18-600 Foundations of Computer Systems

Lecture 24:
"Network Programming – Part 2"

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November 28, 2016

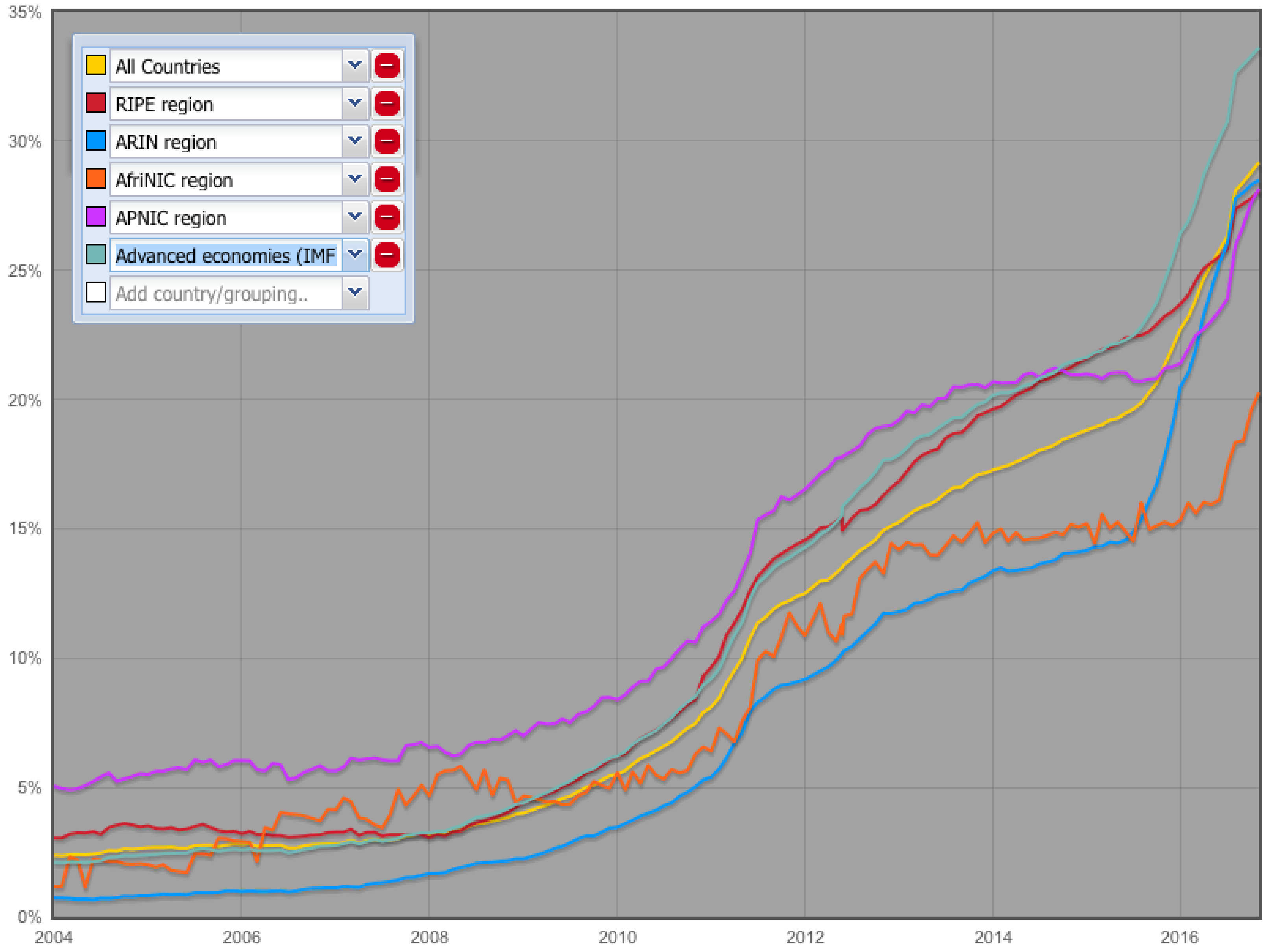
➢ Required Reading Assignment:
- **Chapter 11 of CS:APP (3rd edition) by Randy Bryant & Dave O'Hallaron.**

Electrical & Computer ENGINEERING

Carnegie Mellon University

IPv6 Adoption via IPv6 ASN announcements

- Data from RIPE Network Coordination Center
  - http://v6asns.ripe.net/v/6?s=_ALL;s=_RIR_RIPE_NCC;s=_RIR_ARIN;s=_RIR_AfriNIC;s=_RIR_APNIC;s=_IMF_advanced
- Data captured 28-Nov-2016



18-600 Foundations of Computer Systems

Lecture 24: "Network Programming – Part 2"

- **Using `getaddrinfo` for host and service conversion**
- **Writing clients and servers**
- **Writing Web servers!**

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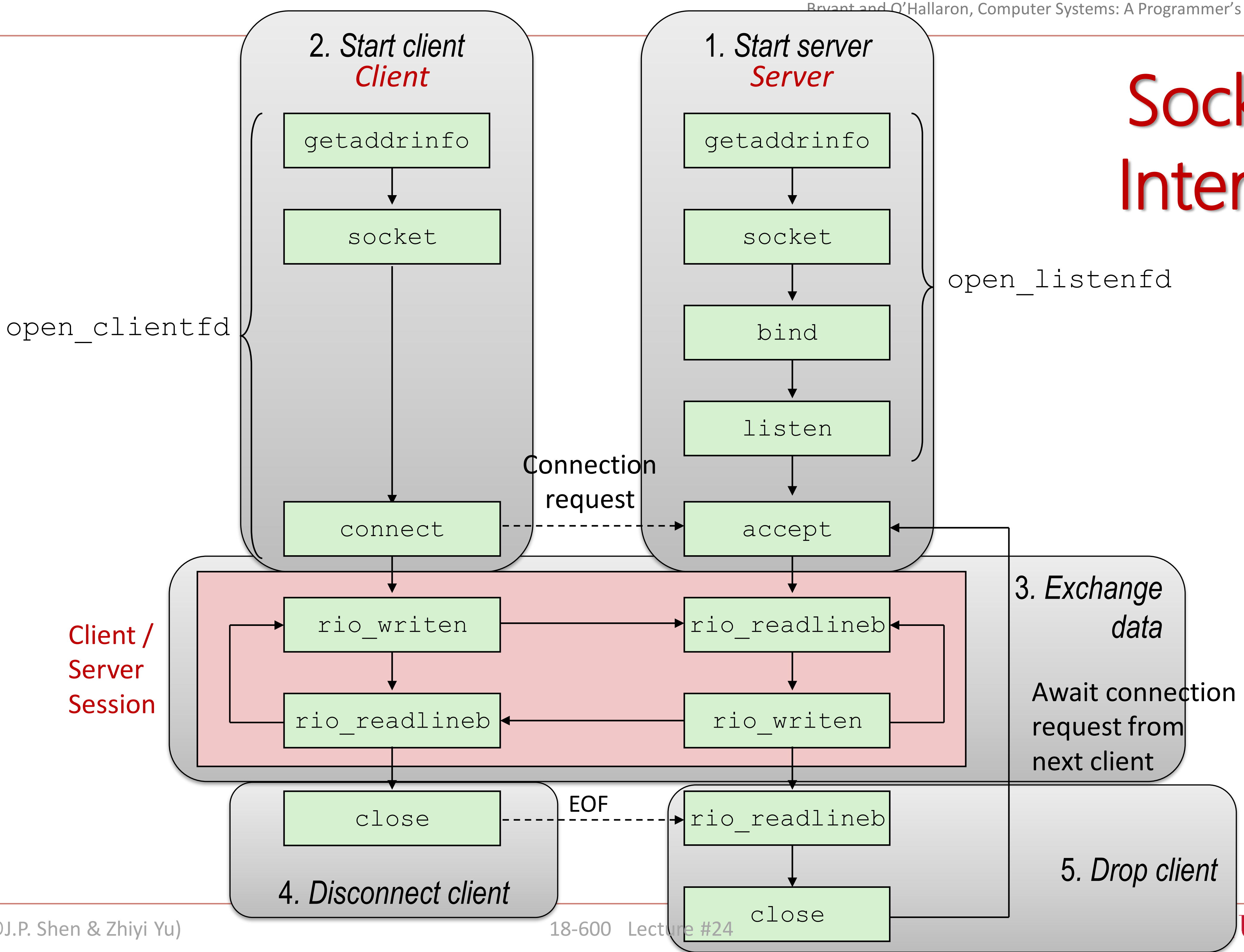
Sockets Interface

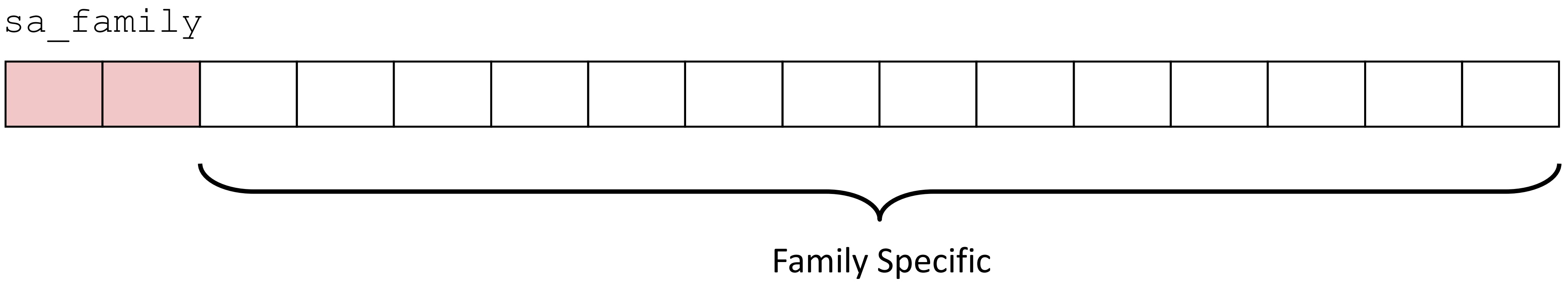


Recall: Socket Address Structures

- **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
  - For casting convenience, we adopt the Stevens convention:

    `typedef struct sockaddr SA;`

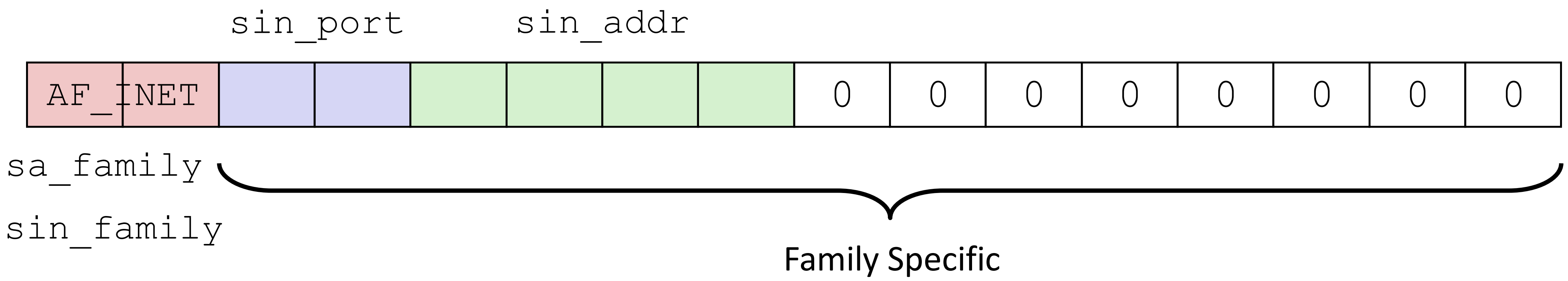
```
struct sockaddr {
  uint16_t  sa_family;    /* Protocol family */
  char      sa_data[14];  /* Address data.   */
};
```



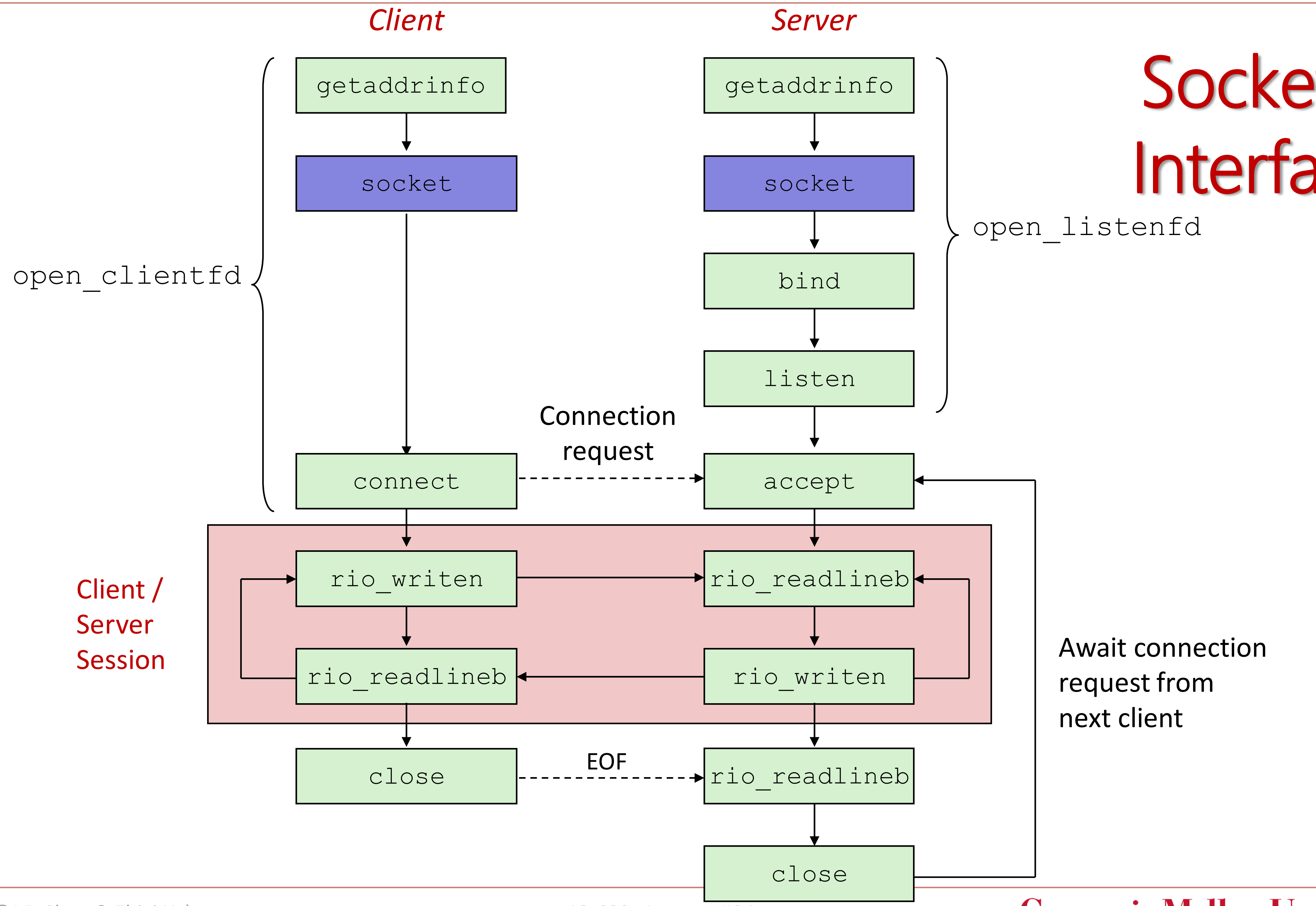
Recall: Socket Address Structures

- **Internet-specific socket address:**
  - Must cast (`struct sockaddr_in *`) to (`struct sockaddr *`) for functions that take socket address arguments.

```
struct sockaddr_in  {
  uint16_t        sin_family;  /* Protocol family (always AF_INET) */
  uint16_t        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) */
};
```



Sockets Interface



Sockets Interface: `socket`

- **Clients and servers use the `socket` function to create a *socket descriptor*:**

```
int socket(int domain, int type, int protocol)
```

- **Example:**

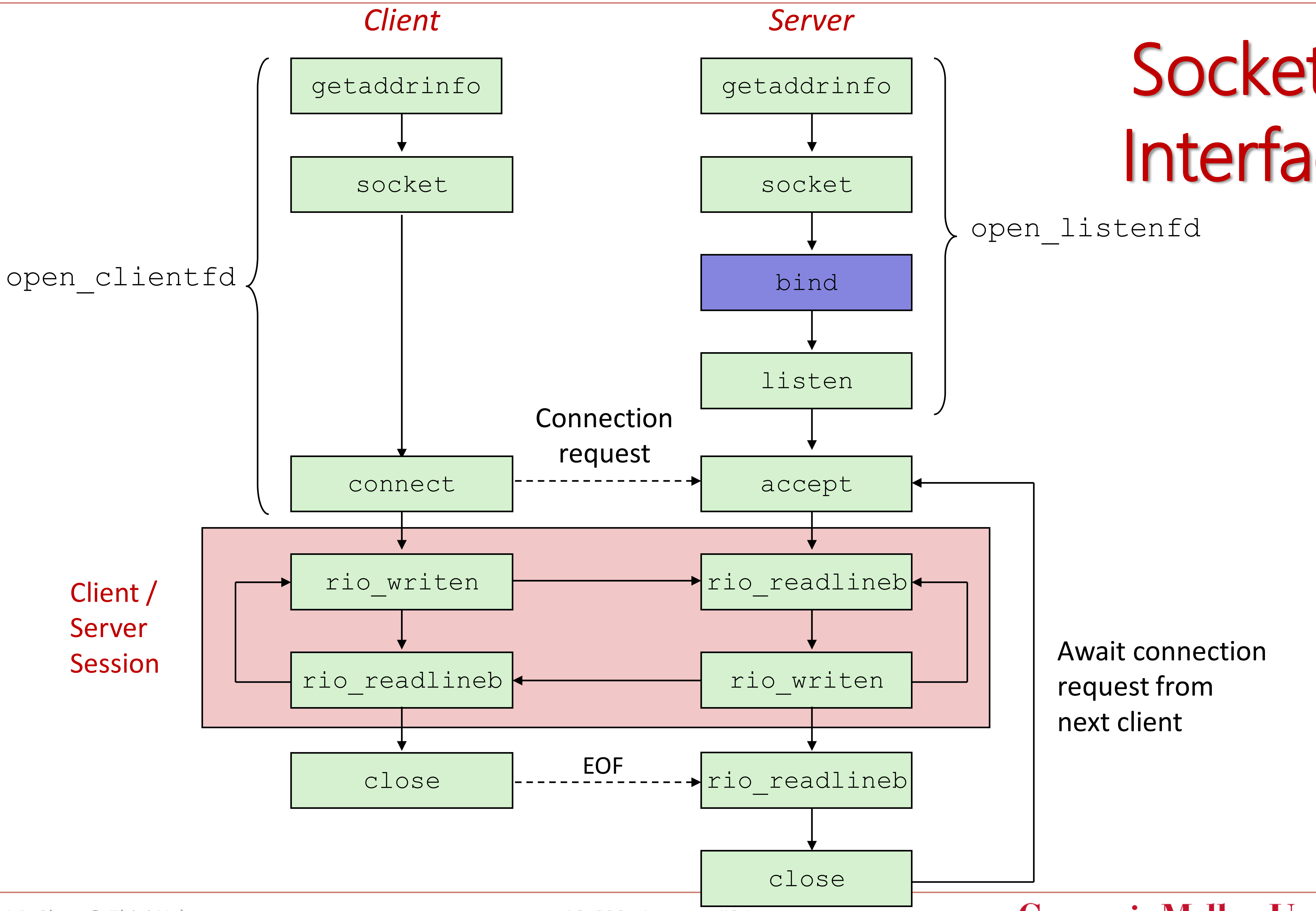
```
int clientfd = Socket(AF_INET, SOCK_STREAM, 0);
```

AF_INET: Indicates that we are using 32-bit IPV4 addresses

SOCK_STREAM: Indicates that the socket will be the end point of a connection

Protocol specific! Best practice is to use `getaddrinfo` to generate the parameters automatically, so that code is protocol independent.

Sockets Interface



Sockets Interface: `bind`

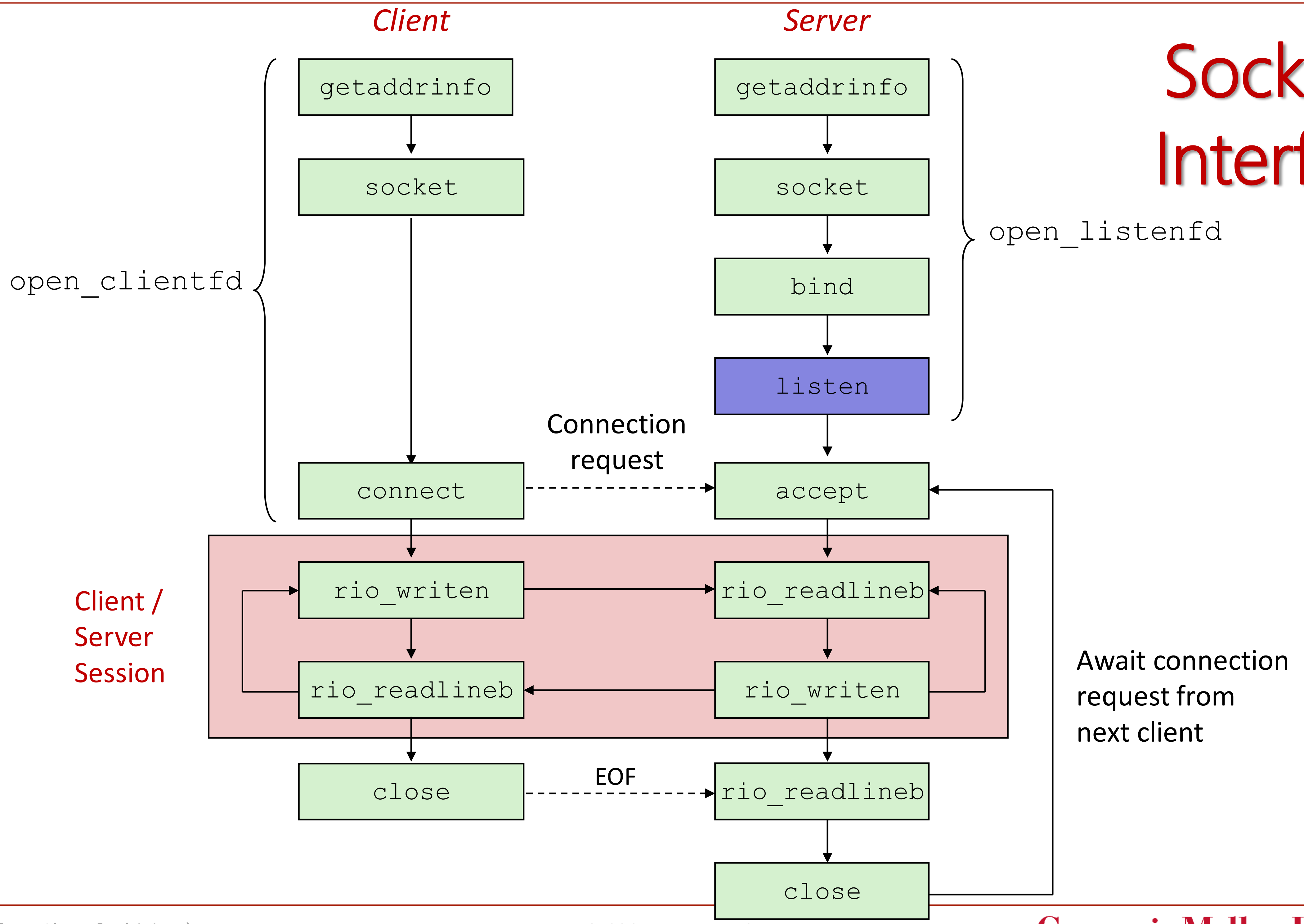
- A server uses `bind` to ask the kernel to associate the server's socket address with a socket descriptor:

```
int bind(int sockfd, SA *addr, socklen_t addrlen);
```

- The process can read bytes that arrive on the connection whose endpoint is `addr` by reading from descriptor `sockfd`.
- Similarly, writes to `sockfd` are transferred along connection whose endpoint is `addr`.

Best practice is to use `getaddrinfo` to supply the arguments `addr` and `addrlen`.

Sockets Interface



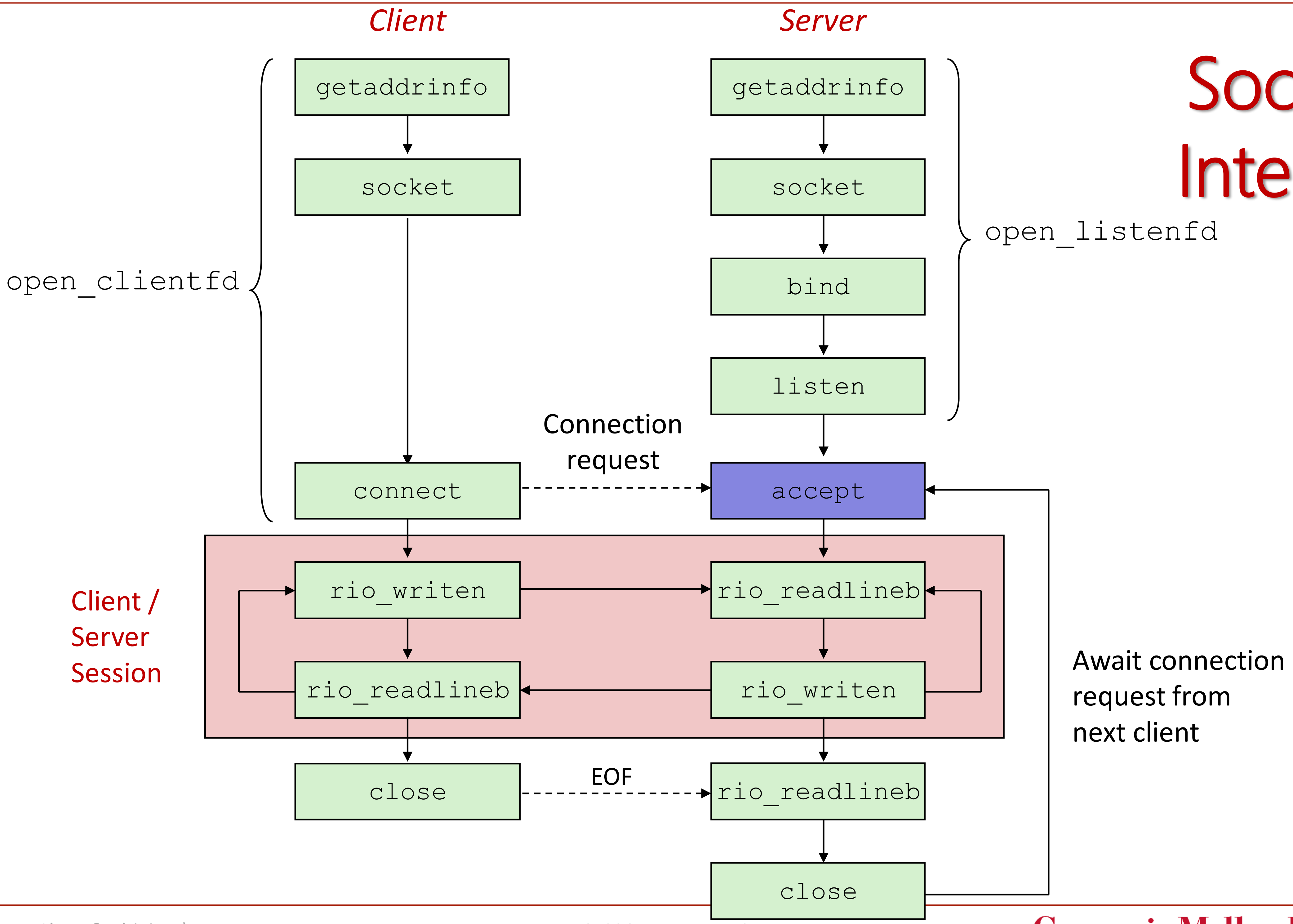
Sockets Interface: `listen`

- By default, kernel assumes that descriptor from socket function is an *active socket* that will be on the client end of a connection.
- A server calls the listen function to tell the kernel that a descriptor will be used by a server rather than a client:

```
int listen(int sockfd, int backlog);
```

- Converts `sockfd` from an active socket to a *listening socket* that can accept connection requests from clients.
- `backlog` is a hint about the number of outstanding connection requests that the kernel should queue up before starting to refuse requests.

Sockets Interface



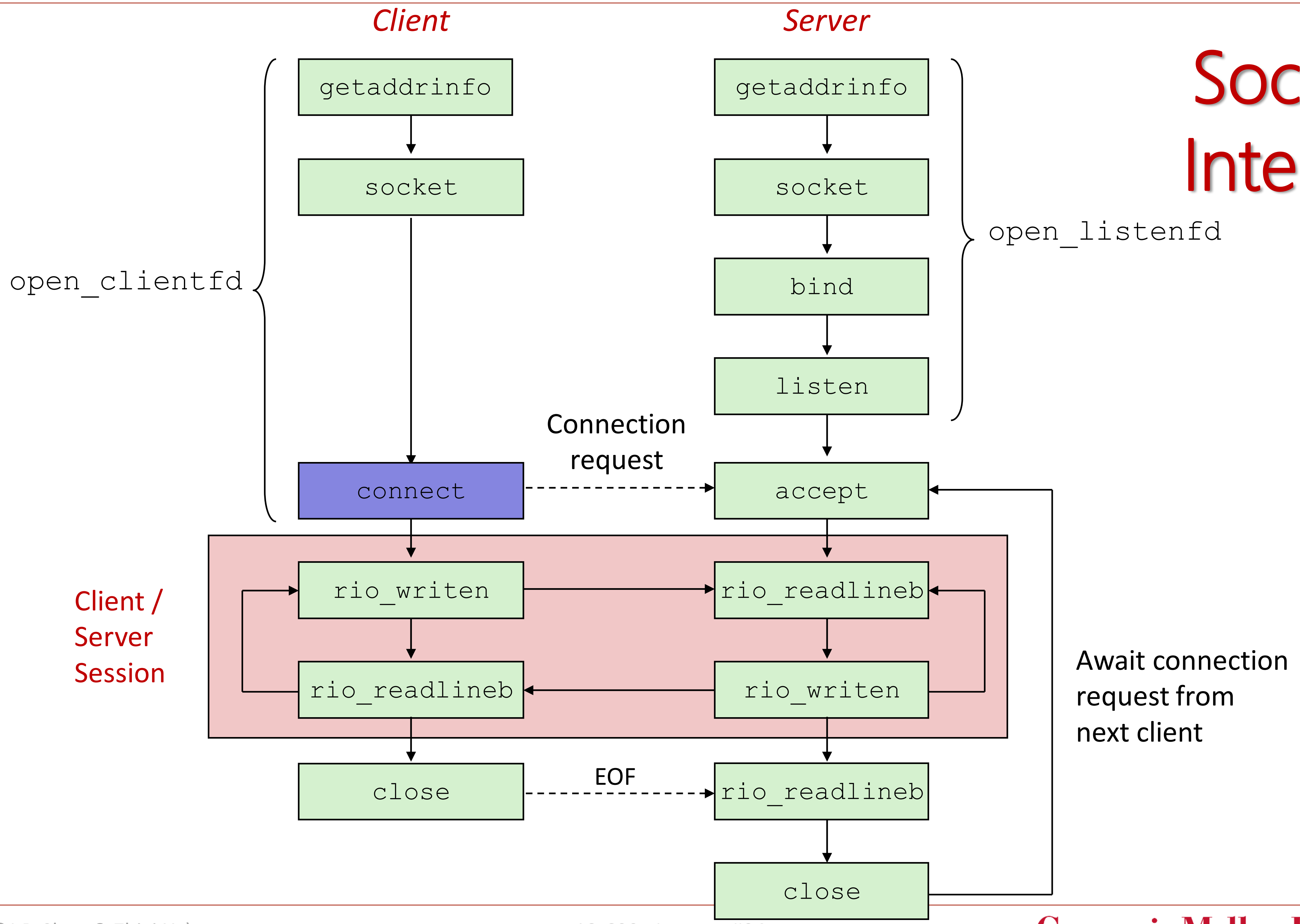
Sockets Interface: `accept`

- **Servers wait for connection requests from clients by calling `accept`:**

```
int accept(int listenfd, SA *addr, int *addrlen);
```

- **Waits for connection request to arrive on the connection bound to `listenfd`, then fills in client's socket address in `addr` and size of the socket address in `addrlen`.**
- **Returns a *connected descriptor* that can be used to communicate with the client via Unix I/O routines.**

Sockets Interface



Sockets Interface: `connect`

- **A client establishes a connection with a server by calling connect:**

```
int connect(int clientfd, SA *addr, socklen_t addrlen);
```

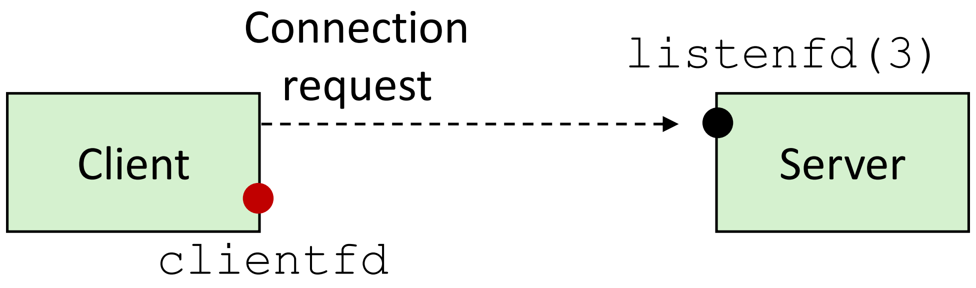
- **Attempts to establish a connection with server at socket address `addr`**
  - If successful, then `clientfd` is now ready for reading and writing.
  - Resulting connection is characterized by socket pair

    `(x:y, addr.sin_addr:addr.sin_port)`
    - `x` is client address
    - `y` is ephemeral port that uniquely identifies client process on client host

Best practice is to use `getaddrinfo` to supply the arguments `addr` and `addrlen`.

`accept` Illustrated

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



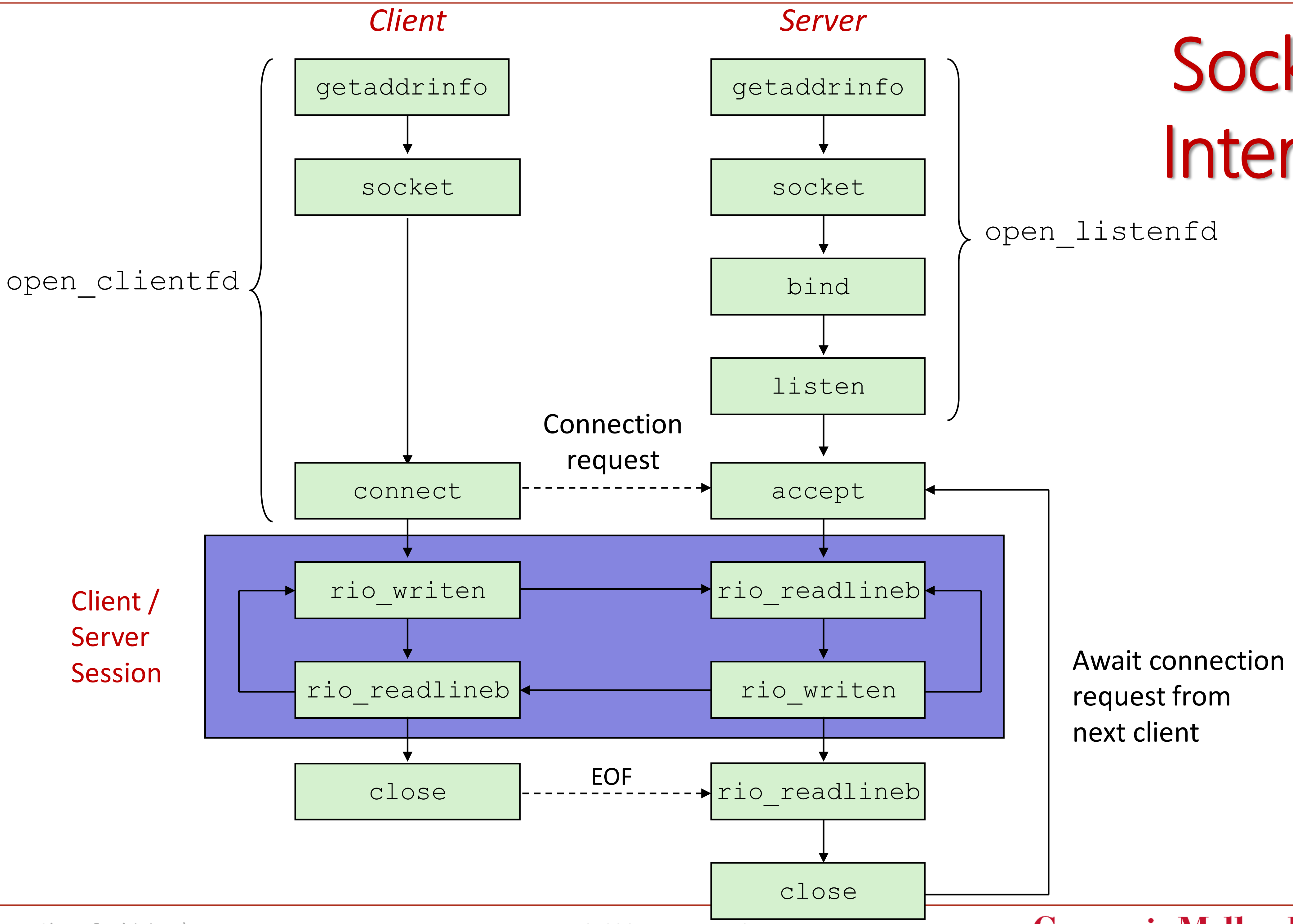
2. Client makes connection request by calling and blocking in `connect`

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

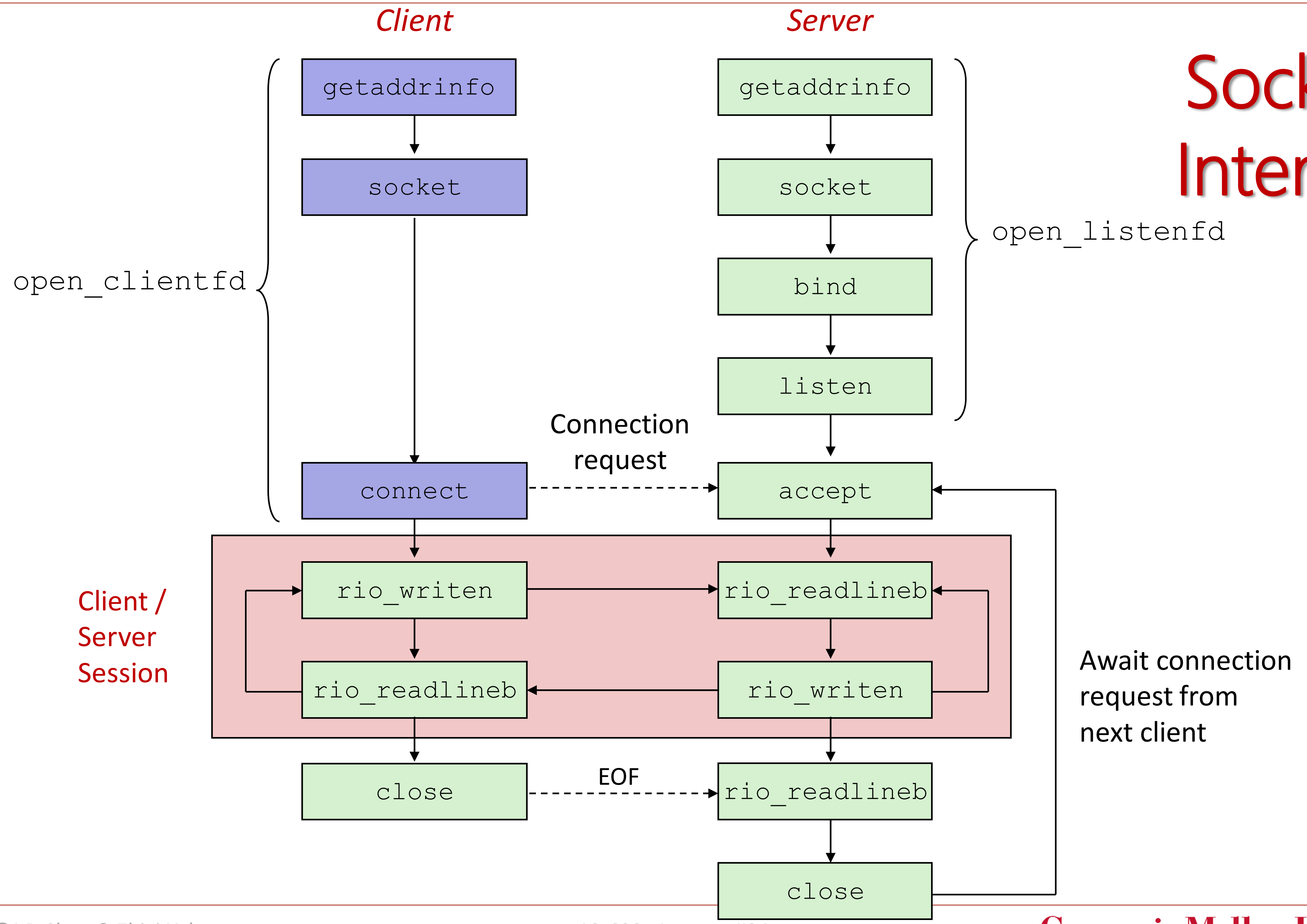
Connected vs. Listening Descriptors

- **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
    - E.g., Each time we receive a new request, we fork a child to handle the request

Sockets Interface



Sockets Interface



Sockets Helper: open_clientfd

- **Establish a connection with a server**

```
int open_clientfd(char *hostname, char *port) {
  int clientfd;
  struct addrinfo hints, *listp, *p;

  /* Get a list of potential server addresses */
  memset(&hints, 0, sizeof(struct addrinfo));
  hints.ai_socktype = SOCK_STREAM;  /* Open a connection */
  hints.ai_flags = AI_NUMERICSERV;  /* …using numeric port arg. */
  hints.ai_flags |= AI_ADDRCONFIG;  /* Recommended for connections */
  Getaddrinfo(hostname, port, &hints, &listp);
```

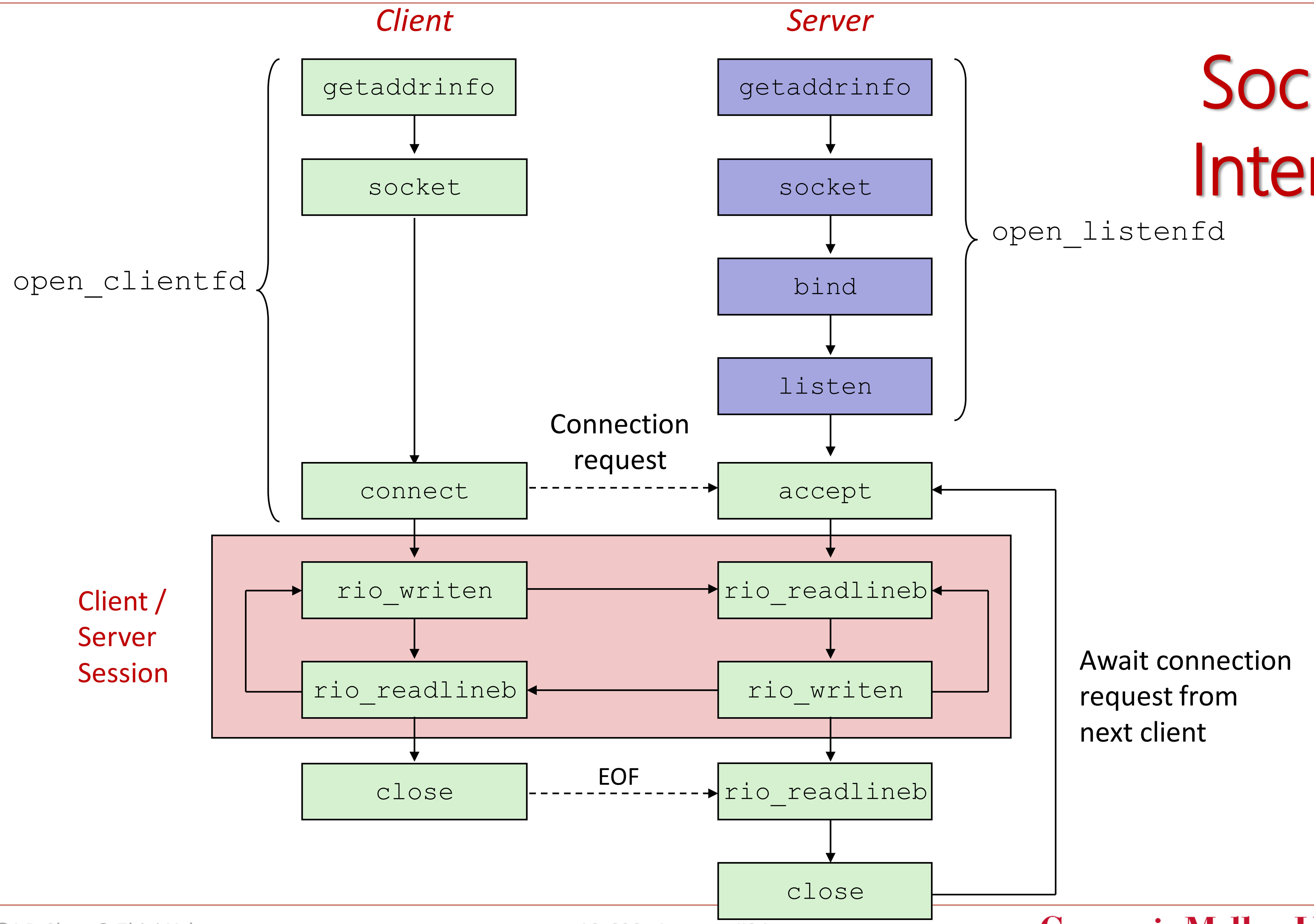
csapp.c

Sockets Helper: **open_clientfd** (cont)

```
    /* Walk the list for one that we can successfully connect to */
    for (p = listp; p; p = p->ai_next) {
        /* Create a socket descriptor */
        if ((clientfd = socket(p->ai_family, p->ai_socktype,
                               p->ai_protocol)) < 0)
            continue; /* Socket failed, try the next */

        /* Connect to the server */
        if (connect(clientfd, p->ai_addr, p->ai_addrlen) != -1)
            break; /* Success */
        Close(clientfd); /* Connect failed, try another */
    }

    /* Clean up */
    Freeaddrinfo(listp);
    if (!p) /* All connects failed */
        return -1;
    else    /* The last connect succeeded */
        return clientfd;
}
```

csapp.c

Sockets Interface



Sockets Helper: open_listenfd

- **Create a listening descriptor that can be used to accept connection requests from clients.**

```
int open_listenfd(char *port)
{
    struct addrinfo hints, *listp, *p;
    int listenfd, optval=1;

    /* Get a list of potential server addresses */
    memset(&hints, 0, sizeof(struct addrinfo));
    hints.ai_socktype = SOCK_STREAM;             /* Accept connect. */
    hints.ai_flags = AI_PASSIVE | AI_ADDRCONFIG; /* …on any IP addr */
    hints.ai_flags |= AI_NUMERICSERV;            /* …using port no. */
    Getaddrinfo(NULL, port, &hints, &listp);
```

csapp.c

Sockets Helper: **open_listenfd** (cont)

```
    /* Walk the list for one that we can bind to */
    for (p = listp; p; p = p->ai_next) {
        /* Create a socket descriptor */
        if ((listenfd = socket(p->ai_family, p->ai_socktype,
                               p->ai_protocol)) < 0)
            continue;  /* Socket failed, try the next */

        /* Eliminates "Address already in use" error from bind */
        Setsockopt(listenfd, SOL_SOCKET, SO_REUSEADDR,
                   (const void *)&optval , sizeof(int));

        /* Bind the descriptor to the address */
        if (bind(listenfd, p->ai_addr, p->ai_addrlen) == 0)
            break; /* Success */
        Close(listenfd); /* Bind failed, try the next */
    }
```

csapp.c

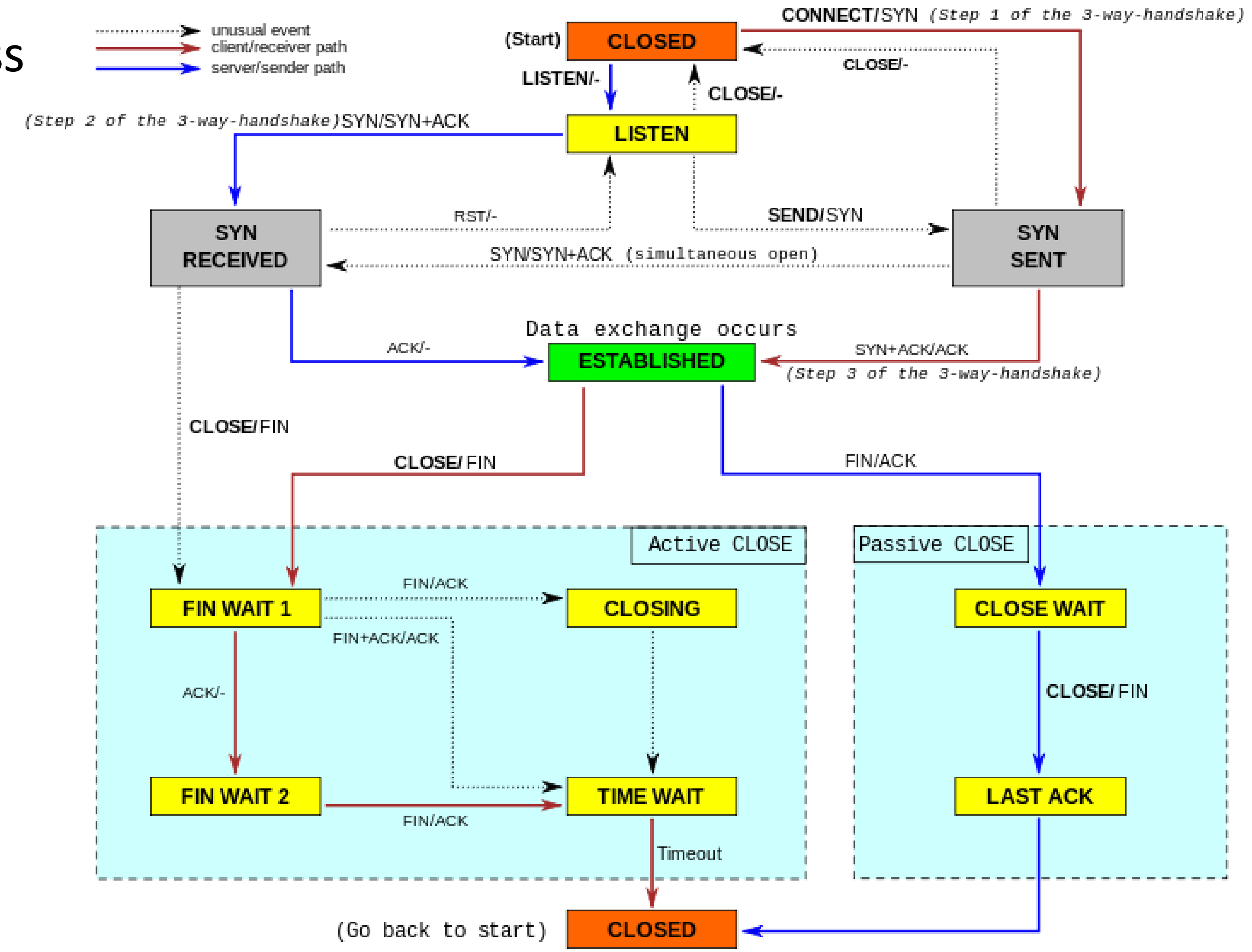
Sockets Helper: `open_listenfd` (cont)

```
    /* Clean up */
    Freeaddrinfo(listp);
    if (!p) /* No address worked */
        return -1;

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

- **Key point:** **`open_clientfd` and `open_listenfd` are both independent of any particular version of IP.**

TCP Connection State Diagram

- `SO_REUSEADDR` – used to get rid of "address already in use" error
- Avoids the "TIME_WAIT" state in the diagram
- Cannot create the socket with the same tuple {IP,Port,Protocol} as an existing socket



Echo Client: Main Routine

```
#include "csapp.h"

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

    host = argv[1];
    port = 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);
}
```

echoclient.c

Iterative Echo Server: Main Routine

```
#include "csapp.h"
void echo(int connfd);

int main(int argc, char **argv)
{
    int listenfd, connfd;
    socklen_t clientlen;
    struct sockaddr_storage clientaddr; /* Enough room for any addr */
    char client_hostname[MAXLINE], client_port[MAXLINE];

    listenfd = Open_listenfd(argv[1]);
    while (1) {
      clientlen = sizeof(struct sockaddr_storage); /* Important! */
      connfd = Accept(listenfd, (SA *)&clientaddr, &clientlen);
      Getnameinfo((SA *) &clientaddr, clientlen,
                  client_hostname, MAXLINE, client_port, MAXLINE, 0);
      printf("Connected to (%s, %s)\n", client_hostname, client_port);
      echo(connfd);
      Close(connfd);
    }
    exit(0);
}
```

echoserveri.c

Echo Server: `echo` function

- **The server uses RIO to read and echo text lines until EOF (end-of-file) condition is encountered.**
  - EOF condition caused by client calling **`close(clientfd)`**

```
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", (int)n);
       Rio_writen(connfd, buf, n);
    }
}
```

echo.c

Testing Servers Using `telnet`

- **The `telnet` program is invaluable for testing servers that transmit ASCII strings over Internet connections**
  - Our simple echo server
  - Web servers
  - Mail servers

- **Usage:**
  - ***`linux> telnet <host> <portnumber>`***
  - Creates a connection with a server running on ***`<host>`*** and listening on port ***`<portnumber>`***

Testing the Echo Server With **telnet**

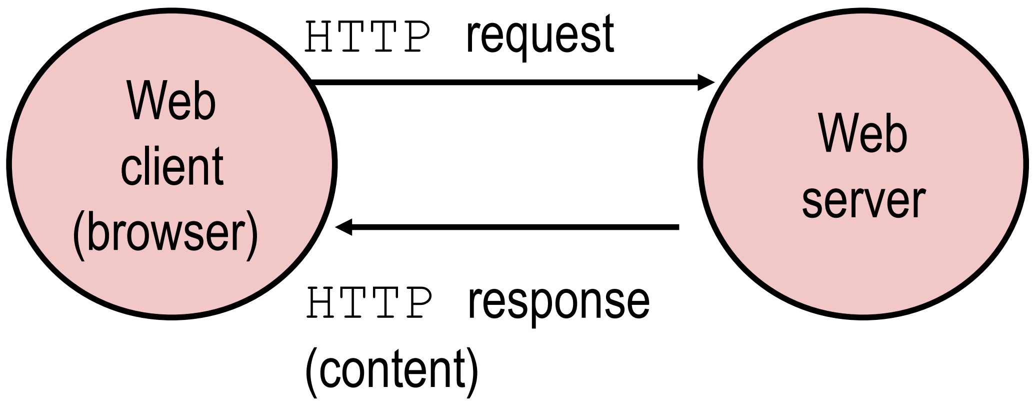
```
whaleshark> ./echoserveri 15213
Connected to (MAKOSHARK.ICS.CS.CMU.EDU, 50280)
server received 11 bytes
server received 8 bytes



makoshark> telnet whaleshark.ics.cs.cmu.edu 15213
Trying 128.2.210.175...
Connected to whaleshark.ics.cs.cmu.edu (128.2.210.175).
Escape character is '^]'.
Hi there!
Hi there!
Howdy!
Howdy!
^]
telnet> quit
Connection closed.
makoshark>
```

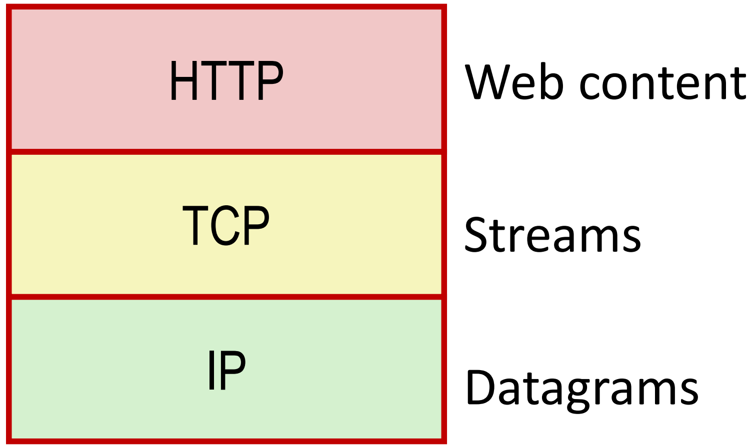
Web Server Basics

- **Clients and servers communicate using the HyperText Transfer Protocol (HTTP)**
  - Client and server establish TCP connection
  - Client requests content
  - Server responds with requested content
  - Client and server close connection (eventually)
- **Current version is HTTP/1.1**
  - ~~RFC 2616, June, 1999.~~
  - RFC 7230, June 2014

~~http://www.w3.org/Protocols/rfc2616/rfc2616.html~~

https://tools.ietf.org/html/rfc7230





Web Content

- **Web servers return *content* to clients**
  - *content:* a sequence of bytes with an associated MIME (Multipurpose Internet Mail Extensions) type

- **Example MIME types**

`text/html`	HTML document
`text/plain`	Unformatted text
`image/gif`	Binary image encoded in GIF format
`image/png`	Binar image encoded in PNG format
`image/jpeg`	Binary image encoded in JPEG format

You can find the complete list of MIME types at:
`http://www.iana.org/assignments/media-types/media-types.xhtml`

Static and Dynamic Content

- **The content returned in HTTP responses can be either *static* or *dynamic***
  - *Static content*: content stored in files and retrieved in response to an HTTP request
    - Examples: HTML files, images, audio clips
    - Request identifies which content file
  - *Dynamic content*: content produced on-the-fly in response to an HTTP request
    - Example: content produced by a program executed by the server on behalf of the client
    - Request identifies file containing executable code
- **Bottom line: *Web content is associated with a file that is managed by the server***

URLs and how clients and servers use them

- **Unique name for a file: URL (Universal Resource Locator)**
- **Example URL: `http://www.cmu.edu:80/index.html`**
- **Clients use *prefix* (`http://www.cmu.edu:80`) to infer:**
  - What kind (protocol) of server to contact (HTTP)
  - Where the server is (`www.cmu.edu`)
  - What port it is listening on (80)
- **Servers use *suffix* (`/index.html`) to:**
  - Determine if request is for static or dynamic content.
    - No hard and fast rules for this
    - One convention: executables reside in `cgi-bin` directory
  - Find file on file system
    - Initial "`/`" in suffix denotes home directory for requested content.
    - Minimal suffix is "`/`", which server expands to configured default filename (usually, `index.html`)

HTTP Requests

- **HTTP request is a *request line*, followed by zero or more *request headers***
- **Request line: `<method> <uri> <version>`**
  - `<method>` is one of `GET`, `POST`, `OPTIONS`, `HEAD`, `PUT`, `DELETE`, or `TRACE`
  - `<uri>` is typically URL for proxies, URL suffix for servers
    - A URL is a type of URI (Uniform Resource Identifier)
    - See ~~http://www.ietf.org/rfc/rfc2396.txt~~
    - See https://tools.ietf.org/html/rfc3986
  - `<version>` is HTTP version of request (`HTTP/1.0` or `HTTP/1.1`)
- **Request headers: `<header name>: <header data>`**
  - Provide additional information to the server

HTTP Responses

- **HTTP response is a *response line* followed by zero or more *response headers*, possibly followed by *content*, with blank line ("`\r\n`") separating headers from content.**

- **Response line:**

  `<version> <status code> <status msg>`

  - <version> is HTTP version of the response
  - <status code> is numeric status
  - <status msg> is corresponding English text
    - 200 OK — Request was handled without error
    - 301 Moved — Provide alternate URL
    - 404 Not found — Server couldn't find the file

- **Response headers: `<header name>: <header data>`**
  - Provide additional information about response
  - `Content-Type:` MIME type of content in response body
  - `Content-Length:` Length of content in response body

Example HTTP Transaction

```
whaleshark> telnet www.cmu.edu 80          Client: open connection to server
Trying 128.2.42.52...                      Telnet prints 3 lines to terminal
Connected to WWW-CMU-PROD-VIP.ANDREW.cmu.edu.
Escape character is '^]'.
GET / HTTP/1.1                             Client: request line
Host: www.cmu.edu                          Client: required HTTP/1.1 header
                                           Client: empty line terminates headers
HTTP/1.1 301 Moved Permanently             Server: response line
Date: Wed, 05 Nov 2014 17:05:11 GMT        Server: followed by 5 response headers
Server: Apache/1.3.42 (Unix)               Server: this is an Apache server
Location: http://www.cmu.edu/index.shtml Server: page has moved here
Transfer-Encoding: chunked                 Server: response body will be chunked
Content-Type: text/html; charset=...       Server: expect HTML in response body
                                           Server: empty line terminates headers
15c                                        Server: first line in response body
<HTML><HEAD>                               Server: start of HTML content
…
</BODY></HTML>                             Server: end of HTML content
0                                          Server: last line in response body
Connection closed by foreign host.         Server: closes connection
```

- **HTTP standard requires that each text line end with "`\r\n`"**
- **Blank line ("`\r\n`") terminates request and response headers**

Example HTTP Transaction, Take 2

```
whaleshark> telnet www.cmu.edu 80        Client: open connection to server
Trying 128.2.42.52...                    Telnet prints 3 lines to terminal
Connected to WWW-CMU-PROD-VIP.ANDREW.cmu.edu.
Escape character is '^]'.
GET /index.shtml HTTP/1.1                Client: request line
Host: www.cmu.edu                        Client: required HTTP/1.1 header
                                         Client: empty line terminates headers
HTTP/1.1 200 OK                          Server: response line
Date: Wed, 05 Nov 2014 17:37:26 GMT      Server: followed by 4 response headers
Server: Apache/1.3.42 (Unix)
Transfer-Encoding: chunked
Content-Type: text/html; charset=...
                                         Server: empty line terminates headers
1000                                     Server: begin response body
<html ..>                                Server: first line of HTML content
…
</html>
0                                        Server: end response body
Connection closed by foreign host.       Server: close connection
```

Tiny Web Server

- **Tiny Web server described in text**
  - Tiny is a sequential Web server
  - Serves static and dynamic content to real browsers
    - text files, HTML files, GIF, PNG, and JPEG images
  - 239 lines of commented C code
  - Not as complete or robust as a real Web server
    - You can break it with poorly-formed HTTP requests (e.g., terminate lines with "\n" instead of "\r\n")

Tiny Operation

- **Accept connection from client**
- **Read request from client (via connected socket)**
- **Split into <method> <uri> <version>**
  - If method not GET, then return error
- **If URI contains "`cgi-bin`" then serve dynamic content**
  - (Would do wrong thing if had file "`abcgi-bingo.html`")
  - Fork process to execute program
- **Otherwise serve static content**
  - Copy file to output

Tiny Serving Static Content

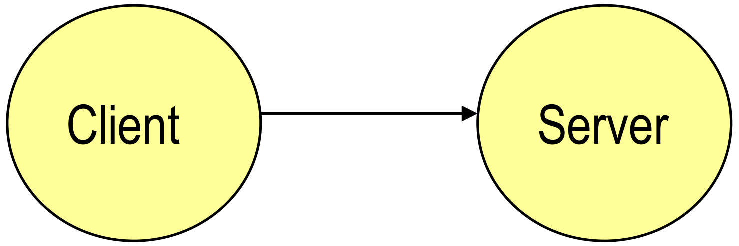
```
void serve_static(int fd, char *filename, int filesize)
{
    int srcfd;
    char *srcp, filetype[MAXLINE], buf[MAXBUF];

    /* Send response headers to client */
    get_filetype(filename, filetype);
    sprintf(buf, "HTTP/1.0 200 OK\r\n");
    sprintf(buf, "%sServer: Tiny Web Server\r\n", buf);
    sprintf(buf, "%sConnection: close\r\n", buf);
    sprintf(buf, "%sContent-length: %d\r\n", buf, filesize);
    sprintf(buf, "%sContent-type: %s\r\n\r\n", buf, filetype);
    Rio_writen(fd, buf, strlen(buf));

    /* Send response body to client */
    srcfd = Open(filename, O_RDONLY, 0);
    srcp = Mmap(0, filesize, PROT_READ, MAP_PRIVATE, srcfd, 0);
    Close(srcfd);
    Rio_writen(fd, srcp, filesize);
    Munmap(srcp, filesize);
}
```

tiny.c

Serving Dynamic Content

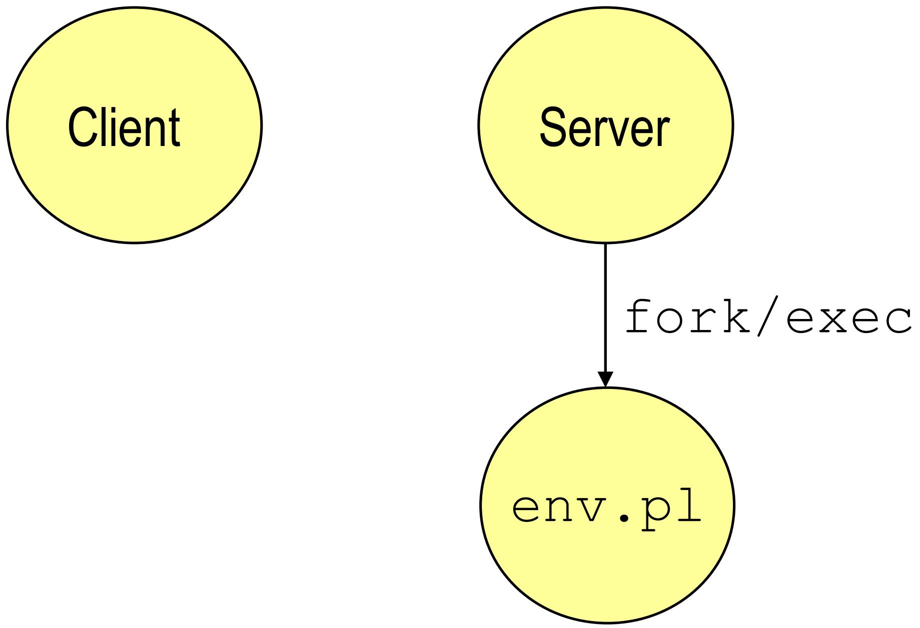
- **Client sends request to server**
- **If request URI contains the string "`/cgi-bin`", the Tiny server assumes that the request is for dynamic content**

```
GET /cgi-bin/env.pl HTTP/1.1
```



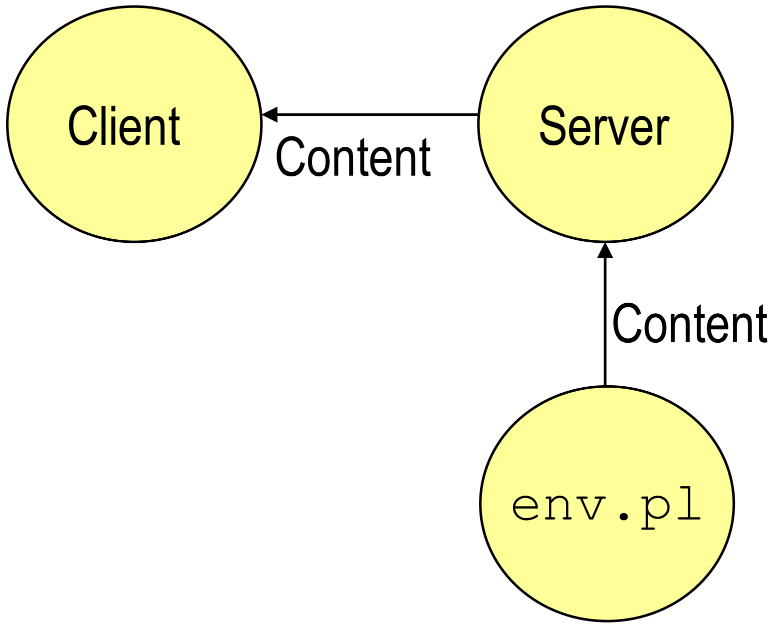
Serving Dynamic Content (cont)

- **The server creates a child process and runs the program identified by the URI in that process**



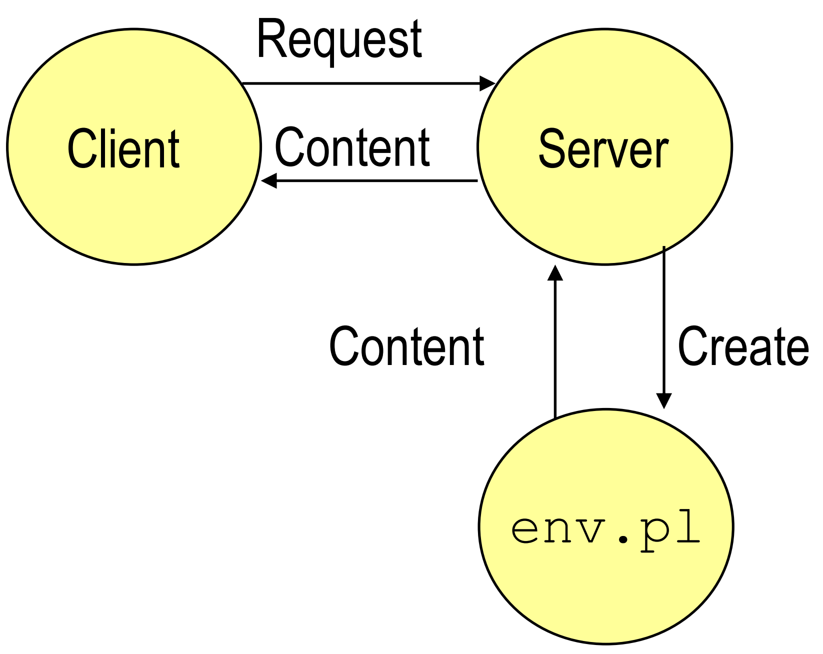
Serving Dynamic Content (cont)

- **The child runs and generates the dynamic content**
- **The server captures the content of the child and forwards it without modification to the client**



Issues in Serving Dynamic Content

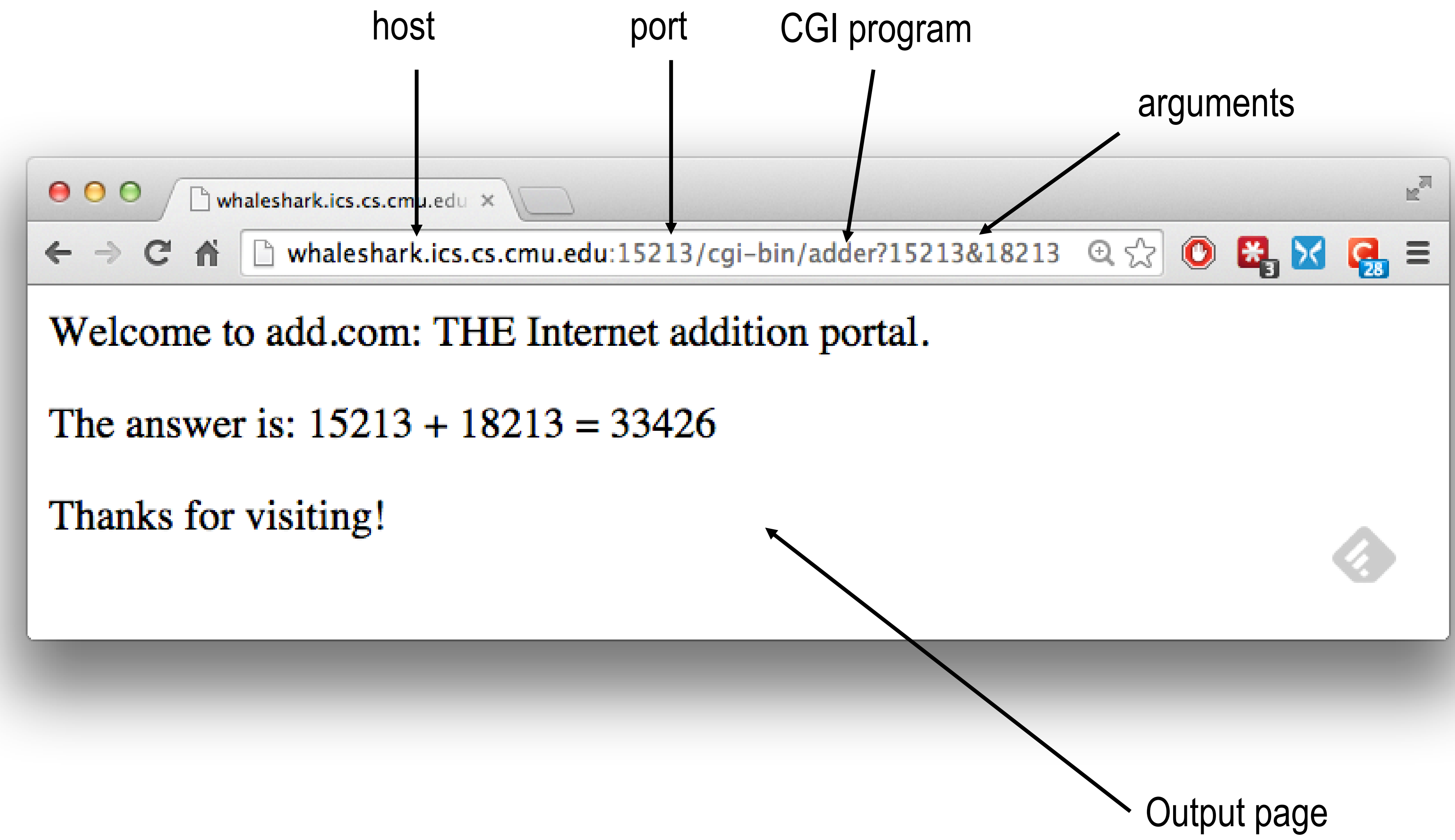
- How does the client pass program arguments to the server?
- How does the server pass these arguments to the child?
- How does the server pass other info relevant to the request to the child?
- How does the server capture the content produced by the child?
- These issues are addressed by the Common Gateway Interface (CGI) specification.



CGI

- **Because the children are written according to the CGI spec, they are often called *CGI programs.***
- **However, CGI really defines a simple standard for transferring information between the client (browser), the server, and the child process.**
- **CGI is the original standard for generating dynamic content. Has been largely replaced by other, faster techniques:**
  - E.g., fastCGI, Apache modules, Java servlets, Rails controllers
  - Avoid having to create process on the fly (expensive and slow).

The add.com Experience



Serving Dynamic Content With GET

- **Question:** How does the client pass arguments to the server?
- **Answer:** The arguments are appended to the URI

- **Can be encoded directly in a URL typed to a browser or a URL in an HTML link**
  - `http://add.com/cgi-bin/adder?15213&18213`
  - `adder` is the CGI program on the server that will do the addition.
  - argument list starts with "`?`"
  - arguments separated by "`&`"
  - spaces represented by "`+`" or "`%20`"

Serving Dynamic Content With GET

- **URL suffix:**
  - `cgi-bin/adder?15213&18213`

- **Result displayed on browser:**

```
Welcome to add.com: THE Internet addition portal.

The answer is: 15213 + 18213 = 33426

Thanks for visiting!
```

Serving Dynamic Content With GET

- **<u>Question</u>: How does the server pass these arguments to the child?**
- **<u>Answer:</u> In environment variable QUERY_STRING**
  - A single string containing everything after the "?"
  - For add: `QUERY_STRING` = "`15213&18213`"

```
/* Extract the two arguments */
if ((buf = getenv("QUERY_STRING")) != NULL) {
    p = strchr(buf, '&');
   *p = '\0';
    strcpy(arg1, buf);
    strcpy(arg2, p+1);
    n1 = atoi(arg1);
    n2 = atoi(arg2);
}
```

adder.c

Serving Dynamic Content with GET

- **Question:** How does the server capture the content produced by the child?
- **Answer:** The child generates its output on `stdout`. Server uses `dup2` to redirect `stdout` to its connected socket.

```
void serve_dynamic(int fd, char *filename, char *cgiargs)
{
    char buf[MAXLINE], *emptylist[] = { NULL };

    /* Return first part of HTTP response */
    sprintf(buf, "HTTP/1.0 200 OK\r\n");
    Rio_writen(fd, buf, strlen(buf));
    sprintf(buf, "Server: Tiny Web Server\r\n");
    Rio_writen(fd, buf, strlen(buf));

    if (Fork() == 0) { /* Child */
        /* Real server would set all CGI vars here */
        setenv("QUERY_STRING", cgiargs, 1);
        Dup2(fd, STDOUT_FILENO);         /* Redirect stdout to client */
        Execve(filename, emptylist, environ); /* Run CGI program */
    }
    Wait(NULL); /* Parent waits for and reaps child */
}
```

tiny.c

Serving Dynamic Content with GET

- **Notice that only the CGI child process knows the content type and length, so it must generate those headers.**

```
/* Make the response body */
sprintf(content, "Welcome to add.com: ");
sprintf(content, "%sTHE Internet addition portal.\r\n<p>", content);
sprintf(content, "%sThe answer is: %d + %d = %d\r\n<p>",
        content, n1, n2, n1 + n2);
sprintf(content, "%sThanks for visiting!\r\n", content);

/* Generate the HTTP response */
printf("Content-length: %d\r\n", (int)strlen(content));
printf("Content-type: text/html\r\n\r\n");
printf("%s", content);
fflush(stdout);

exit(0);
```

adder.c

Serving Dynamic Content With GET

```
bash:makoshark> telnet whaleshark.ics.cs.cmu.edu 15213
Trying 128.2.210.175...
Connected to whaleshark.ics.cs.cmu.edu (128.2.210.175).
Escape character is '^]'.
GET /cgi-bin/adder?15213&18213 HTTP/1.0

HTTP/1.0 200 OK
Server: Tiny Web Server
Connection: close
Content-length: 117
Content-type: text/html

Welcome to add.com: THE Internet addition portal.
<p>The answer is: 15213 + 18213 = 33426
<p>Thanks for visiting!
Connection closed by foreign host.
bash:makoshark>
```

HTTP request sent by client

HTTP response generated by the server

HTTP response generated by the CGI program

For More Information

- **W. Richard Stevens et. al. "Unix Network Programming: The Sockets Networking API", Volume 1, Third Edition, Prentice Hall, 2003**
  - THE network programming bible.
- **Michael Kerrisk, "The Linux Programming Interface", No Starch Press, 2010**
  - THE Linux programming bible.
- **Complete versions of all code in this lecture is available from the 213 schedule page.**
  - `http://www.cs.cmu.edu/~213/schedule.html`
  - csapp.{.c,h}, hostinfo.c, echoclient.c, echoserveri.c, tiny.c, adder.c
  - You can use any of this code in your assignments.

Additional slides

Web History

- **1989:**
  - Tim Berners-Lee (CERN) writes internal proposal to develop a distributed hypertext system
    - Connects "a web of notes with links"
    - Intended to help CERN physicists in large projects share and manage information
- **1990:**
  - Tim BL writes a graphical browser for Next machines

Web History (cont)

- **1992**
  - NCSA server released
  - 26 WWW servers worldwide
- **1993**
  - Marc Andreessen releases first version of NCSA Mosaic browser
  - Mosaic version released for (Windows, Mac, Unix)
  - Web (port 80) traffic at 1% of NSFNET backbone traffic
  - Over 200 WWW servers worldwide
- **1994**
  - Andreessen and colleagues leave NCSA to form "Mosaic Communications Corp" (predecessor to Netscape)

HTTP Versions

- **Major differences between HTTP/1.1 and HTTP/1.0**
  - HTTP/1.0 uses a new connection for each transaction
  - HTTP/1.1 also supports *persistent connections*
    - multiple transactions over the same connection
    - `Connection: Keep-Alive`
  - HTTP/1.1 requires `HOST` header
    - `Host: www.cmu.edu`
    - Makes it possible to host multiple websites at single Internet host
  - HTTP/1.1 supports *chunked encoding*
    - `Transfer-Encoding: chunked`
  - HTTP/1.1 adds additional support for caching

GET Request to Apache Server From Firefox Browser

URI is just the suffix, not the entire URL

```
GET /~bryant/test.html HTTP/1.1
Host: www.cs.cmu.edu
User-Agent: Mozilla/5.0 (Windows; U; Windows NT 6.0; en-US;
rv:1.9.2.11) Gecko/20101012 Firefox/3.6.11
Accept:
text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
Accept-Language: en-us,en;q=0.5
Accept-Encoding: gzip,deflate
Accept-Charset: ISO-8859-1,utf-8;q=0.7,*;q=0.7
Keep-Alive: 115
Connection: keep-alive
CRLF (\r\n)
```

GET Response From Apache Server

```
HTTP/1.1 200 OK
Date: Fri, 29 Oct 2010 19:48:32 GMT
Server: Apache/2.2.14 (Unix) mod_ssl/2.2.14 OpenSSL/0.9.7m
mod_pubcookie/3.3.2b PHP/5.3.1
Accept-Ranges: bytes
Content-Length: 479
Keep-Alive: timeout=15, max=100
Connection: Keep-Alive
Content-Type: text/html
<html>
<head><title>Some Tests</title></head>

<body>
<h1>Some Tests</h1>
 . . .
</body>
</html>
```

What a modern web page load looks like

- **Loading a major ad supported web site includes 10's – 100's of individual loads of various resources**
- **Much of the loading doesn't come from the site in the URL of the web browser**
- **Content Distribution Networks (CDN) play a major role**

- **Not to be left out: Advertising Networks and Tracking Networks**

Pktstat results (partial) from loading www.bbc.co.uk

```
interface: em0
bps

   bps      % desc
             tcp 10.64.22.15:8080 <-> 172.16.58.133:20461
             tcp 10.64.22.15:8080 <-> 172.16.58.133:20462
             tcp 104.16.27.216:http <-> 172.16.58.133:20499
             └ 200 POST /gsorganizationvalsha2g2
             tcp 104.16.27.216:http <-> 172.16.58.133:20500
             tcp 104.16.27.216:http <-> 172.16.58.133:20501
             └ 200 POST /gsorganizationvalsha2g2
             tcp 138.108.7.20:http <-> 172.16.58.133:20515
             - 200 GET /cgi-bin/m?ci=us-804789h&amp
 182.4    0% tcp 151.101.32.175:http <-> 172.16.58.133:20532
             └ GET /userdata/get?pub=5d7aaa39-eeed-454f-bb7d-ecea38d770fc&techno
             tcp 151.101.32.175:http <-> 172.16.58.133:20533
             tcp 151.101.32.175:http <-> 172.16.58.133:20540
             tcp 151.101.32.175:http <-> 172.16.58.133:20541
             tcp 151.101.32.175:http <-> 172.16.58.133:20542
             tcp 151.101.32.249:http <-> 172.16.58.133:20612
 182.4    0% tcp 151.101.32.81:http <-> 172.16.58.133:20514
             └ GET /favicon.ico
             tcp 151.101.32.81:https <-> 172.16.58.133:20505
             tcp 151.101.32.81:https <-> 172.16.58.133:20506
             tcp 151.101.32.81:https <-> 172.16.58.133:20525
             tcp 151.101.32.81:https <-> 172.16.58.133:20526
 182.4    0% tcp 172.16.58.133:20463 <-> rtr2:https
             tcp 172.16.58.133:20464 <-> ec2-52-25-169-254:https
 182.4    0% tcp 172.16.58.133:20465 <-> 72.21.91.29:http
             tcp 172.16.58.133:20467 <-> ec2-52-25-169-254:https
             tcp 172.16.58.133:20471 <-> a96-17-88-36:http
             └ GET /notification-ui/2.6.4-mvt/js/NotificationsMain.js
             tcp 172.16.58.133:20472 <-> a104-70-70-171:http
             └ GET /id/0.36.23/modules/idcta/fallbackTranslations.js
             tcp 172.16.58.133:20473 <-> a23-10-188-71:http
             └ GET /orbit/1.0.0-332.19a2158/img/blq-orbit-blocks_grey.svg
             tcp 172.16.58.133:20474 <-> a23-10-188-71:http
             └ GET /searchbox/1.0.0-123/img/gel-icon-search-dark.svg
             tcp 172.16.58.133:20475 <-> a23-10-188-71:http
             └ 200 GET /searchbox/1.0.0-123/css/main.css
             tcp 172.16.58.133:20476 <-> a104-70-70-171:http
             └ GET /id/0.36.23/modules/idcta/statusbar.js
```

Data Transfer Mechanisms

- **Standard**
  - Specify total length with content-length
  - Requires that program buffer entire message
- **Chunked**
  - Break into blocks
  - Prefix each block with number of bytes (Hex coded)

Chunked Encoding Example

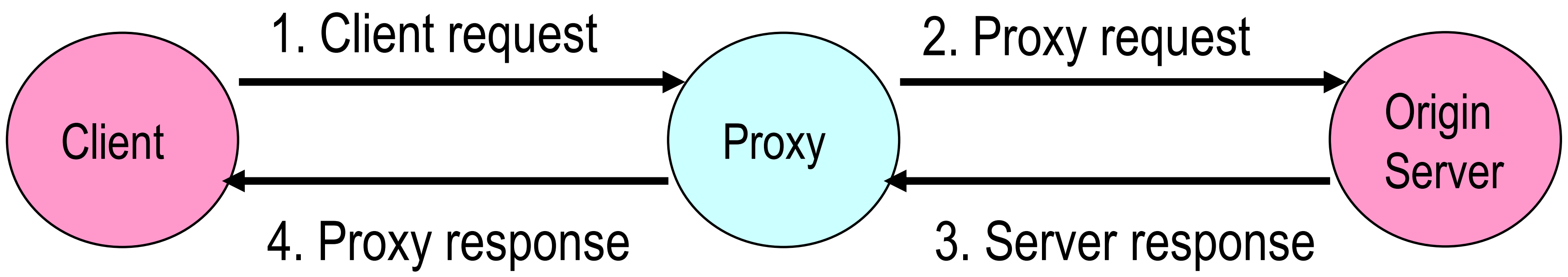
```
HTTP/1.1 200 OK\n
Date: Sun, 31 Oct 2010 20:47:48 GMT\n
Server: Apache/1.3.41 (Unix)\n
Keep-Alive: timeout=15, max=100\n
Connection: Keep-Alive\n
Transfer-Encoding: chunked\n
Content-Type: text/html\n
\r\n
d75\r\n
<html>
<head>
.<link href="http://www.cs.cmu.edu/style/calendar.css" rel="stylesheet"
type="text/css">
</head>
<body id="calendar_body">

<div id='calendar'><table width='100%'  border='0' cellpadding='0'
cellspacing='1' id='cal'>


 . . .
</body>
</html>
\r\n
0\r\n
\r\n
```

First Chunk: 0xd75 = 3445 bytes

Second Chunk: 0 bytes (indicates last chunk)

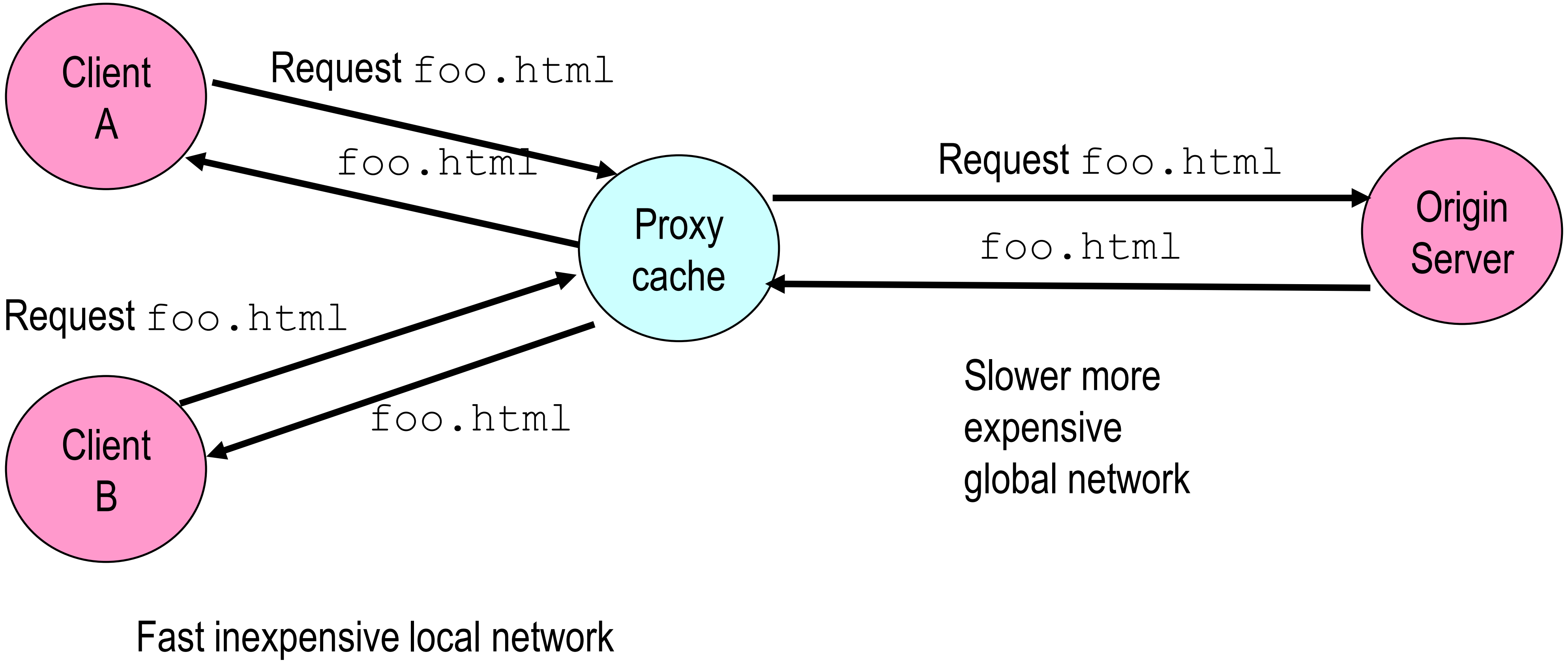
Proxies

- **A *proxy* is an intermediary between a client and an *origin server***
  - To the client, the proxy acts like a server
  - To the server, the proxy acts like a client



Why Proxies?

- **Can perform useful functions as requests and responses pass by**
  - Examples: Caching, logging, anonymization, filtering, transcoding



Just for fun

- Same browser as visited www.bbc.co.uk
- *For the record: default Firefox configuration in a test virtual machine*
- Results from:
  - https://panopticlick.eff.org/

Browser Characteristic	bits of identifying information	one in x browsers have this value	value
Limited supercookie test	0.42	1.34	DOM localStorage: Yes, DOM sessionStorage: Yes, IE userData: No
Hash of canvas fingerprint	12.1	4389.09	a024ba620bdd303e7b634c4ccf00517f
Screen Size and Color Depth	17.53	188731.0	1467x955x24
Browser Plugin Details	1.74	3.35	undefined
Time Zone	3.56	11.76	300
DNT Header Enabled?	1.23	2.34	False
HTTP_ACCEPT Headers	2.49	5.64	text/html, */*; q=0.01 gzip, deflate, br en-US,en;q=0.5
Hash of WebGL fingerprint	15.53	47182.75	41d2c47e27c33b1dc19037147510e844
Language	1.05	2.07	en-US
System Fonts	12.4	5392.31	Bitstream Vera Sans Mono, Courier, Wingdings 2, Wingdings 3 (via javascript)
Platform	8.64	399.85	FreeBSD amd64
User Agent	13.72	13480.79	Mozilla/5.0 (X11; FreeBSD amd64; rv:50.0) Gecko/20100101 Firefox/50.0
Touch Support	0.5	1.41	Max touchpoints: 0; TouchEvent supported: false; onTouchStart supported: false
Are Cookies Enabled?	0.21	1.15	Yes

18-600 Foundations of Computer Systems

Lecture 25:
"Concurrent Programming"

John P. Shen & Zhiyi Yu
November 30, 2016

Next Time …

➢ Required Reading Assignment:
- **Chapter 12 of CS:APP (3rd edition) by Randy Bryant & Dave O'Hallaron.**

Electrical & Computer ENGINEERING