15-441

Network Programming Introduction
Jan. 25, 2006

(Borrowing heavily from 15-213)

Topics

- Programmer's view of the Internet
- Sockets interface
- Writing clients and servers
- Concurrency with I/O multiplexing

About This Lecture

"Intro to writing client/server programs with TCP"

- Stolen from 15-213
- Should be "review"
- Will zoom through these slides
  - You may review at your leisure

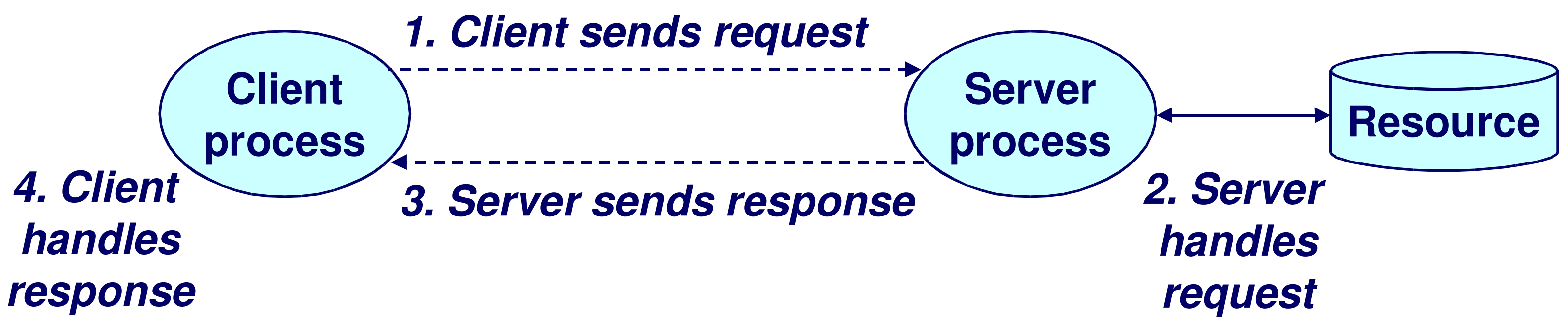
Extensions to reach Project 1

- 15-213 "rio" package may not be advisable
- You'll use UDP, not TCP
  - Packet protocol rather than byte-stream
  - No "connections" (hence no "disconnections" aka EOFs)
  - You may find error reporting confusing at first

A Client-Server Transaction

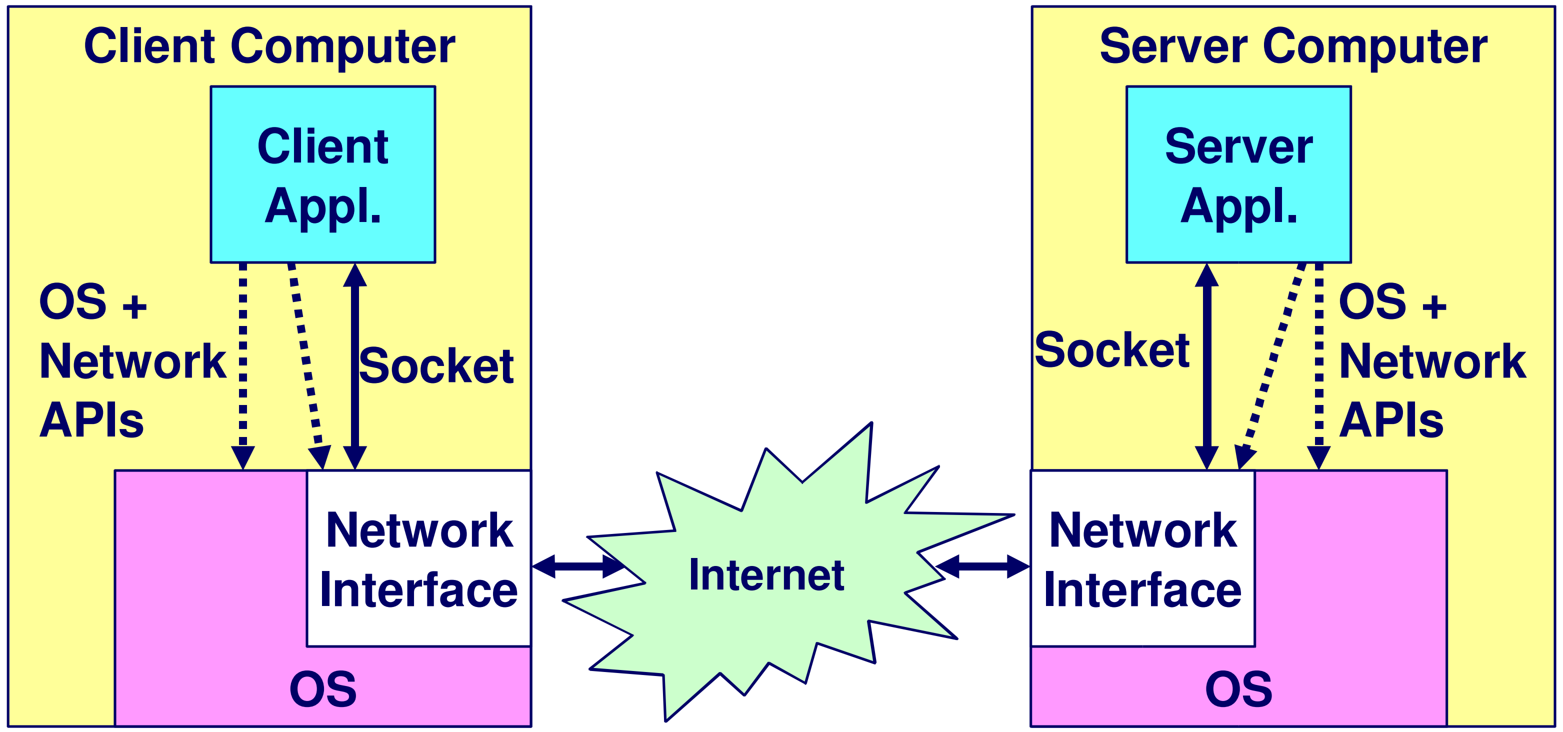
Every network application is based on the client-server model:

- A *server* process and one or more *client* processes
- Server manages some *resource*.
- Server provides *service* by manipulating resource for clients.



Note: clients and servers are processes running on hosts (can be the same or different hosts).

Network Applications



Access to Network via Program Interface

- Sockets make network I/O look like files
- Call system functions to control and communicate
- Network code handles issues of routing, reliability, ordering, &c.

Clients

Examples of client programs

- Web browsers, `ftp`, `telnet`, `ssh`

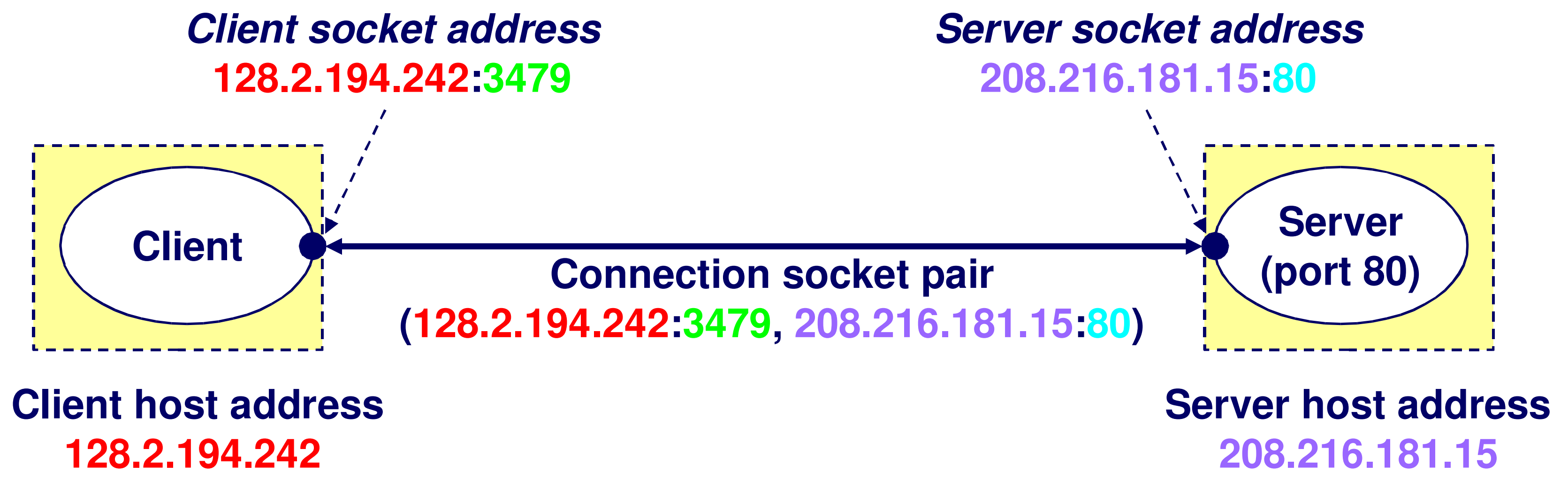
How does a client specify a server?

- The IP address in the server socket address identifies the host *(more precisely, an adaptor on the host)*
- The (well-known) port in the server socket address identifies the service, and thus implicitly identifies the server process that performs that service.
- Examples of well-known ports
  - Port 7: Echo server
  - Port 23: Telnet server
  - Port 25: Mail server
  - Port 80: Web server

Internet Connections (TCP/IP)

Clients and servers communicate by sending streams of bytes over *connections*.

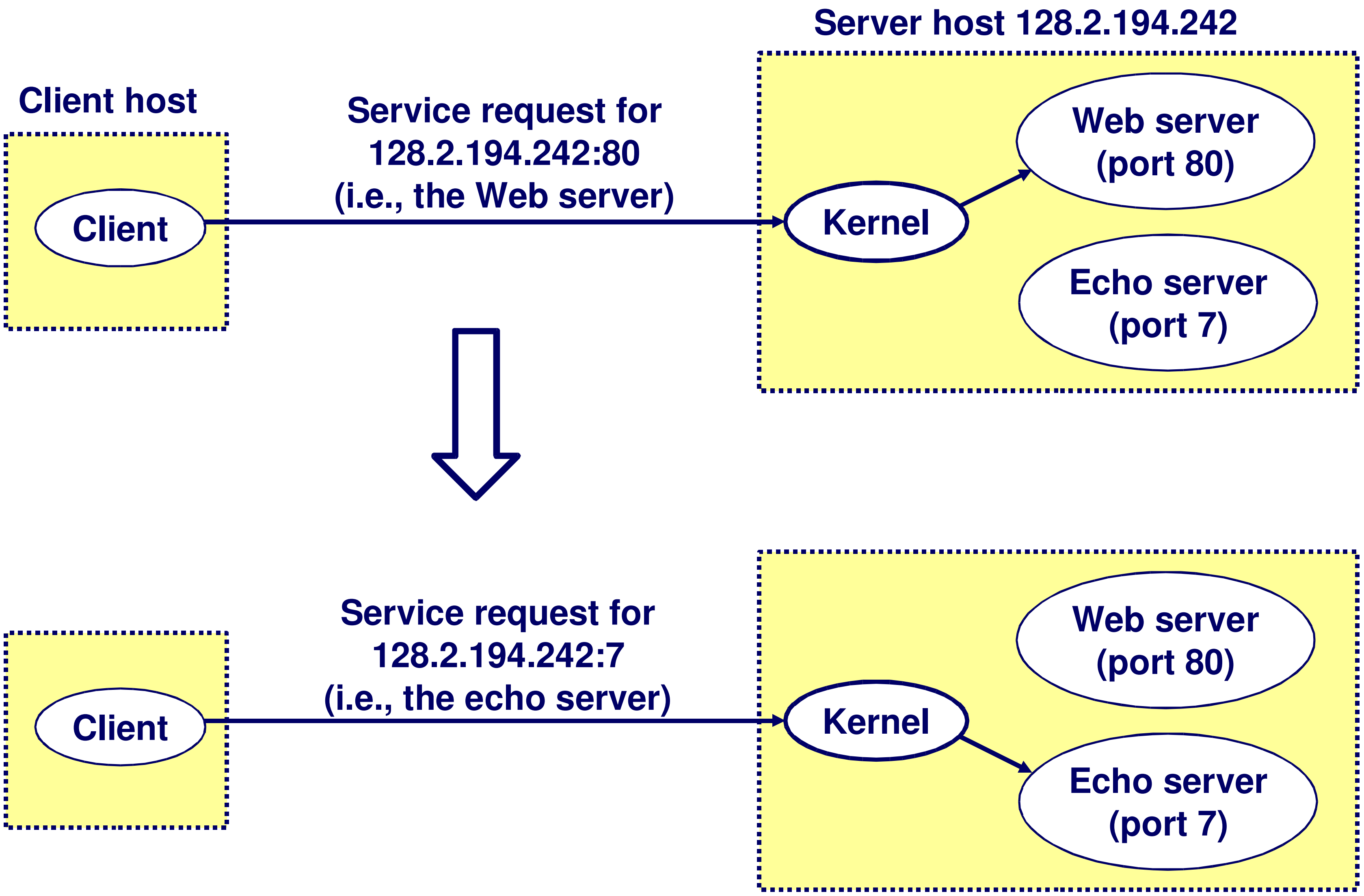
Connections are point-to-point, full-duplex (2-way communication), and reliable.



Note: 3479 is an ephemeral port allocated by the kernel

Note: 80 is a well-known port associated with Web servers

Using Ports to Identify Services



Servers

Servers are long-running processes (daemons).

- Created at boot-time (typically) by the init process (process 1)
- Run continuously until the machine is turned off.

Each server waits for requests to arrive on a well-known port associated with a particular service.

- Port 7: echo server
- Port 23: telnet server
- Port 25: mail server
- Port 80: HTTP server

See `/etc/services` for a list of semi-standard service to port bindings.

A machine that runs a server process is also often referred to as a "server."

Sockets Interface

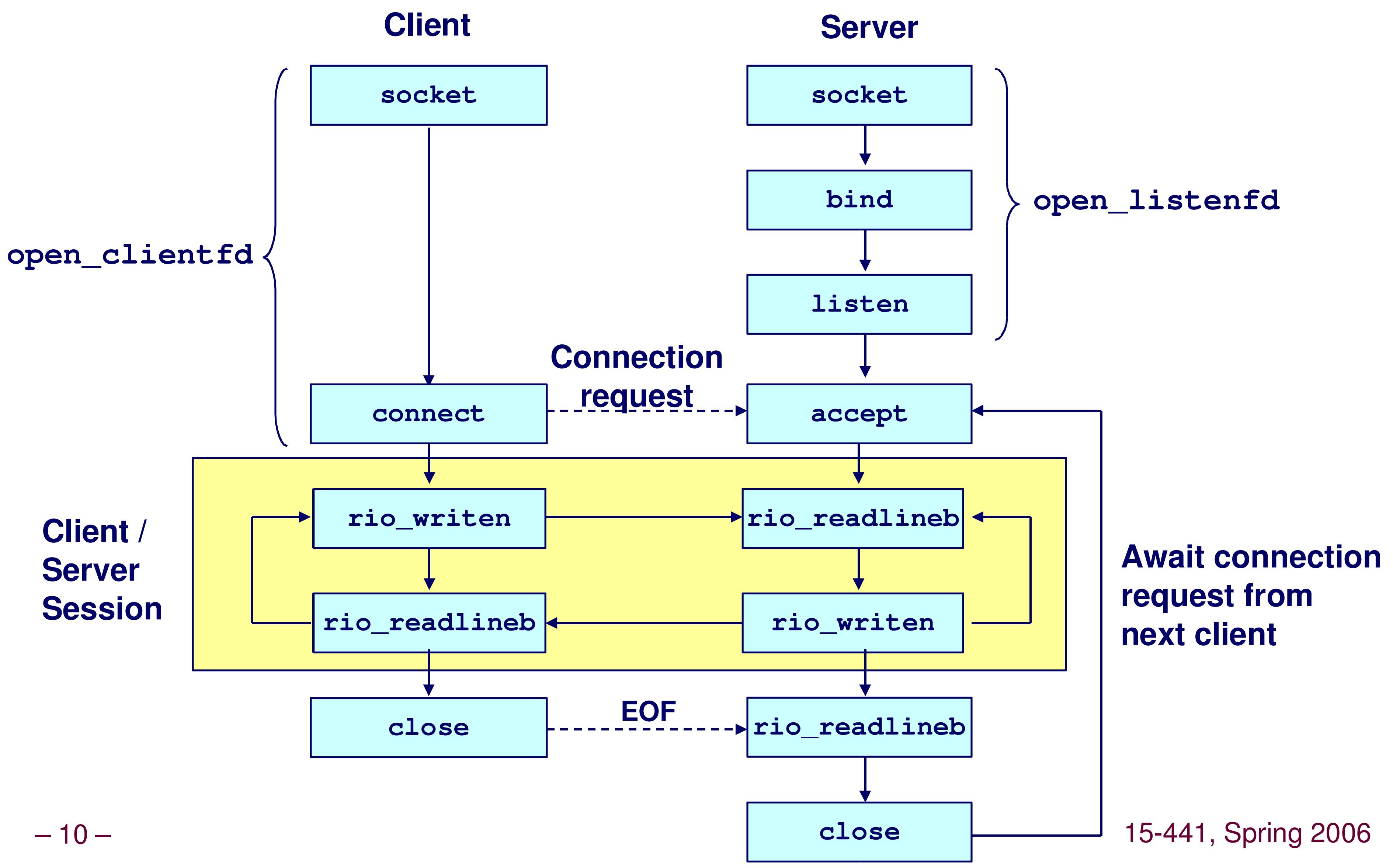
Created in the early 80's as part of the original Berkeley distribution of Unix that contained an early version of the Internet protocols.

Provides a user-level interface to the network.

Underlying basis for all Internet applications.

Based on client/server programming model.

Overview of the Sockets Interface



Sockets

What is a socket?

- To the kernel, a socket is an endpoint of communication.
- To an application, a socket is a file descriptor that lets the application read/write from/to the network.
  - Remember: All Unix I/O devices, including networks, are modeled as files.

Clients and servers communicate with each by reading from and writing to socket descriptors.

The main distinction between regular file I/O and socket I/O is how the application "opens" the socket descriptors.

Socket Address Structures

Generic socket address:

- For address arguments to `connect`, `bind`, and `accept`.
- Necessary only because C did not have generic (`void *`) pointers when the sockets interface was designed.

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

Internet-specific socket address:

- Must cast (`sockaddr_in *`) to (`sockaddr *`) for `connect`, `bind`, and `accept`.

```
struct sockaddr_in  {
  unsigned short  sin_family;  /* address family (always AF_INET) */
  unsigned short  sin_port;    /* port num in network byte order */
  struct in_addr  sin_addr;    /* IP addr in network byte order */
  unsigned char   sin_zero[8]; /* pad to sizeof(struct sockaddr) */
};
```

Reliable I/O (RIO) Summary

I/O Package Developed by David O'Hallaron

- http://csapp.cs.cmu.edu/public/code.html (csapp.{h,c})
- Allows mix of buffered and unbuffered I/O

Important Functions

- `rio_writen(int fd, void *buf, size_t n)`
  - Writes `n` bytes from buffer `buf` to file `fd`.
- `rio_readlineb(rio_t *rp, void *buf, size_t maxn)`
  - Read complete text line from file `rp` into buffer `buf`.
    - » Line must be terminated by newline (`\n`) character
  - Up to maximum of `maxn` bytes

Echo Client Main Routine

```
#include "csapp.h"

/* usage: ./echoclient host port */
int main(int argc, char **argv)
{
    int clientfd, port;
    char *host, buf[MAXLINE];
    rio_t rio;

    host = argv[1];
    port = atoi(argv[2]);

    clientfd = Open_clientfd(host, port);
    Rio_readinitb(&rio, clientfd);

    while (Fgets(buf, MAXLINE, stdin) != NULL) {
        Rio_writen(clientfd, buf, strlen(buf));
        Rio_readlineb(&rio, buf, MAXLINE);
        Fputs(buf, stdout);
    }
    Close(clientfd);
    exit(0);
}
```

Send line to server

Receive line from server

Echo Client: `open_clientfd`

```
int open_clientfd(char *hostname, int port)
{
  int clientfd;
  struct hostent *hp;
  struct sockaddr_in serveraddr;

  if ((clientfd = socket(AF_INET, SOCK_STREAM, 0)) < 0)
    return -1; /* check errno for cause of error */

  /* Fill in the server's IP address and port */
  if ((hp = gethostbyname(hostname)) == NULL)
    return -2; /* check h_errno for cause of error */
  bzero((char *) &serveraddr, sizeof(serveraddr));
  serveraddr.sin_family = AF_INET;
  bcopy((char *)hp->h_addr,
        (char *)&serveraddr.sin_addr.s_addr, hp->h_length);
  serveraddr.sin_port = htons(port);

  /* Establish a connection with the server */
  if (connect(clientfd, (SA *) &serveraddr, sizeof(serveraddr)) < 0)
    return -1;
  return clientfd;
}
```

This function opens a connection from the client to the server at `hostname:port`

Echo Client: `open_clientfd` (`socket`)

`socket` creates a socket descriptor on the client.

- `AF_INET`: indicates that the socket is associated with Internet protocols
  - Not Xerox XNS, DEC DECnet, not machine-local "Unix sockets"
- `SOCK_STREAM`: selects a reliable byte stream connection.
  - (AF_INET, SOCK_STREAM, 0) ⇒ TCP
  - (AF_INET, SOCK_DGRAM, 0) ⇒ UDP

```
int clientfd;  /* socket descriptor */

if ((clientfd = socket(AF_INET, SOCK_STREAM, 0)) < 0)
    return -1; /* check errno for cause of error */

... (more)
```

Echo Client: `open_clientfd (gethostbyname)`

The client then builds the server's Internet address.

```
int clientfd;                    /* socket descriptor */
struct hostent *hp;              /* DNS host entry */
struct sockaddr_in serveraddr; /* server's IP address */

...

/* fill in the server's IP address and port */
if ((hp = gethostbyname(hostname)) == NULL)
    return -2; /* check h_errno for cause of error */
bzero((char *) &serveraddr, sizeof(serveraddr));
serveraddr.sin_family = AF_INET;
bcopy((char *)hp->h_addr,
      (char *)&serveraddr.sin_addr.s_addr, hp->h_length);
serveraddr.sin_port = htons(port);
```

Echo Client: `open_clientfd` `(connect)`

Finally the client creates a connection with the server.

- **Client process suspends (blocks) until the connection is created.**
- **After resuming, the client is ready to begin exchanging messages with the server via Unix I/O calls on descriptor `sockfd`.**

```
  int clientfd;                         /* socket descriptor */
  struct sockaddr_in serveraddr;        /* server address */
  typedef struct sockaddr SA;           /* generic sockaddr */
...
  /* Establish a connection with the server */
  if (connect(clientfd, (SA *)&serveraddr, sizeof(serveraddr)) < 0)
    return -1;
  return clientfd;
}
```

Echo Server: Main Routine

```
int main(int argc, char **argv) {
    int listenfd, connfd, port, clientlen;
    struct sockaddr_in clientaddr;
    struct hostent *hp;
    char *haddrp;

    port = atoi(argv[1]); /* the server listens on a port passed
                             on the command line */
    listenfd = open_listenfd(port);

    while (1) {
        clientlen = sizeof(clientaddr);
        connfd = Accept(listenfd, (SA *)&clientaddr, &clientlen);
        hp = Gethostbyaddr((const char *)&clientaddr.sin_addr.s_addr,
                        sizeof(clientaddr.sin_addr.s_addr), AF_INET);
        haddrp = inet_ntoa(clientaddr.sin_addr);
        printf("Fd %d connected to %s (%s:%s)\n",
               connfd, hp->h_name, haddrp, ntohs(clientaddr.sin_port));
        echo(connfd);
        Close(connfd);
    }
}
```

Echo Server: `open_listenfd`

```
int open_listenfd(int port)
{
    int listenfd, optval=1;
    struct sockaddr_in serveraddr;

    /* Create a socket descriptor */
    if ((listenfd = socket(AF_INET, SOCK_STREAM, 0)) < 0)
        return -1;

    /* Eliminates "Address already in use" error from bind. */
    if (setsockopt(listenfd, SOL_SOCKET, SO_REUSEADDR,
                   (const void *)&optval , sizeof(int)) < 0)
        return -1;

... (more)
```

Echo Server: `open_listenfd` (cont)

```
...

  /* Listenfd will be an endpoint for all requests to port
       on any IP address for this host */
    bzero((char *) &serveraddr, sizeof(serveraddr));
    serveraddr.sin_family = AF_INET;
    serveraddr.sin_addr.s_addr = htonl(INADDR_ANY);
    serveraddr.sin_port = htons((unsigned short)port);
    if (bind(listenfd, (SA *)&serveraddr, sizeof(serveraddr)) < 0)
        return -1;

    /* Make it a listening socket ready to accept
       connection requests */
    if (listen(listenfd, LISTENQ) < 0)
        return -1;

   return listenfd;
}
```

Echo Server: `open_listenfd` (`socket`)

`socket` creates a socket descriptor on the server.

- `AF_INET`: indicates that the socket is associated with Internet protocols.
- `SOCK_STREAM`: selects a reliable byte stream connection.

```
int listenfd; /* listening socket descriptor */

/* Create a socket descriptor */
if ((listenfd = socket(AF_INET, SOCK_STREAM, 0)) < 0)
    return -1;
```

Echo Server: `open_listenfd` (initialize socket address)

Next, we initialize the socket with the server's Internet address (IP address and port)

```
  struct sockaddr_in serveraddr; /* server's socket addr */
...
  /* listenfd will be an endpoint for all requests to port
     on any IP address for this host */
  bzero((char *) &serveraddr, sizeof(serveraddr));
  serveraddr.sin_family = AF_INET;
  serveraddr.sin_addr.s_addr = htonl(INADDR_ANY);
  serveraddr.sin_port = htons((unsigned short)port);
```

IP addr and port stored in network (big-endian) byte order

- **`htonl()` converts longs from host byte order to network byte order.**
- **`htons()` converts shorts from host byte order to network byte order.**

Echo Server: `open_listenfd` (bind)

bind assigns a "name" to the socket

- Internet-domain byte-stream sockets are TCP
- TCP socket names are (IP address, port)
  - INADDR_ANY means "all IP addresses of this machine"
- Once the socket is named clients can connect to it

```
int listenfd;                     /* listening socket */
struct sockaddr_in serveraddr; /* server's socket addr */


...
  /* listenfd will be an endpoint for all requests to port
     on any IP address for this host */
  if (bind(listenfd, (SA *)&serveraddr, sizeof(serveraddr)) < 0)
      return -1;
```

Echo Server: `open_listenfd` (`listen`)

`listen` indicates that this socket will accept connection (`connect`) requests from clients.

```
int listenfd; /* listening socket */

...
 /* Make it a listening socket ready to accept connection requests */
    if (listen(listenfd, LISTENQ) < 0)
        return -1;
    return listenfd;
}
```

We're finally ready to enter the main server loop that accepts and processes client connection requests.

Echo Server: Main Loop

The server loops endlessly, waiting for connection requests, then reading input from the client, and echoing the input back to the client.

```
main() {

   /* create and configure the listening socket */

   while(1) {
      /* Accept(): wait for a connection request */
      /* echo(): read and echo input lines from client til EOF */
      /* Close(): close the connection */
   }
}
```

Echo Server: `accept`

`accept()` **blocks waiting for a connection request.**

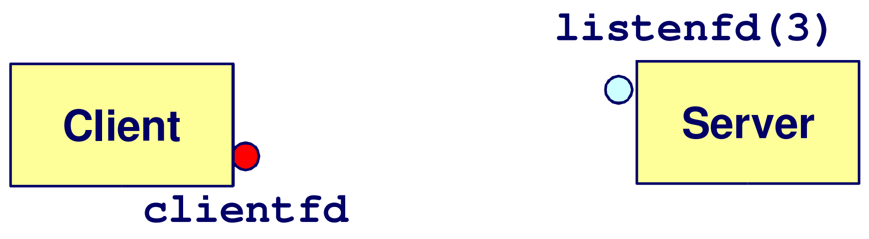
```
    int listenfd; /* listening descriptor */
    int connfd;   /* connected descriptor */
    struct sockaddr_in clientaddr;
    int clientlen;

    clientlen = sizeof(clientaddr);
    connfd = Accept(listenfd, (SA *)&clientaddr, &clientlen);
```

`accept` **returns a** ***connected descriptor*** **(`connfd`) with the same properties as the** ***listening descriptor*** **(`listenfd`)**

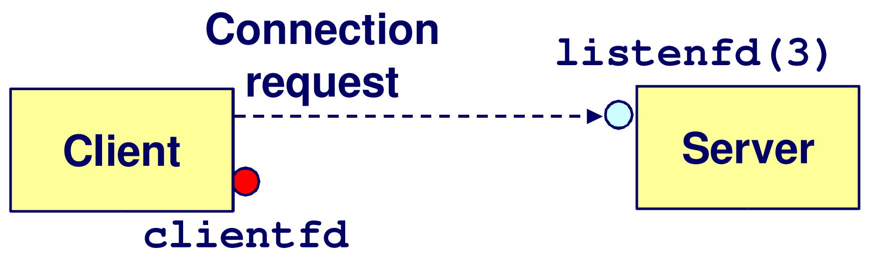
- **Returns when the connection between client and server is created and ready for I/O transfers.**
- **All I/O with the client will be done via the connected socket.**

`accept` **also fills in client's IP address.**

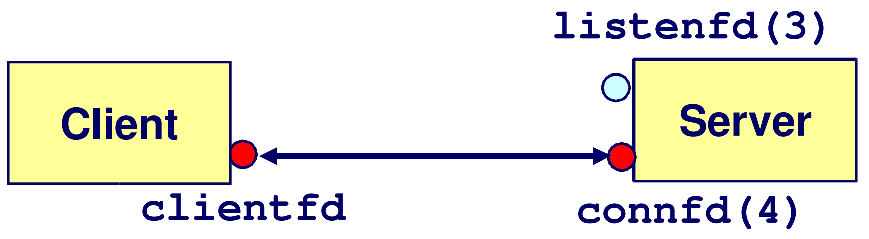
Echo Server: `accept` Illustrated



1. Server blocks in `accept`, waiting for connection request on listening descriptor `listenfd`.



2. Client makes connection request by calling and blocking in `connect`.



3. Server returns `connfd` from `accept`. Client returns from `connect`. Connection is now established between `clientfd` and `connfd`.

Connected vs. Listening Descriptors

Listening descriptor

- End point for client connection requests.
- Created once and exists for lifetime of the server.

Connected descriptor

- End point of the connection between client and server.
- A new descriptor is created each time the server accepts a connection request from a client.
- Exists only as long as it takes to service client.

Why the distinction?

- Allows for concurrent servers that can communicate over many client connections simultaneously.

Echo Server: Identifying the Client

The server can determine the domain name, IP address, and port of the client.

```
    struct hostent *hp;  /* pointer to DNS host entry */
    char *haddrp;        /* pointer to dotted decimal string */

    hp = Gethostbyaddr((const char *)&clientaddr.sin_addr.s_addr,
                       sizeof(clientaddr.sin_addr.s_addr), AF_INET);
    haddrp = inet_ntoa(clientaddr.sin_addr);
    printf("Fd %d connected to %s (%s:%s)\n",
            connfd, hp->h_name, haddrp, ntohs(clientaddr.sin_port));
```

Echo Server: `echo`

The server uses RIO to read and echo text lines until EOF (end-of-file) is encountered.

- EOF notification caused by client calling `close(clientfd)`.
- IMPORTANT: EOF is a condition, not a particular data byte.

```
void echo(int connfd)
{
    size_t n;
    char buf[MAXLINE];
    rio_t rio;

    Rio_readinitb(&rio, connfd);
    while((n = Rio_readlineb(&rio, buf, MAXLINE)) != 0) {
        printf("server received %d bytes\n", n);
        Rio_writen(connfd, buf, n);
    }
}
```

Receive line from client

Send line to client

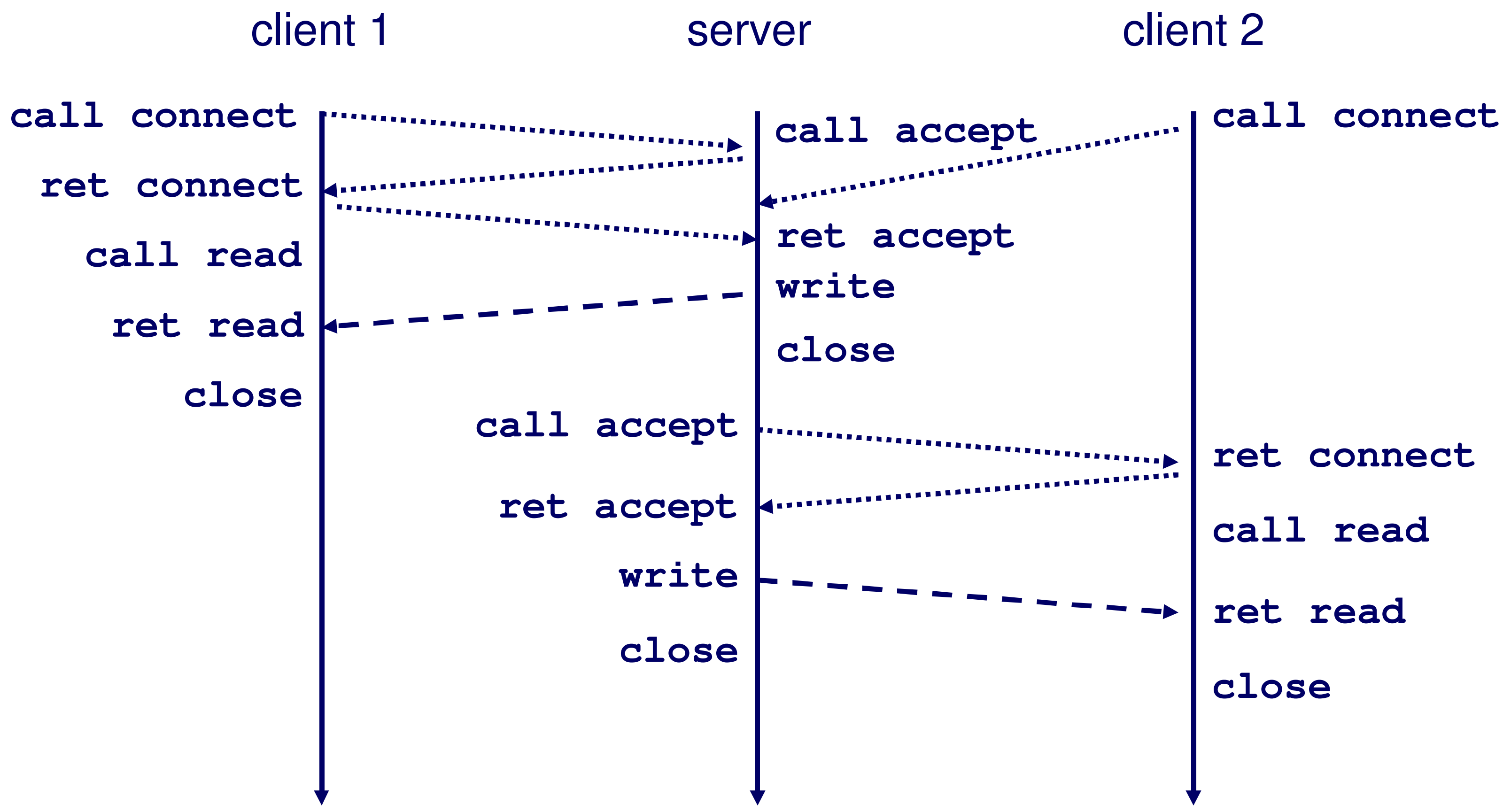
Running Echo Client/Server

```
[bryant@bryant echo]$ ./echoservers 15441
fd 4 connected to BRYANT-TP2.VLSI.CS.CMU.EDU
(128.2.222.198:3507)
Server received 12 (12 total) bytes on fd 4
```

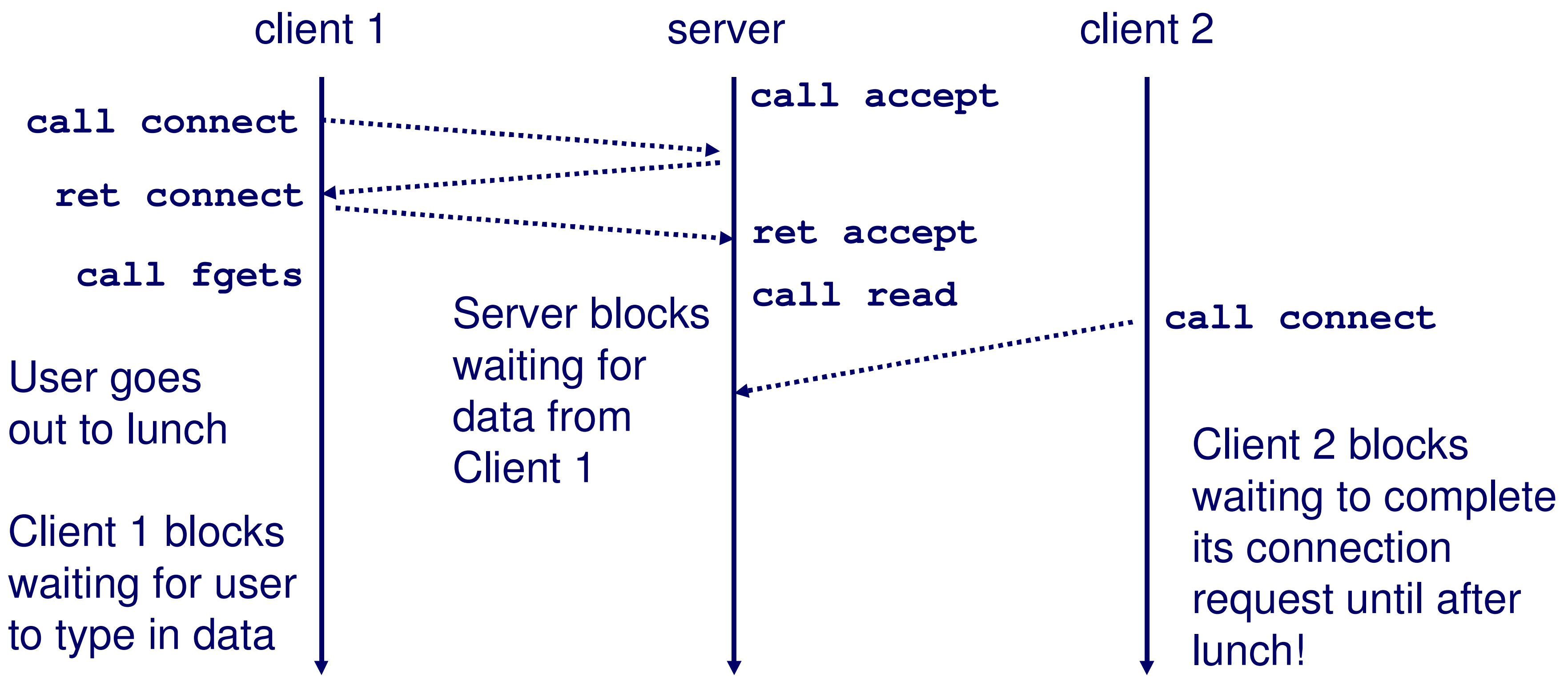
```
[bryant@bryant-tp2 echo]$ ./echoclient bryant.vlsi.cs.cmu.edu 15441
hello world
hello world
```

Iterative Servers

Iterative servers process one request at a time.



Fundamental Flaw of Iterative Servers

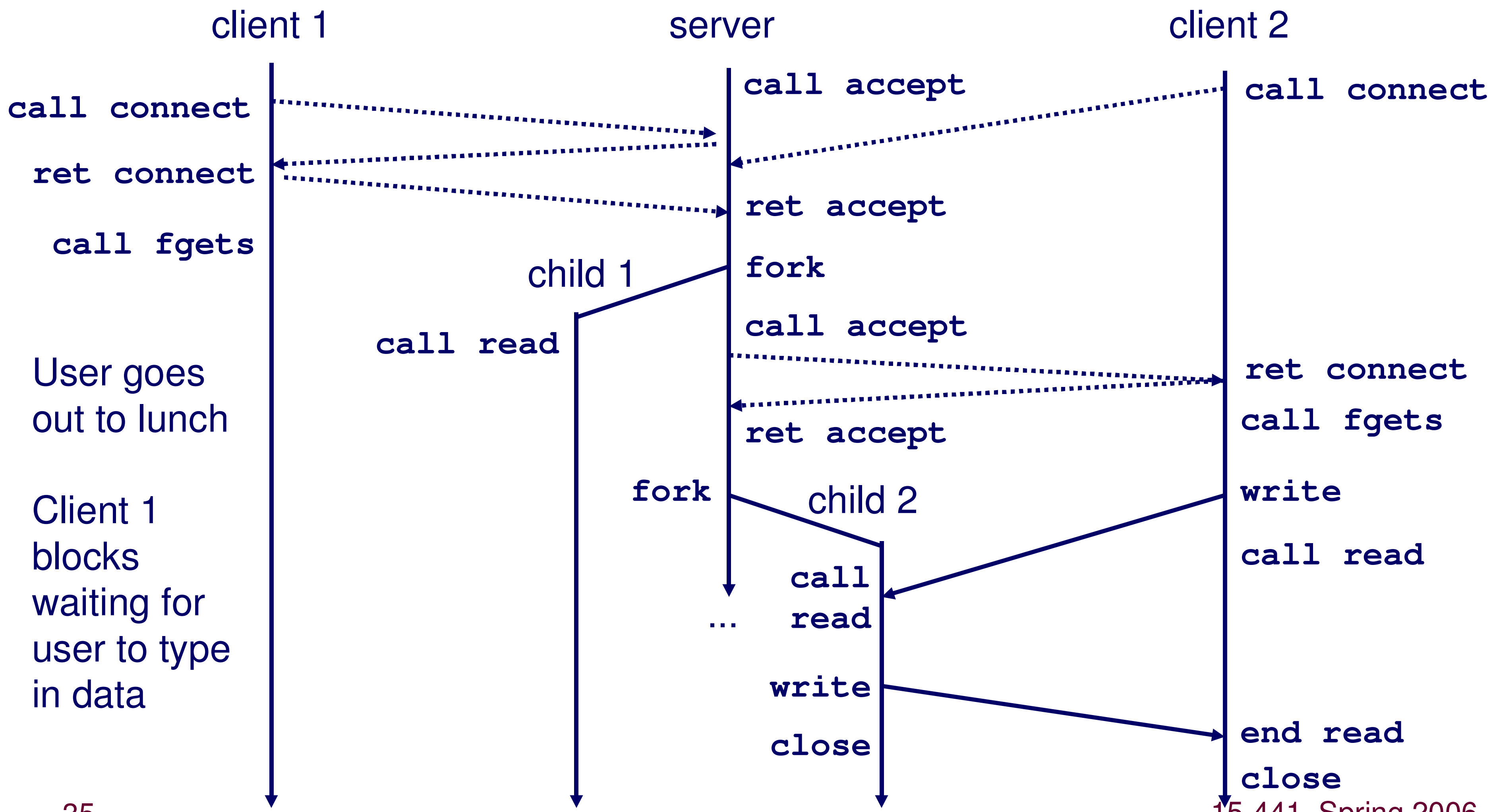

client 1
server
client 2
call connect
call accept
ret connect
ret accept
call fgets
call read
call connect
Server blocks waiting for data from Client 1
User goes out to lunch
Client 1 blocks waiting for user to type in data
Client 2 blocks waiting to complete its connection request until after lunch!

Solution: use *concurrent servers* instead.

- **Concurrent servers use multiple concurrent flows to serve multiple clients at the same time.**

Concurrent Servers

Concurrent servers handle multiple requests concurrently.



Possible Mechanisms for Creating Concurrent Flows

1. Processes

- Kernel automatically interleaves multiple logical flows.
- Each flow has its own private address space.

2. I/O multiplexing with `select()`

Our Focus

- User manually interleaves multiple logical flows.
- Each flow shares the same address space.
- Popular for high-performance server designs.

3. Threads

- Kernel automatically interleaves multiple logical flows.
- Each flow shares the same address space.
- Hybrid of processes and I/O multiplexing!

Event-Based Concurrent Servers Using I/O Multiplexing

Maintain a pool of connected descriptors.

Repeat the following forever:

- Use the Unix `select` function to block until:
  - (a) New connection request arrives on the listening descriptor.
  - (b) New data arrives on an existing connected descriptor.
- If (a), add the new connection to the pool of connections.
- If (b), read any available data from the connection
  - Close connection on EOF and remove it from the pool.

The `select` Function

`select()` sleeps until one or more file descriptors in the set `readset` ready for reading.

```
#include <sys/select.h>

int select(int maxfdp1, fd_set *readset, NULL, NULL, NULL);
```

`readset`

- Opaque bit vector (max FD_SETSIZE bits) that indicates membership in a *descriptor set.*
    - On Linux machines, FD_SETSIZE = 1024
- If bit k is 1, then descriptor k is a member of the descriptor set.
- When call **`select`**, should have readset indicate which descriptors to test

`maxfdp1`

- Maximum descriptor in descriptor set plus 1.
- Tests descriptors 0, 1, 2, ..., maxfdp1 - 1 for set membership.

`select()` returns the number of ready descriptors and keeps on each bit of `readset` for which corresponding descriptor is ready

Macros for Manipulating Set Descriptors

`void FD_ZERO(fd_set *fdset);`

- Turn off all bits in `fdset`.

`void FD_SET(int fd, fd_set *fdset);`

- Turn on bit `fd` in `fdset`.

`void FD_CLR(int fd, fd_set *fdset);`

- Turn off bit `fd` in `fdset`.

`int FD_ISSET(int fd, *fdset);`

- Is bit `fd` in `fdset` turned on?

Event-based Concurrent Echo Server

```
/*
 * echoservers.c - A concurrent echo server based on select
 */
#include "csapp.h"

typedef struct { /* represents a pool of connected descriptors */
    int maxfd;        /* largest descriptor in read_set */
    fd_set read_set;  /* set of all active 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 */
} pool;

int byte_cnt = 0; /* counts total bytes received by server */
```

Event-based Concurrent Server (cont)

```
int main(int argc, char **argv)
{
    int listenfd, connfd, clientlen = sizeof(struct sockaddr_in);
    struct sockaddr_in clientaddr;
    static pool pool;

    listenfd = Open_listenfd(argv[1]);
    init_pool(listenfd, &pool);

    while (1) {
        pool.ready_set = pool.read_set;
        pool.nready = Select(pool.maxfd+1, &pool.ready_set,
                             NULL, NULL, NULL);

        if (FD_ISSET(listenfd, &pool.ready_set)) {
            connfd = Accept(listenfd, (SA *)&clientaddr,&clientlen);
            add_client(connfd, &pool);
        }
        check_clients(&pool);
    }
}
```

Event-based Concurrent Server (cont)

```
/* initialize the descriptor pool */
void init_pool(int listenfd, pool *p)
{
    /* Initially, there are no connected descriptors */
    int i;
    p->maxi = -1;
    for (i=0; i< FD_SETSIZE; i++)
        p->clientfd[i] = -1;

    /* Initially, listenfd is only member of select read set */
    p->maxfd = listenfd;
    FD_ZERO(&p->read_set);
    FD_SET(listenfd, &p->read_set);
}
```

Event-based Concurrent Server (cont)

```
void add_client(int connfd, pool *p)  /* add connfd to pool p */
{
    int i;
    p->nready--;

   for (i = 0; i < FD_SETSIZE; i++)  /* Find available slot */
        if (p->clientfd[i] < 0) {
            p->clientfd[i] = connfd;
            Rio_readinitb(&p->clientrio[i], connfd);

            FD_SET(connfd, &p->read_set); /* Add desc to read set */

            if (connfd > p->maxfd) /* Update max descriptor num */
                p->maxfd = connfd;
            if (i > p->maxi) /* Update pool high water mark */
                p->maxi = i;
            break;
        }
    if (i == FD_SETSIZE) /* Couldn't find an empty slot */
        app_error("add_client error: Too many clients");
}
```

Event-based Concurrent Server (cont)

```
void check_clients(pool *p) { /* echo line from ready descs in pool p */
    int i, connfd, n;
    char buf[MAXLINE];
    rio_t rio;

    for (i = 0; (i <= p->maxi) && (p->nready > 0); i++) {
        connfd = p->clientfd[i];
        rio = p->clientrio[i];

        /* If the descriptor is ready, echo a text line from it */
        if ((connfd > 0) && (FD_ISSET(connfd, &p->ready_set))) {
            p->nready--;
            if ((n = Rio_readlineb(&rio, buf, MAXLINE)) != 0) {
                byte_cnt += n;
                Rio_writen(connfd, buf, n);
            }
            else {/* EOF detected, remove descriptor from pool */
                Close(connfd);
                FD_CLR(connfd, &p->read_set);
                p->clientfd[i] = -1;
            }
        }
    }
}
```

Pro and Cons of Event-Based Designs

+ One logical control flow.

+ Can single-step with a debugger.

+ No process or thread control overhead.

  - Design of choice for high-performance Web servers and search engines.

- Significantly more complex to code than process- or thread-based designs.

- Can be vulnerable to two forms of denial of service attacks

  - How?

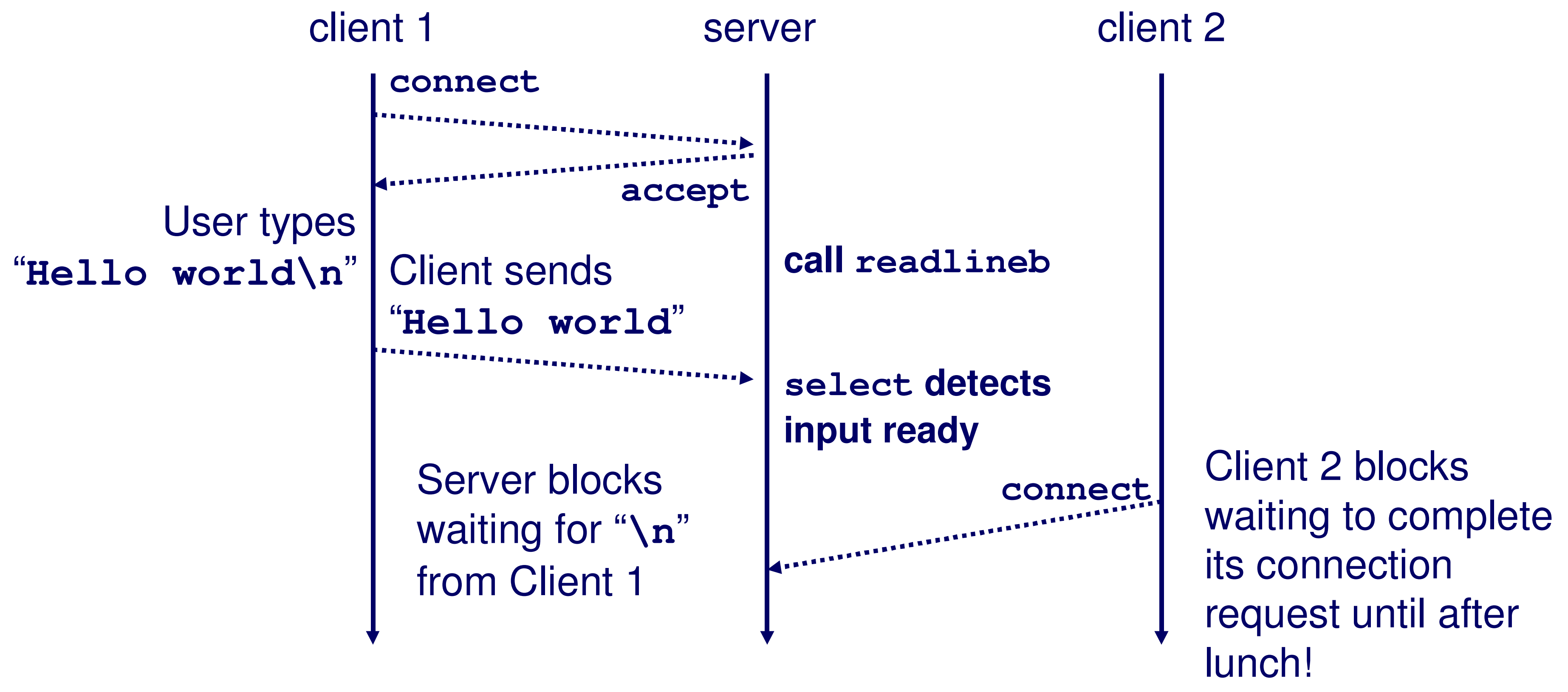
Attack #1

Overwhelm Server with Connections

- Limited to FD_SETSIZE – 4 (typically 1020) connections

Defenses?

Attack #2: Partial Lines


client 1
server
client 2
connect
accept
User types "Hello world\n"
Client sends "Hello world"
call readlineb
select detects input ready
connect
Server blocks waiting for "\n" from Client 1
Client 2 blocks waiting to complete its connection request until after lunch!

- **Client gets attention of server by sending partial line**
- **Server blocks until line completed**

Flaky Client

```
    while (Fgets(buf, MAXLINE, stdin) != NULL) {
        Rio_writen(clientfd, buf, strlen(buf)-1);
        Fgets(buf, MAXLINE, stdin);  /* Read & ignore line */
        Rio_writen(clientfd, "\n", 1);
        Rio_readlineb(&rio, buf, MAXLINE);
        Fputs(buf, stdout);
    }
```

- Sends everything up to newline
- Doesn’t send newline until user types another line
- Meanwhile, server will block

Implementing a Robust Server

Break Up Reading Line into Multiple Partial Reads

- Every time connection selected, read as much as is available
- Construct line in separate buffer for each connection

Must Use Unix Read

- `read(int fd, void *buf, size_t maxn)`
  - Read as many bytes as are available from file `fd` into buffer `buf`.
  - Up to maximum of `maxn` bytes

Cannot Use RIO Version

- `rio_readn(int fd, void *buf, size_t n)`
  - Read `n` bytes into buffer `buf`.
  - Blocks until all `n` read or EOF

Robust Server

```c
/*
 * echoserverub.c - A robust, concurrent echo server based on select
 */
#include "csapp.h"

typedef struct { /* represents a pool of connected descriptors */
    int maxfd;          /* largest descriptor in read_set */
    fd_set read_set;    /* set of all active 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 */
    char clientbuf[FD_SETSIZE][MAXBUF]; /* set of read buffers */
    int clientcnt[FD_SETSIZE]; /* Count of characters in buffers */
} pool;

int byte_cnt = 0; /* counts total bytes received by server */
```

Robust Server Loop

```
void check_clients(pool *p)
{
    int i, connfd, n;
    for (i = 0; (i <= p->maxi) && (p->nready > 0); i++) {
        connfd = p->clientfd[i];
        char *buf = p->clientbuf[i]; /* Private buffer */
        int cnt =   p->clientcnt[i]; /* Number of chars read so far */
        if ((connfd > 0) && (FD_ISSET(connfd, &p->ready_set))) {
            p->nready--;
            if ((n = Read(connfd, buf+cnt, MAXBUF-cnt)) != 0) {
                byte_cnt += n; cnt += n;
                if (buf[cnt-1] == '\n') {
                  Write(connfd, buf, cnt); /* End of line */
                  p->clientcnt[i] = 0;
                } else
                  p->clientcnt[i] = cnt;
            }
        }  else { ... }
    }
}
```

Robustness Principles

Client

- Nothing user does/types should make program crash
    - Must perform complete checking for user errors

Server

- Nothing a client does should cause server to malfunction
    - Possibly malicious clients

Things to Worry About

- Error return codes by system calls
- String overflows
- Malformed messages
- Memory/resource leaks
    - Especially for server

Echo Client Main Routine

```
#include "csapp.h"

/* usage: ./echoclient host port */
int main(int argc, char **argv)
{
    int clientfd, port;
    char *host, buf[MAXLINE];
    rio_t rio;

    host = argv[1];
    port = atoi(argv[2]);

    clientfd = Open_clientfd(host, port);
    Rio_readinitb(&rio, clientfd);

    while (Fgets(buf, MAXLINE, stdin) != NULL) {
        Rio_writen(clientfd, buf, strlen(buf));
        Rio_readlineb(&rio, buf, MAXLINE);
        Fputs(buf, stdout);
    }
    Close(clientfd);
    exit(0);
}
```

No checking of command line arguments

Wrappers exit on error

fgets does not insert \n when string too long

Robust Version of Echo Client (1)

```
#include <limits.h>

/* To demonstrate truncation */
#define LINELEN 20

/* Maximum number of errors to tolerate before exiting */
int errlimit = 5;

void errcheck(char *message, int fatal)
{
  if (--errlimit == 0 || fatal) {
    fprintf(stderr, "Error: %s.  Exiting\n", message);
    exit(1);
  }
  fprintf(stderr, "Error: %s.  Continuing\n", message);
}

void usage(char *progname) {
  fprintf(stderr, "Usage: %s host port\n", progname);
  exit(0);
}
```

Robust Version of Echo Client (2)

```
int main(int argc, char **argv)
{
  int clientfd, port;
  char *host, buf[LINELEN];
  rio_t rio;

  if (argc != 3)
    usage(argv[0]);

  host = argv[1];
  port = atoi(argv[2]);

  if (port <= 0 || port > SHRT_MAX)
    errcheck("Invalid Port", 1);

  clientfd = open_clientfd(host, port);
  if (clientfd < 0)
    errcheck("Couldn't open connection to server", 1);

  rio_readinitb(&rio, clientfd);
  ...
```

Robust Version of Echo Client (3)

```
...
while (fgets(buf, LINELEN, stdin) != NULL) {
  int n;
  if (strlen(buf) == LINELEN-1 && buf[LINELEN-1] != '\n')
    strcpy(buf+LINELEN-5, "...\n"); /* Truncate string */
  if (rio_writen(clientfd, buf, strlen(buf)) < 0) {
    errcheck("Failed to send message", 0);
    continue;
  }
  if ((n = rio_readlineb(&rio, buf, LINELEN) <= 0)) {
    if (n == 0)
      errcheck("Unexpected EOF from server\n", 1);
    else
      errcheck("Failed to receive reply from server", 0);
  }
  if (fputs(buf, stdout) < 0)
    errcheck("Couldn't print reply\n", 0);
}
...
```

Robust Version of Echo Client (4)

```
  ...
  if (close(clientfd) < 0)
    errcheck("Couldn't close connection to server", 1);
  exit(0);
}
```

Design Issues

Error Classification & Recovery

- Fatal vs. nonfatal errors
  - Server code should only have fatal error when something is wrong on server machine
- What to do when when encounter nonfatal error
  - Skip to next activity
  - Server might close connection to malfunctioning client

Other Types of Errors

- Client dormant too long
  - Add timeouts to code
  - Gets very messy
- Denial of service attacks
  - Difficult to detect and/or handle

Scripting Languages

General Features

- Easy to write “quick & dirty” code
  - Minimal type checking
  - Interpretive
- Good support for strings, regular expressions, invoking other programs

Scripting Languages

Examples

- awk, shell code
    - Developed originally at Bell Labs. Not very popular
- tcl
    - Developed by John Ousterhout (CMU PhD 1980)
    - Nice integration with tk graphics interface package
- perl
    - Developed by Larry Wall to aid system administration
    - Big & messy, but very powerful
- python
    - Developed by Guido van Rossum
    - Indentation is significant
        - » (ouch)

Echo Client in Perl

```perl
#!/usr/bin/perl -w

use sigtrap;
use IO::Socket;

$host = $ARGV[0];
$port = $ARGV[1];

$socket = IO::Socket::INET->new("$host:$port")
  || die("Couldn't connect to $host:$port: $!\n");


while (<STDIN>) {
  $line = $_;
  print $socket $line;
  $reply = <$socket>;
  print $reply;
}
```

Conceptual Model

Maintain State Machine for Each Connection

- First Version: State is just identity of connfd
- Second Version: State includes partial line + count of characters

`Select` Determines Which State Machine to Update

- First Version: Process entire line
- Second Version: Process as much of line as is available

Design Issue

- Must set granularity of state machine to avoid server blocking

For More Information

W. Richard Stevens, *Unix Network Programming: Networking APIs: Sockets and XTI*, Volume 1, Second Edition, Prentice Hall, 1998.

- THE network programming “bible”.

Complete versions of original echo client and server are developed in *Computer Systems*: *A Programmer’s Perspective*.

- Available from `csapp.cs.cmu.edu`
- You may compile and run them for yourselves to see how they work.
- Feel free to borrow any of this code.
- But be careful---it isn’t sufficiently robust for our programming assignments
  - » Most routines exit when any kind of error encountered