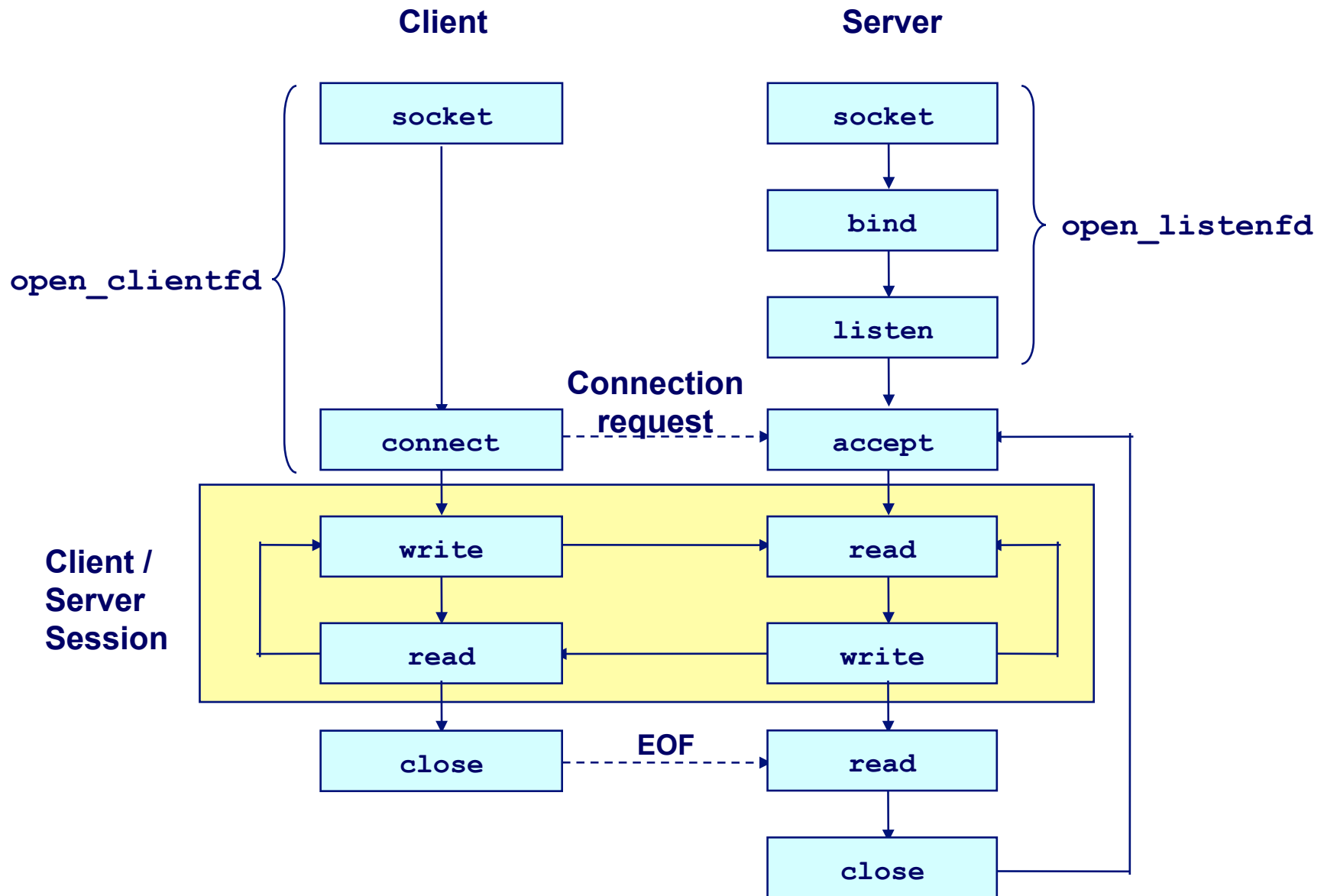
We Are Connected

- Server accepting connections and client connecting to servers
- Send and receive data
 - *ssize_t read(int fd, void *buf, size_t len);*
 - *ssize_t write(int fd, const void *buf, size_t len);*
- For example,
 - *read(sockfd, buffer, sizeof(buffer));*
 - *write(sockfd, "hey\n", strlen("hey\n"));*

TCP Framing

- TCP does NOT guarantee message boundaries
 - IRC commands are terminated by a newline
 - But you may not get one at the end of read(), e.g.
 - One Send “Hello\n”
 - Multiple Receives “He”, “llo\n”
 - If you don’t get the entire line from one read(), use a buffer

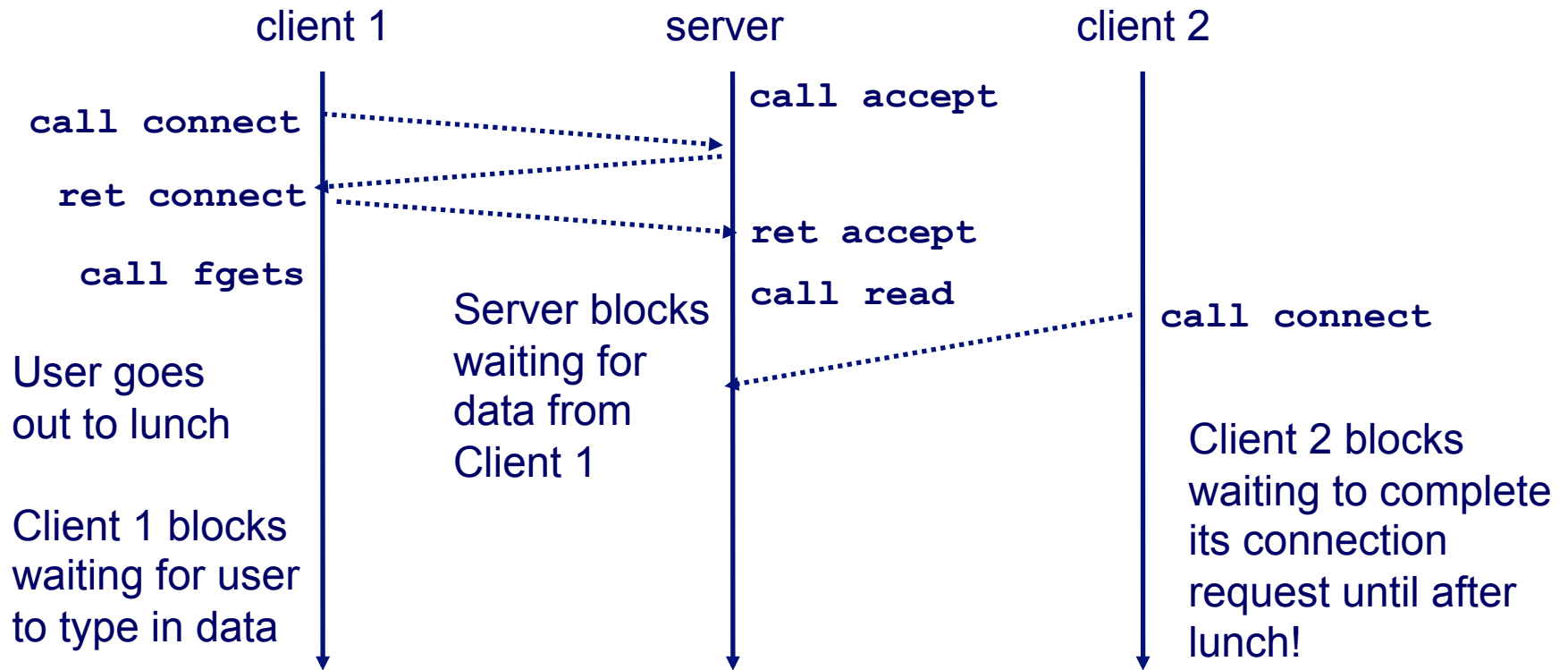
Revisited



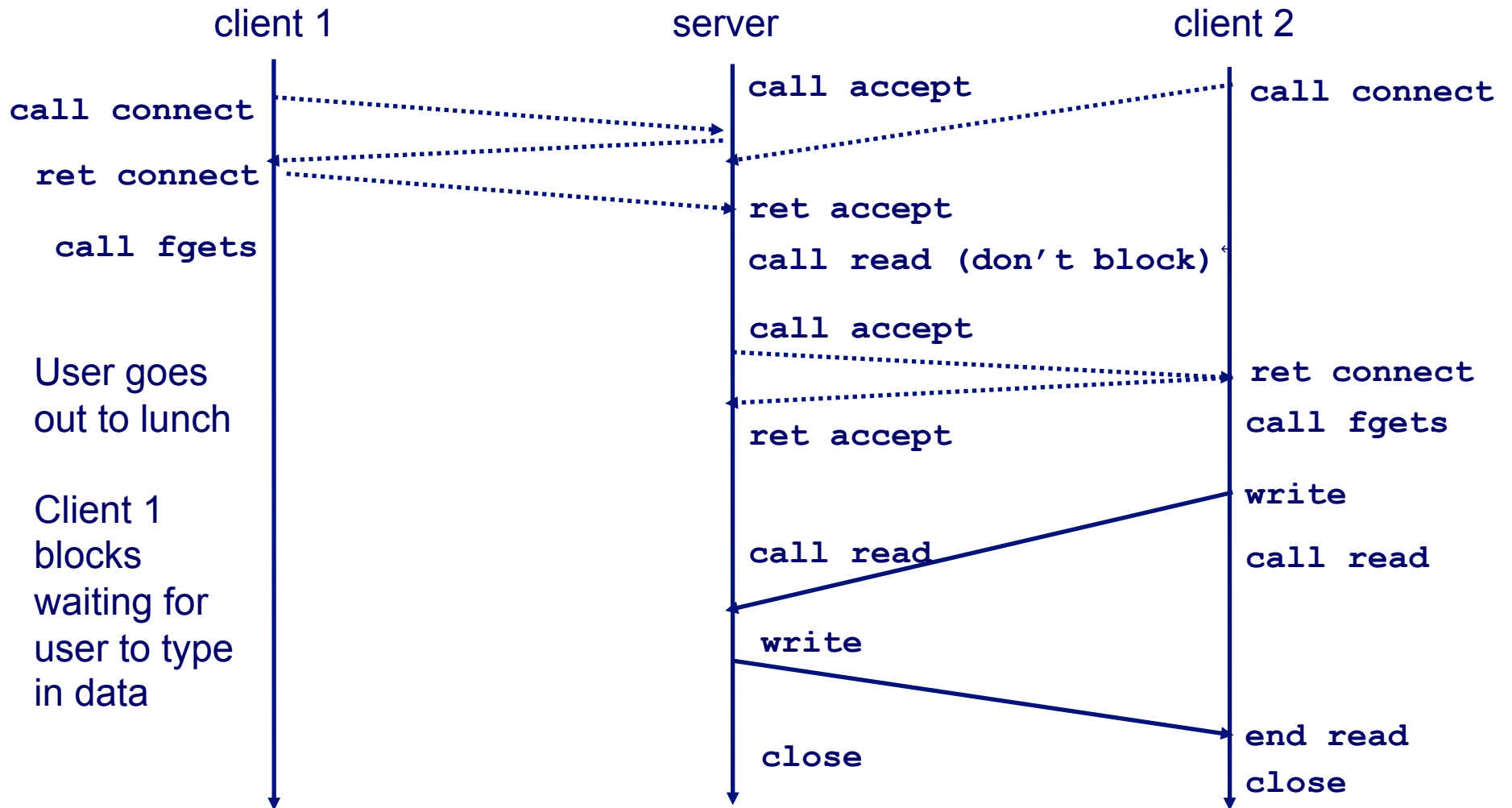
Close the Socket

- Don't forget to close the socket descriptor, like a file
 - *int close(int sockfd);*
- Now server can loop around and accept a new connection when the old one finishes
- What's wrong here?

Server Flaw



Concurrent Servers



Concurrency

- Threading
 - Easier to understand
 - Race conditions increase complexity
- Select()
 - Explicit control flows, no race conditions
 - Explicit control more complicated
- There is no clear winner, but you **MUST** use select()...

What is select()?

- Monitor multiple descriptors
- How does it work?
 - Setup sets of sockets to monitor
 - select(): blocking until something happens
 - “Something” could be
 - Incoming connection: accept()
 - Clients sending data: read()
 - Pending data to send: write()
 - Timeout

Concurrency – Step 1

- Allowing address reuse

```
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));
```

- Then we set the sockets to be non-blocking

```
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
```


Concurrency – Step 2

- **Monitor sockets with select()**
 - *int select(int maxfd, fd_set *readfds, fd_set *writefds, fd_set *exceptfds, const struct timespec *timeout);*
- *maxfd*
 - max file descriptor + 1
- *fd_set*: bit vector with FD_SETSIZE bits
 - *readfds*: bit vector of read descriptors to monitor
 - *writefds*: bit vector of write descriptors to monitor
 - *exceptfds*: set to NULL
- *timeout*
 - how long to wait without activity before returning

What about bit vectors?

- *void FD_ZERO(fd_set *fdset);*
 - clear out all bits
- *void FD_SET(int fd, fd_set *fdset);*
 - set one bit
- *void FD_CLR(int fd, fd_set *fdset);*
 - clear one bit
- *int FD_ISSET(int fd, fd_set *fdset);*
 - test whether fd bit is set

The Server

```
// 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);
```

What is pool?

```
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 PROJECT1
} pool;
```

What about checking clients?

- The main loop only tests for incoming connections
 - There are other reasons the server wakes up
 - Clients are sending data, pending data to write to buffer, clients closing connections, etc.
- Store all client file descriptors
 - in pool
- Keep the while(1) loop thin
 - Delegate to functions
- Come up with your own design

Summary

- Sockets
 - socket setup
 - I/O
 - close
- Client: `socket()`----->`connect()`->I/O->`close()`
- Server: `socket()`->`bind()`->`listen()`->`accept()`--->I/O->`close()`
- DNS
 - `gethostbyname()`
- Concurrency
 - `select()`
- Bit vector operations
 - `fd_set`, `FD_ZERO()`, `FD_SET()`, `FD_CLR()`, `FD_ISSET()`

About Project 1

- Standalone IRC server
 - Checkpoint 1: subversion and Makefile
 - Check in a Makefile and source code
 - Makefile can build executable named *sircd*
 - No server functions necessary
 - Checkpoint 2: echo server
 - Use `select()` to handle multiple clients

Suggestions

- Start early!
 - Work ahead of checkpoints
- Read the man pages
- Email Kaushik (kaushik AT cs DOT cmu DOT edu) if you didn't get a svn username and password

Reference for Socket Programming

- <http://www.lowtek.com/sockets/>
- Feel free to share your reference on the bboard!