Socket Programming

15-441 Computer Networks, Fall 2010

Your TAs

Lecture Today

- Motivation for sockets
- What’s in a socket?
- Working with socket
- Concurrent network applications
- Project 1

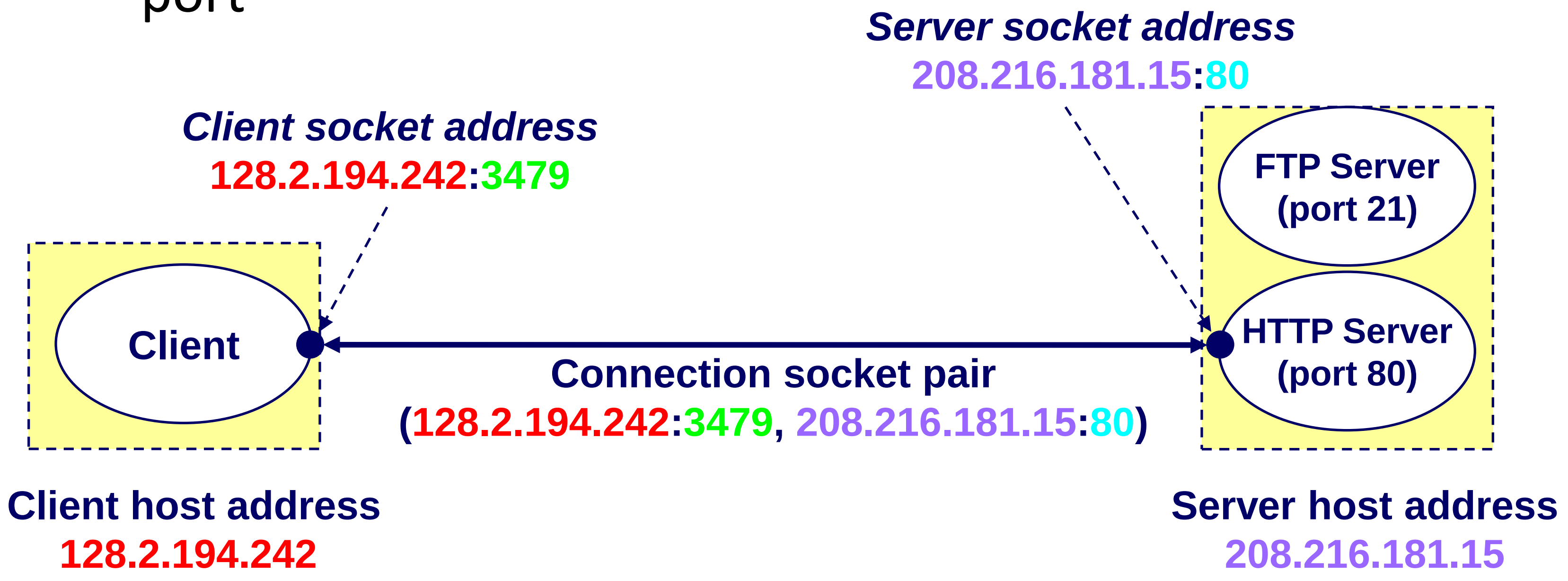
Why Socket?

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

- IPC - Interprocess Communication

Identify the Destination

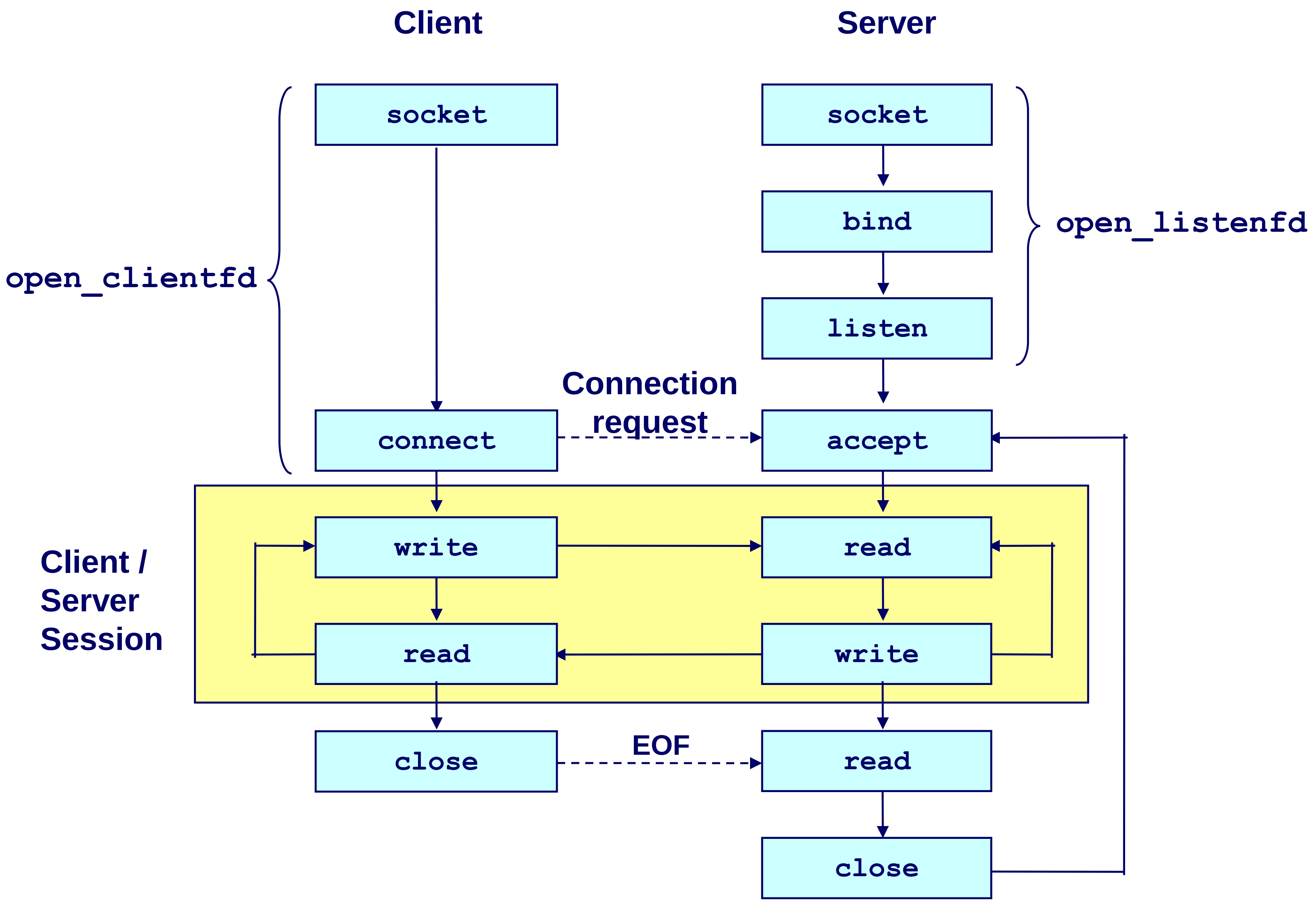
- Addressing
  - IP address
  - hostname (resolve to IP address via DNS)
- Multiplexing
  - port



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



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 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 *) &caddr, &clen);*

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");
        ...
}
```

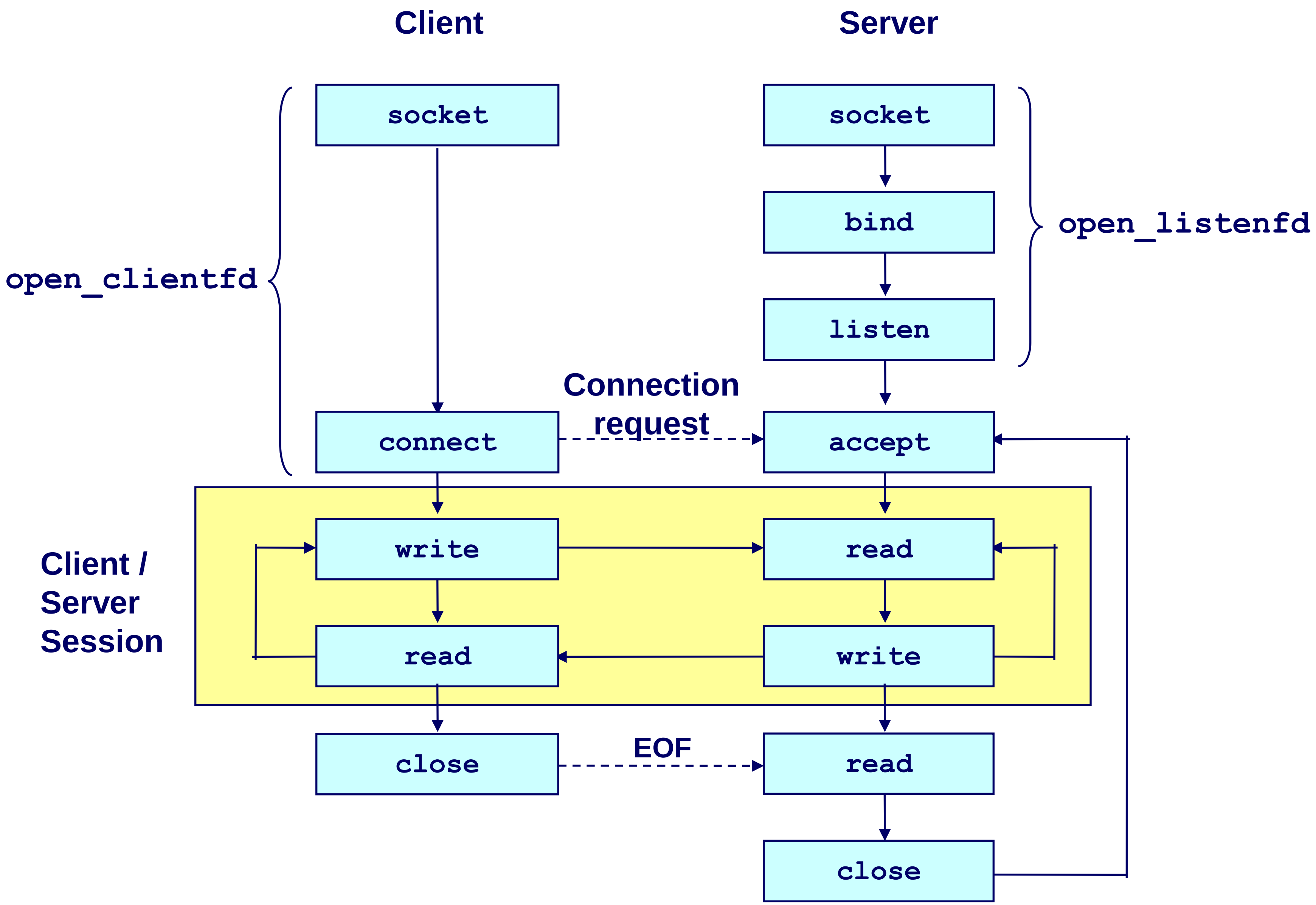
We Are Connected

- 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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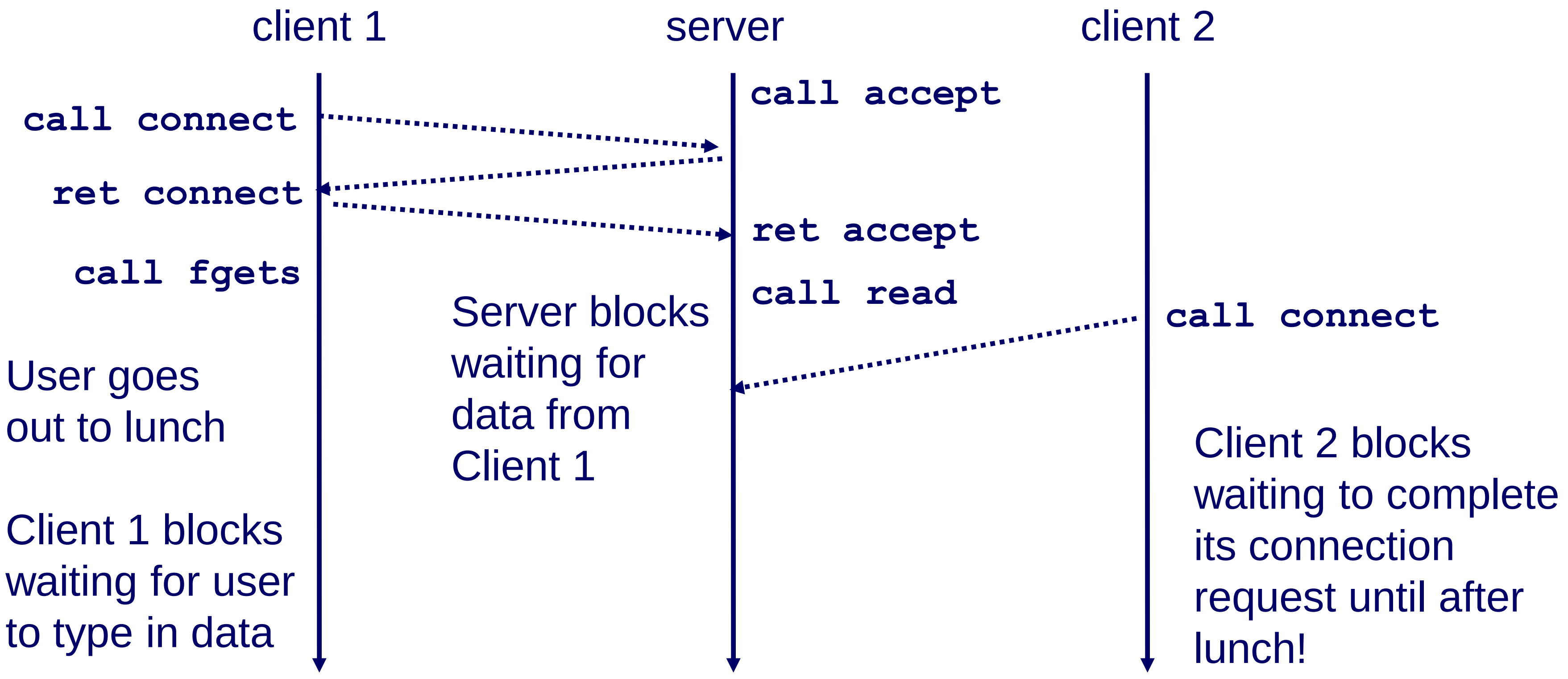
Close the Socket

- Don’t forget to close the socket descriptor, like a file
  - *int close(int sockfd);*

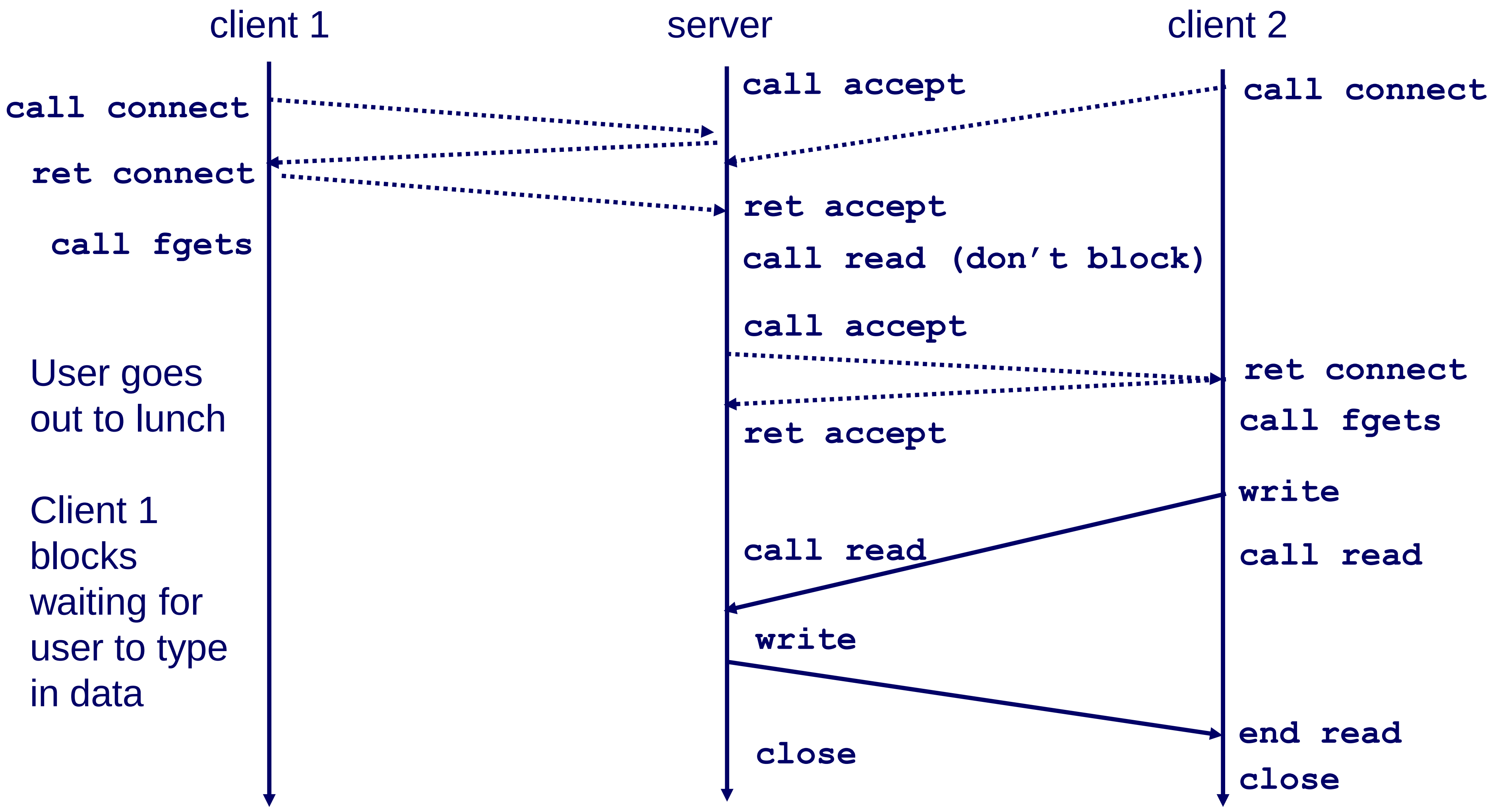
- Now server can loop around and accept a new connection when the old one finishes
- What’s wrong here?

Server Flaw


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!

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

Concurrent Servers



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

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 (mtschant at cs dot cmu dot edu) if you didn’t get a svn username and password