

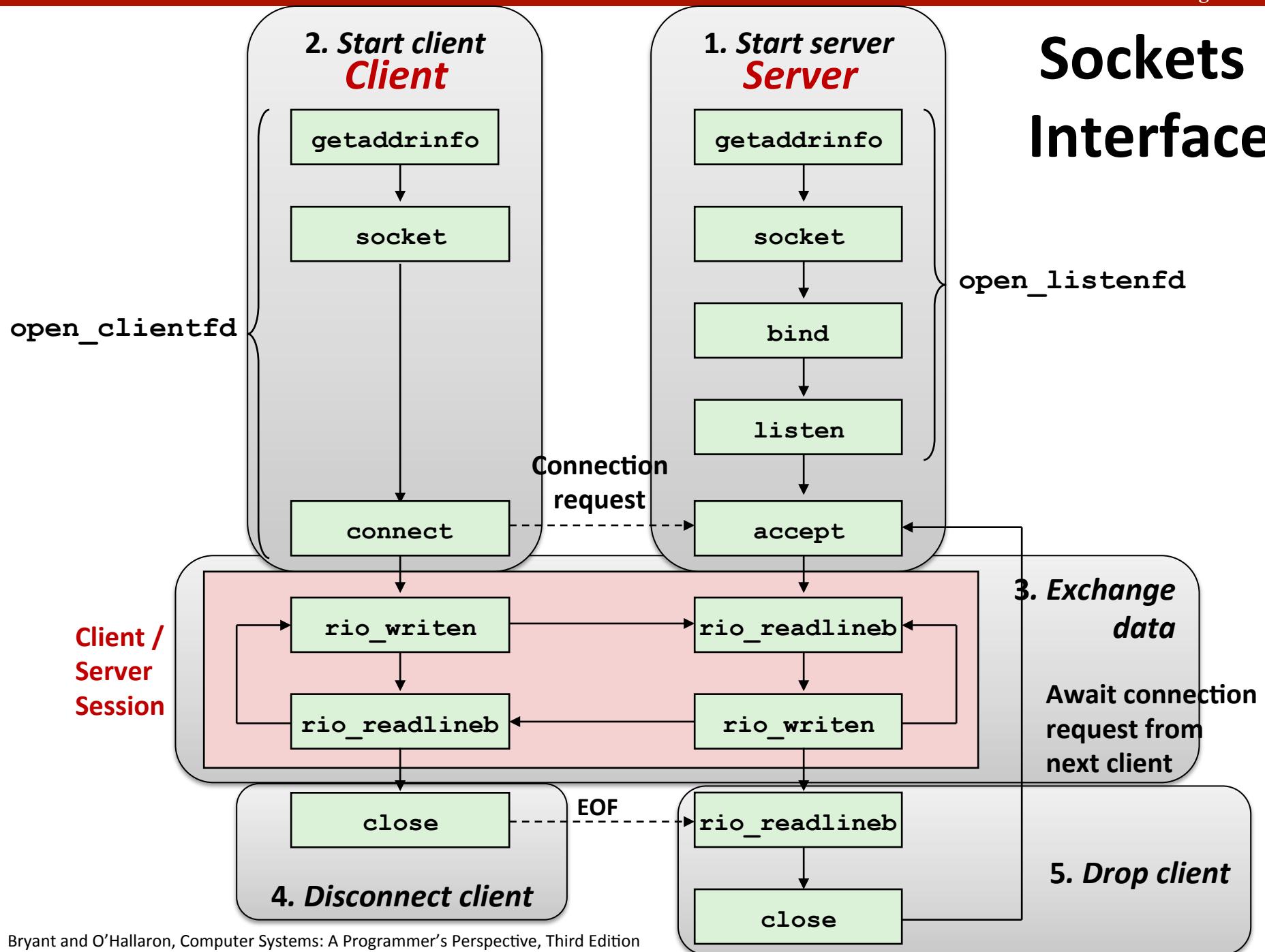
Network Programming: Part II

15-213: Introduction to Computer Systems
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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. */  
};
```

`sa_family`



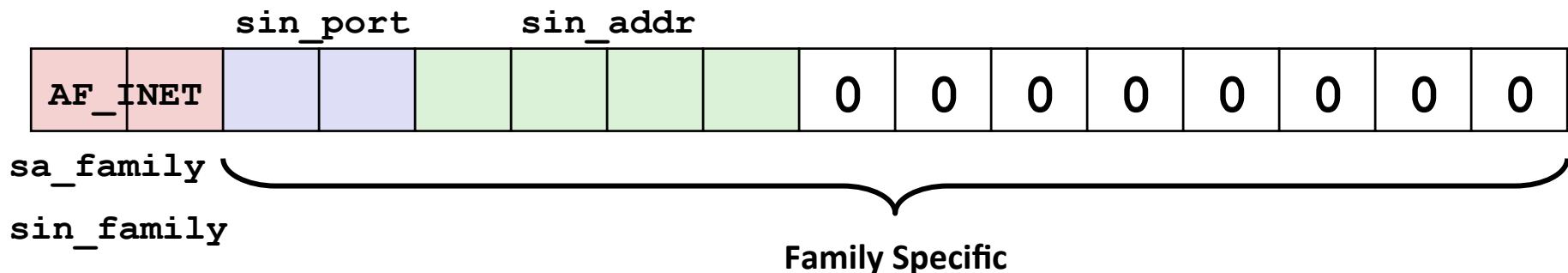
Family Specific

Recall: Socket Address Structures

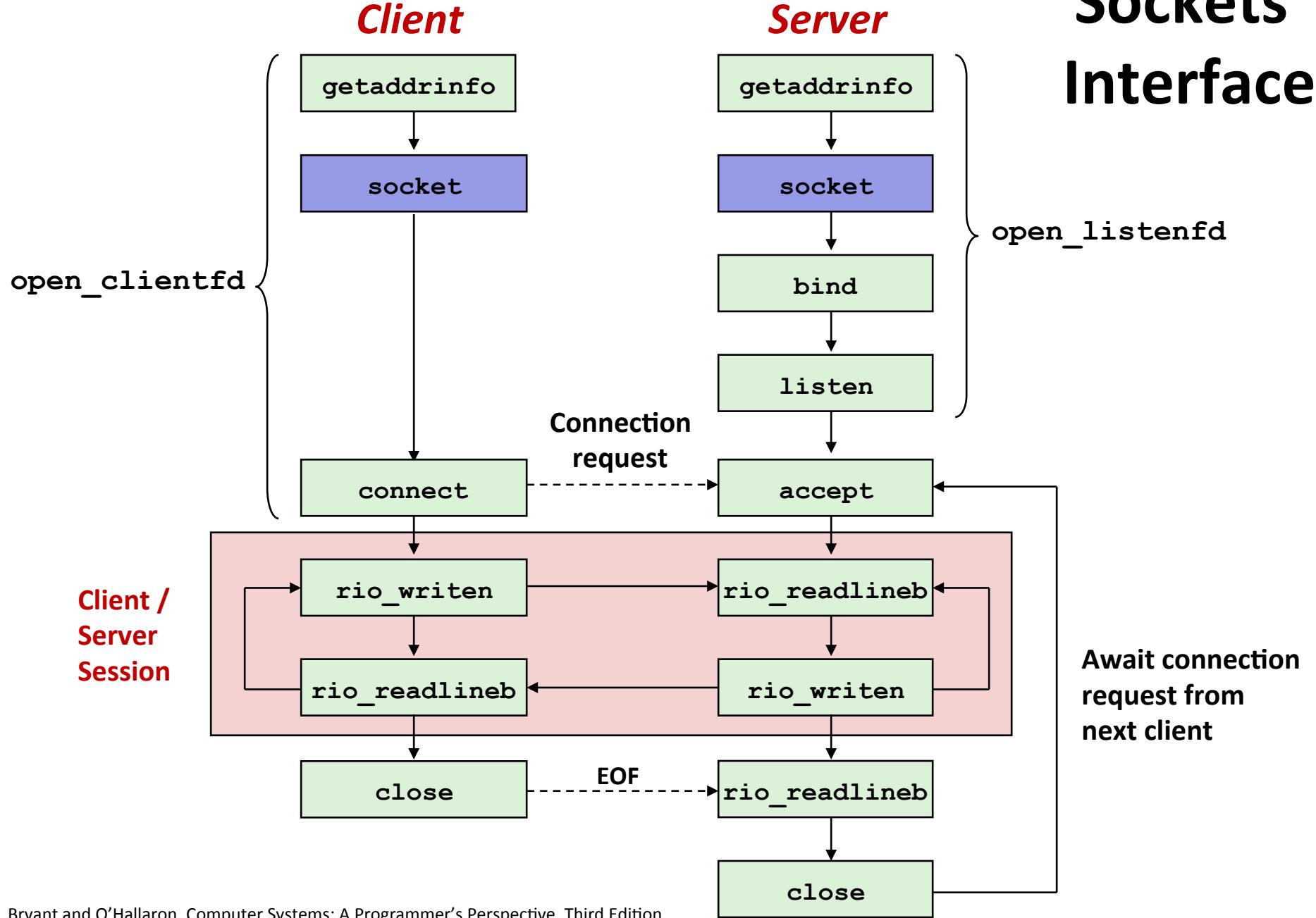
■ Internet-specific socket address:

- 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:

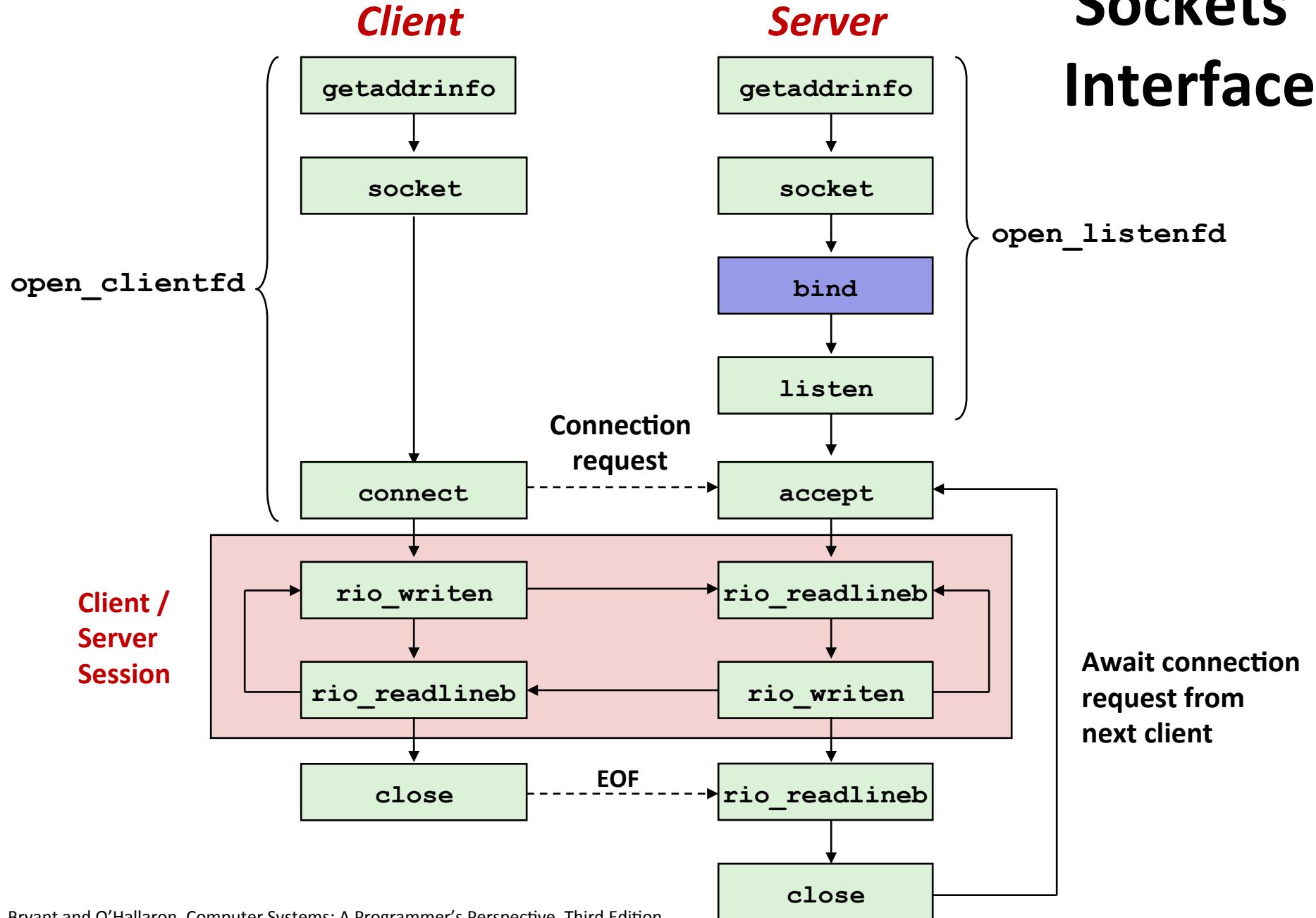
```
int clientfd = Socket(AF_INET, SOCK_STREAM, 0);
```

Indicates that we are using
32-bit IPV4 addresses

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

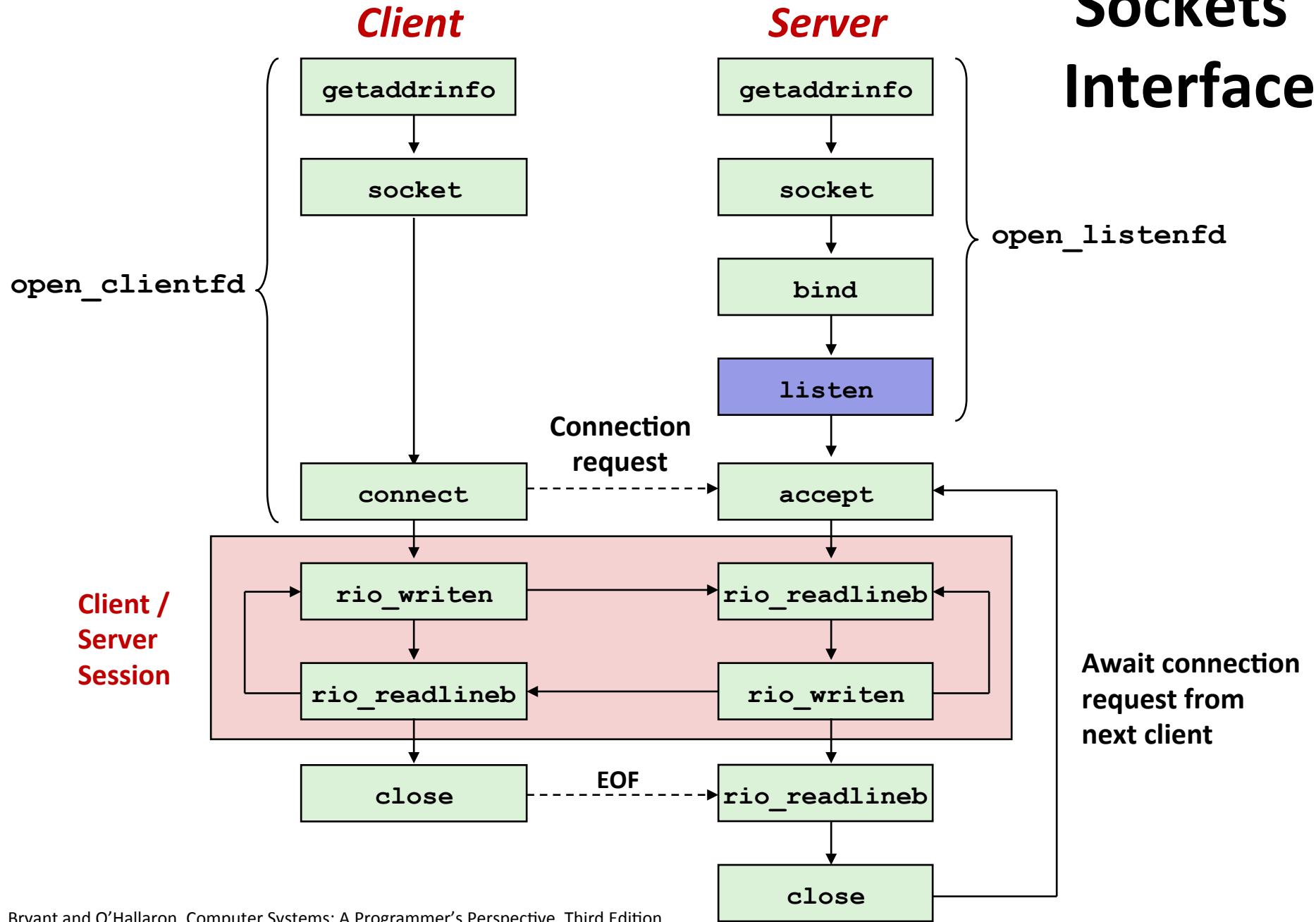
- A server uses `bind` to ask the kernel to associate the server's socket address with a socket descriptor:

```
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



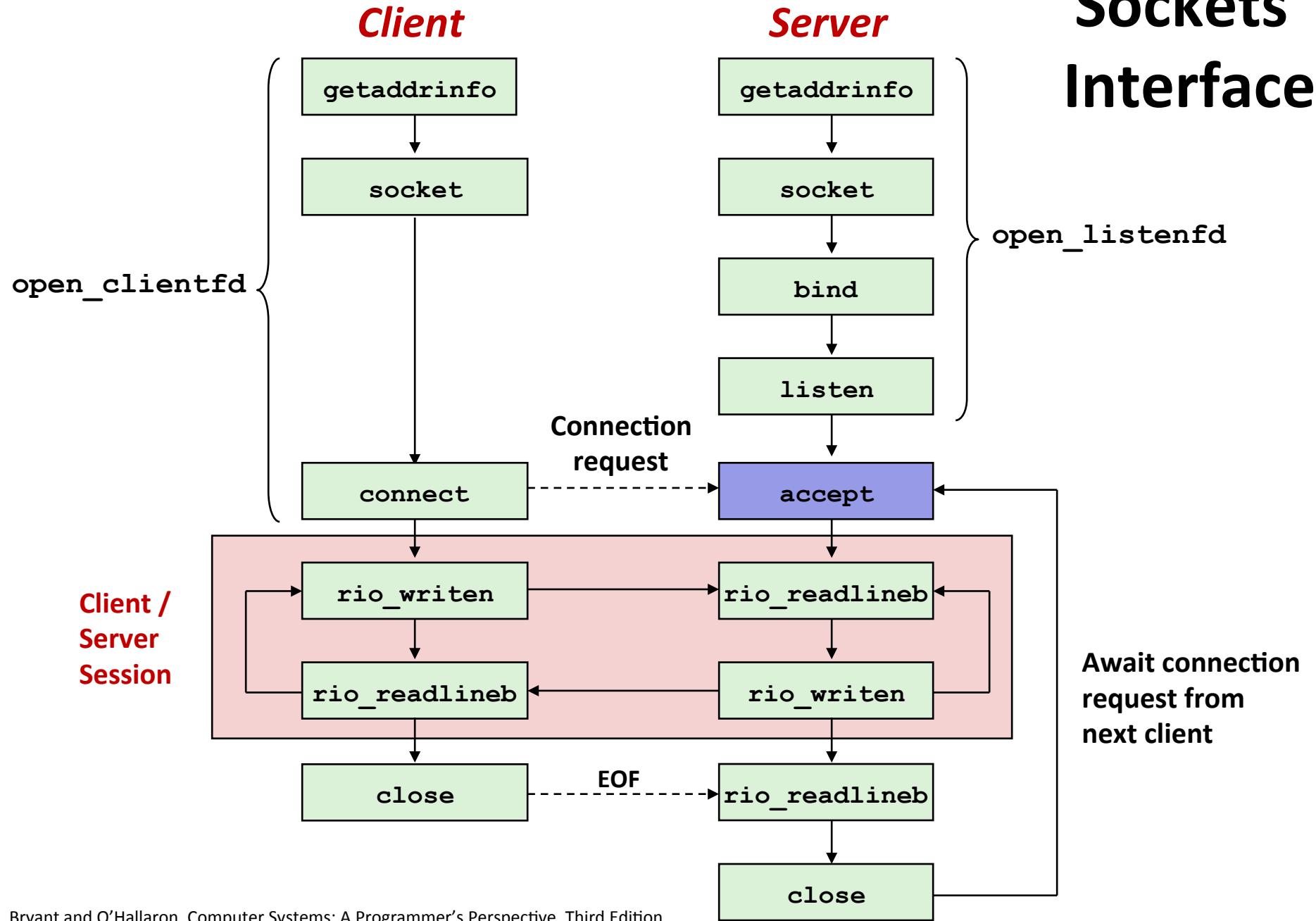
Sockets Interface: `listen`

- 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



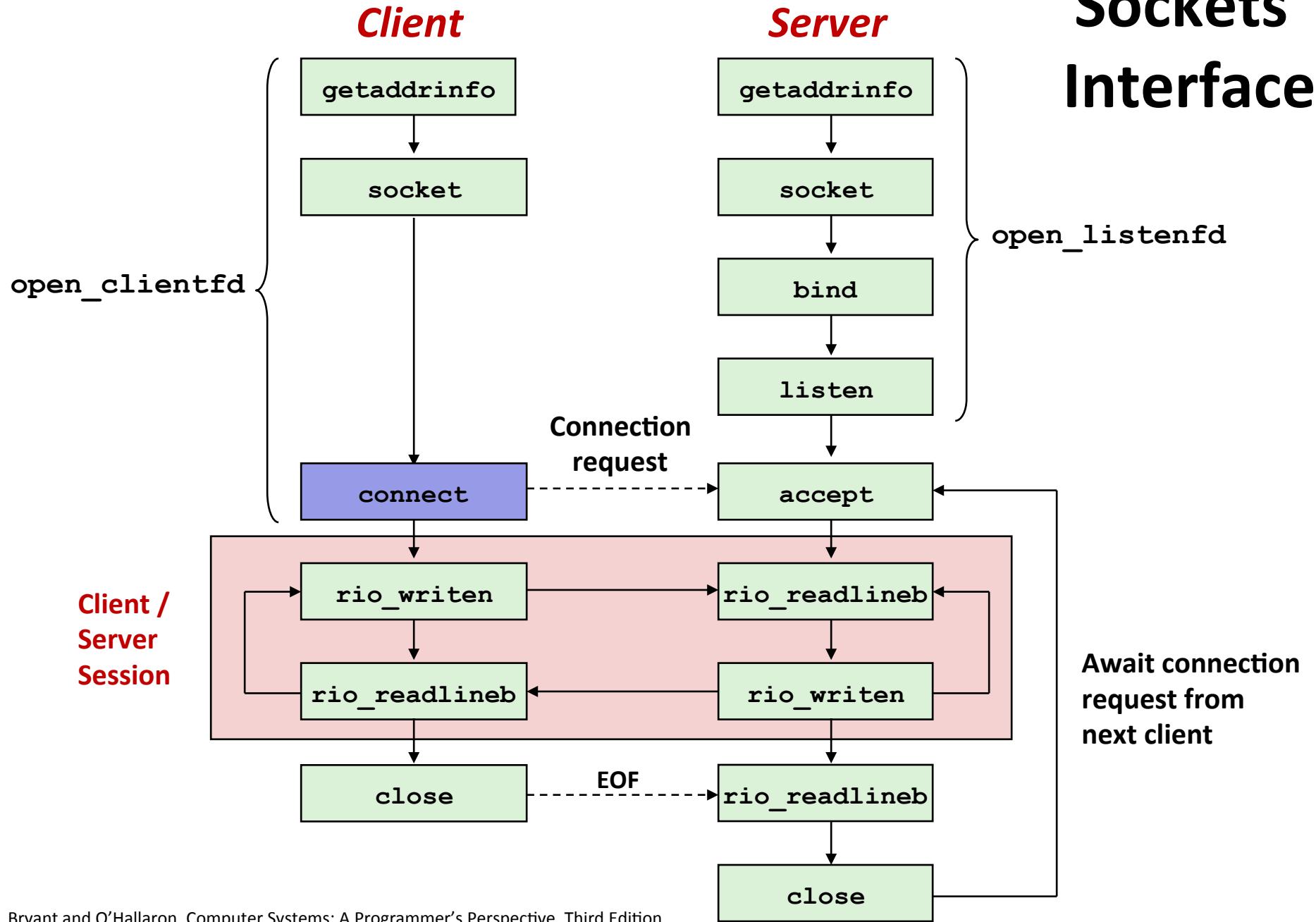
Sockets Interface: accept

- 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.

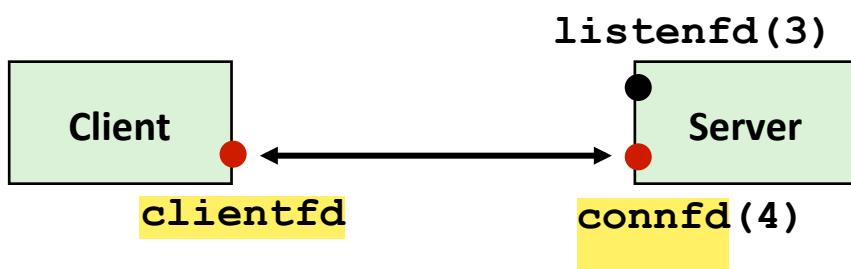
accept Illustrated



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

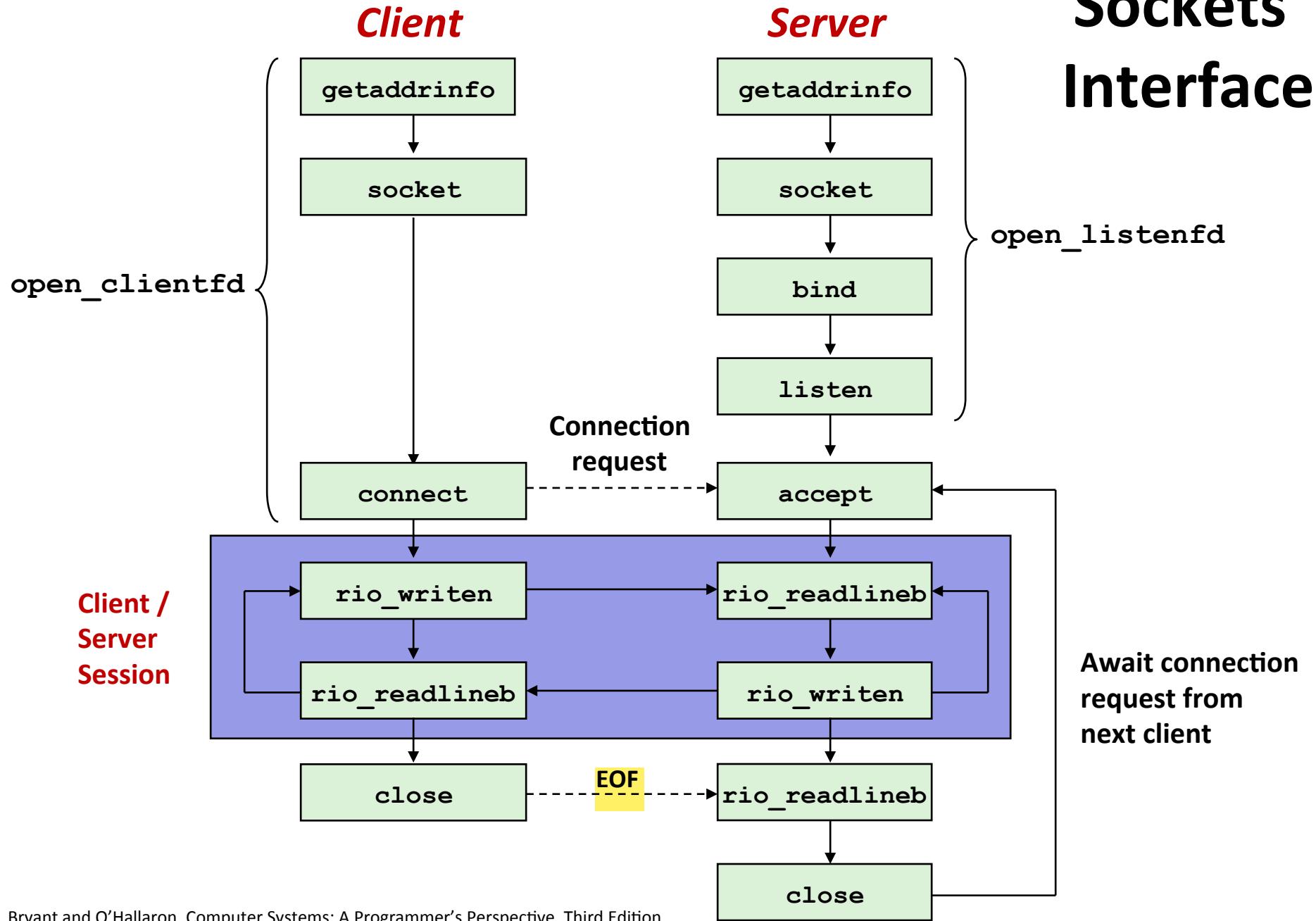
■ Connected descriptor

- 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

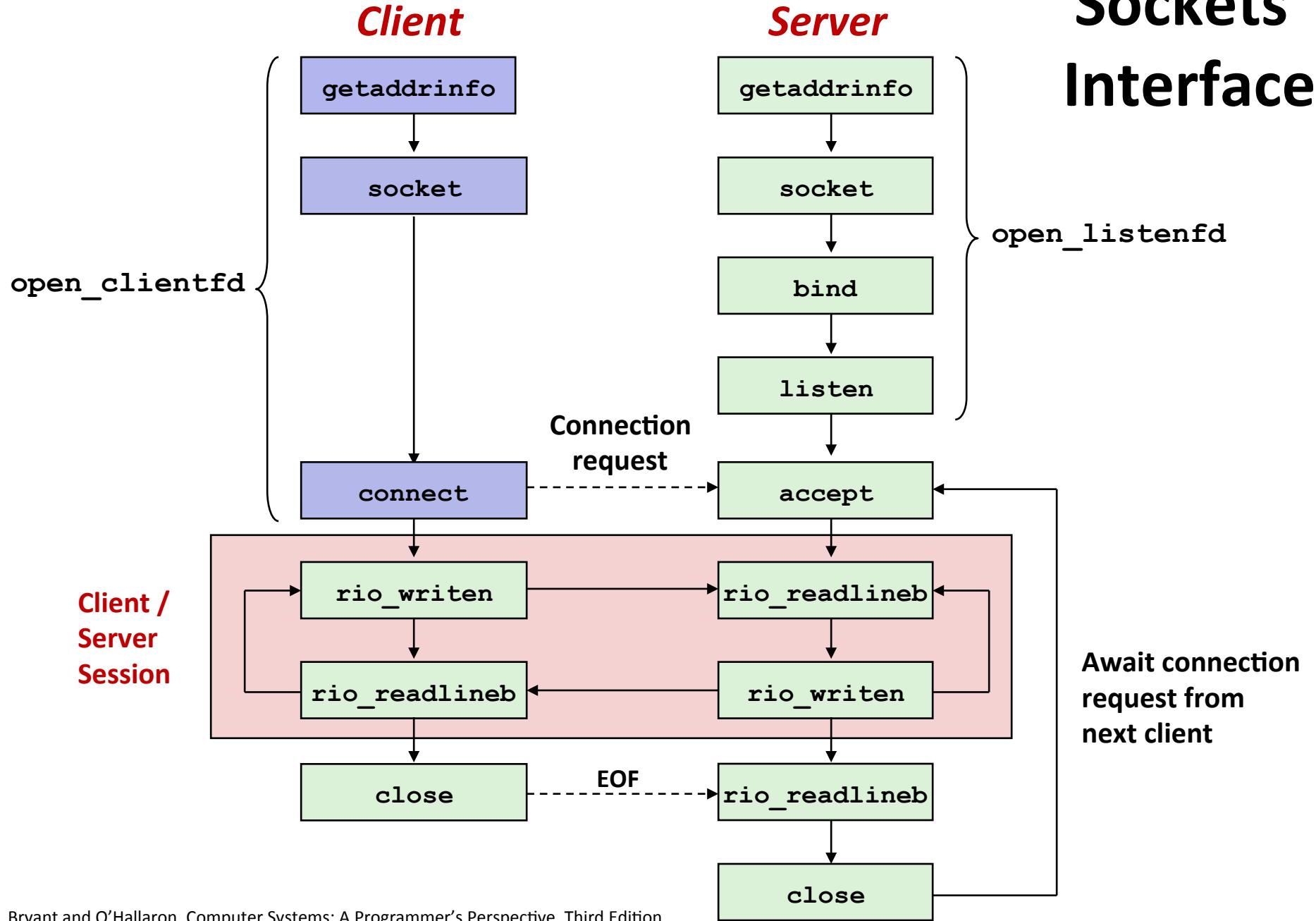
■ Why the distinction?

- 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)

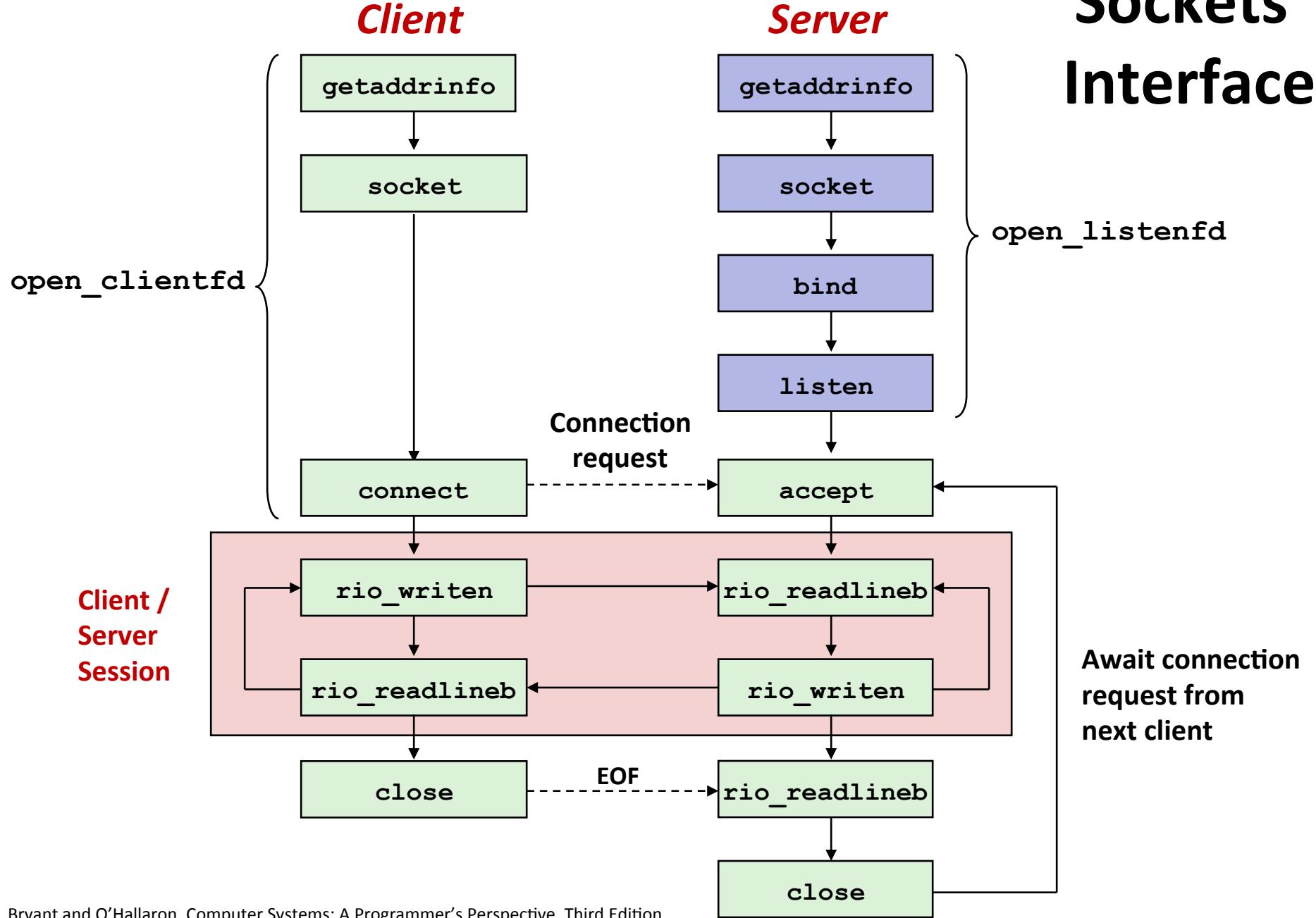
```
/* Walk the list for one that we can successfully connect to */
for (p = listp; p; p = p->ai_next) {
    /* Create a socket descriptor */
    if ((clientfd = socket(p->ai_family, p->ai_socktype,
                           p->ai_protocol)) < 0)
        continue; /* Socket failed, try the next */

    /* 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.

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>`

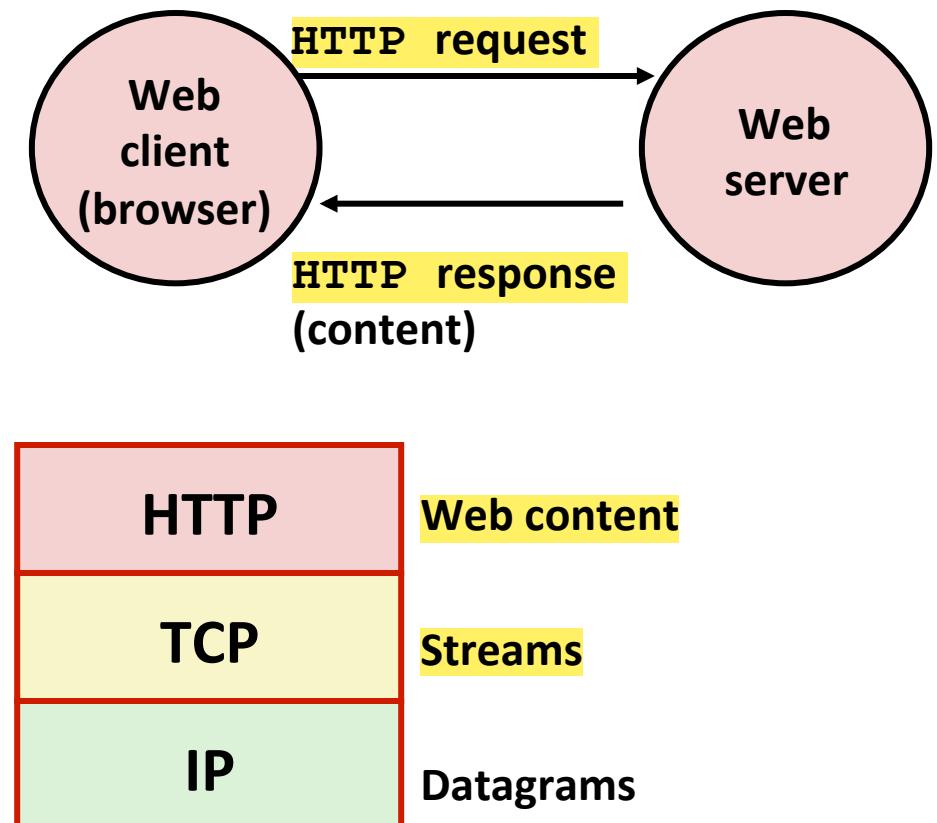
Testing the Echo Server With telnet

```
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.



<http://www.w3.org/Protocols/rfc2616/rfc2616.html>

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 | Binary 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>
 - <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
```

Trying 128.2.42.52...

Connected to WWW-CMU-PROD-VIP.ANDREW.cmu.edu.

Escape character is '^]'.

GET / HTTP/1.1

Host: www.cmu.edu

HTTP/1.1 301 Moved Permanently

Date: Wed, 05 Nov 2014 17:05:11 GMT

Server: Apache/1.3.42 (Unix)

Location: http://www.cmu.edu/index.shtml

Transfer-Encoding: chunked

Content-Type: text/html; charset=...

15c

<HTML><HEAD>

...

</BODY></HTML>

0

Connection closed by foreign host.

Client: open connection to server

Telnet prints 3 lines to terminal

Client: request line

Client: required HTTP/1.1 header

Client: empty line terminates headers

Server: response line

Server: followed by 5 response headers

Server: this is an Apache server

Server: page has moved here

Server: response body will be chunked

Server: expect HTML in response body

Server: empty line terminates headers

Server: first line in response body

Server: start of HTML content

Server: end of HTML content

Server: last line in response body

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
Trying 128.2.42.52...
Connected to WWW-CMU-PROD-VIP.ANDREW.cmu.edu.
Escape character is '^]'.
GET /index.shtml HTTP/1.1
Host: www.cmu.edu

HTTP/1.1 200 OK
Date: Wed, 05 Nov 2014 17:37:26 GMT
Server: Apache/1.3.42 (Unix)
Transfer-Encoding: chunked
Content-Type: text/html; charset=...

1000
<html ..>
...
</html>
0
Connection closed by foreign host.
```

Client: open connection to server
Telnet prints 3 lines to terminal

Client: request line
Client: required HTTP/1.1 header
Client: empty line terminates headers
Server: response line
Server: followed by 4 response headers

Server: empty line terminates headers
Server: begin response body
Server: first line of HTML content

Server: end response body
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));

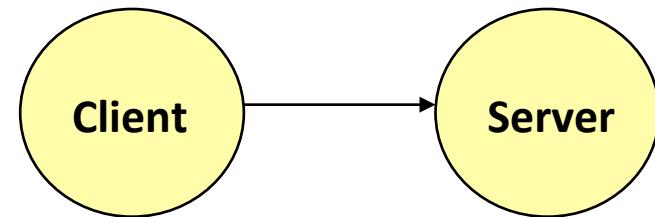
    /* Send response body to client */
    srcfd = Open(filename, O_RDONLY, 0);
    srcp = Mmap(0, filesize, PROT_READ, MAP_PRIVATE, srcfd, 0);
    Close(srcfd);
    Rio_writen(fd, srcp, filesize);
    Munmap(srcp, filesize);
}
```

tiny.c

Serving Dynamic Content

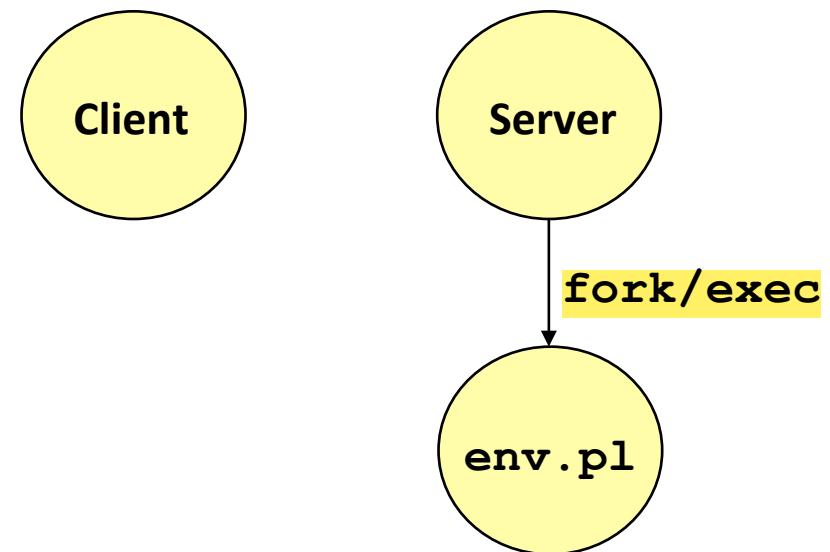
- Client sends request to server
- If request URI contains the string “/cgi-bin”, the Tiny server assumes that the request is for dynamic content

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



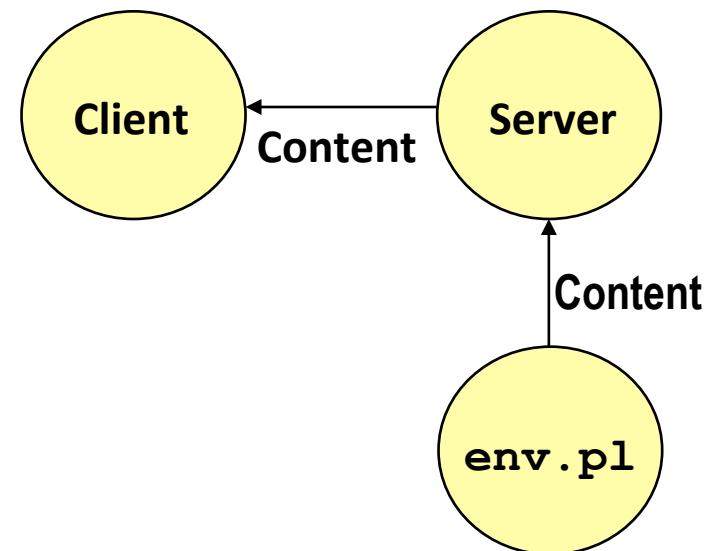
Serving Dynamic Content (cont)

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



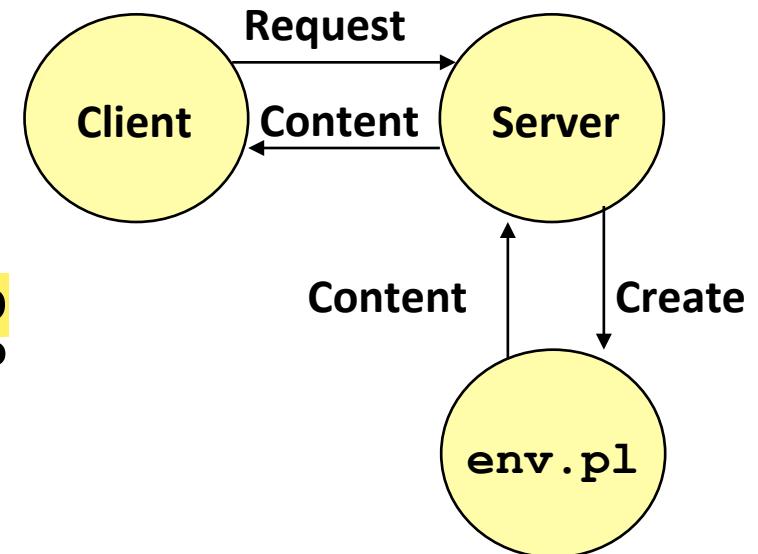
Serving Dynamic Content (cont)

- 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

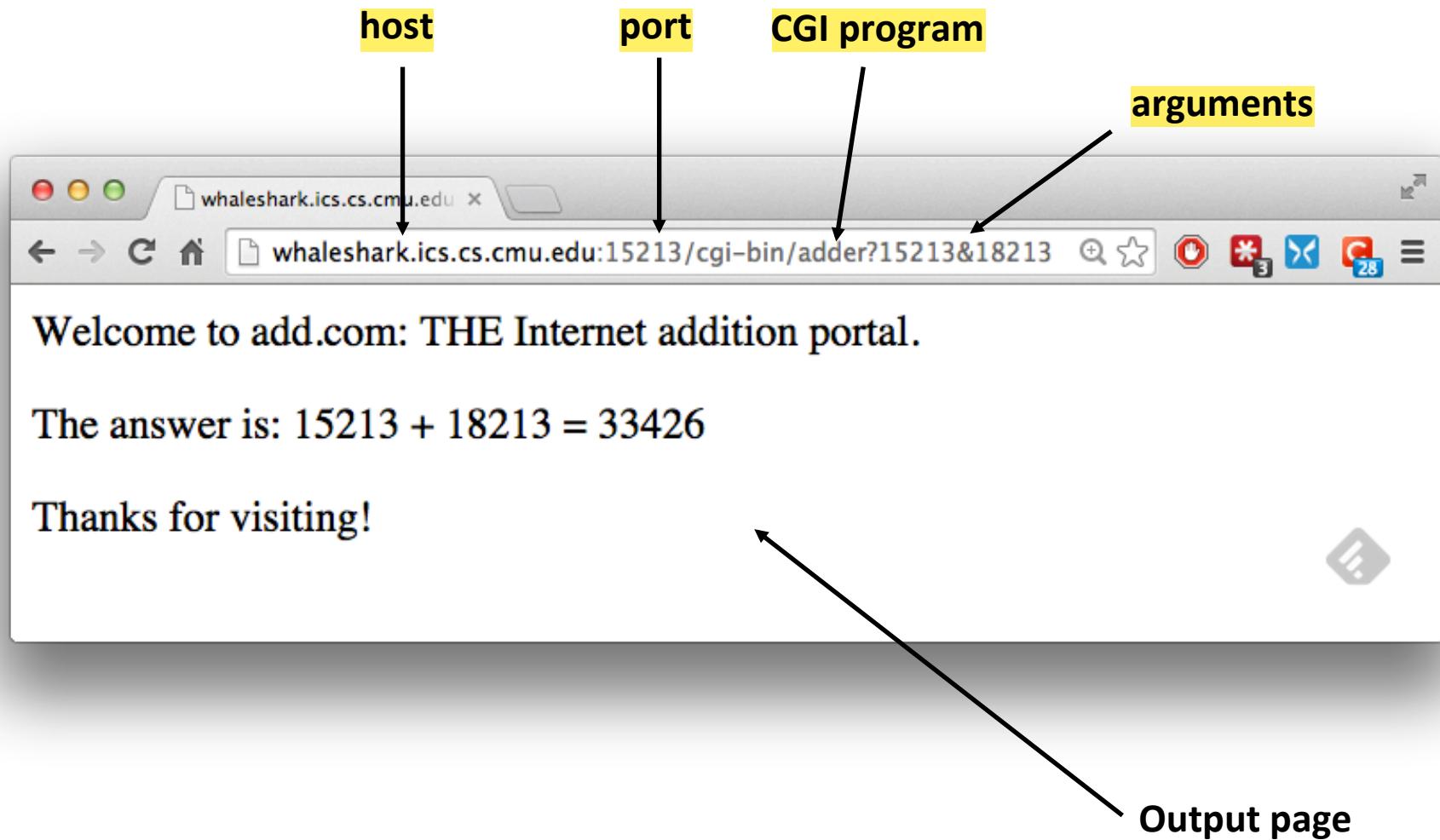
- How does the client pass program arguments to the server?
- How does the server pass these arguments to the child?
- How does the server pass other info relevant to the request to the child?
- How does the server capture the content produced by the child?
- These issues are addressed by the **Common 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

- Question: How does the server pass these arguments to the child?
- Answer: 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 */
}
```

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 request sent by client

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

*HTTP response generated
by the server*

```
Welcome to add.com: THE Internet addition portal.
<p>The answer is: 15213 + 18213 = 33426
<p>Thanks for visiting!
```

*HTTP response generated
by the CGI program*

```
Connection closed by foreign host.
bash:makoshark>
```

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>
```

Data Transfer Mechanisms

■ Standard

- Specify total length with content-length
- Requires that program buffer entire message

■ Chunked

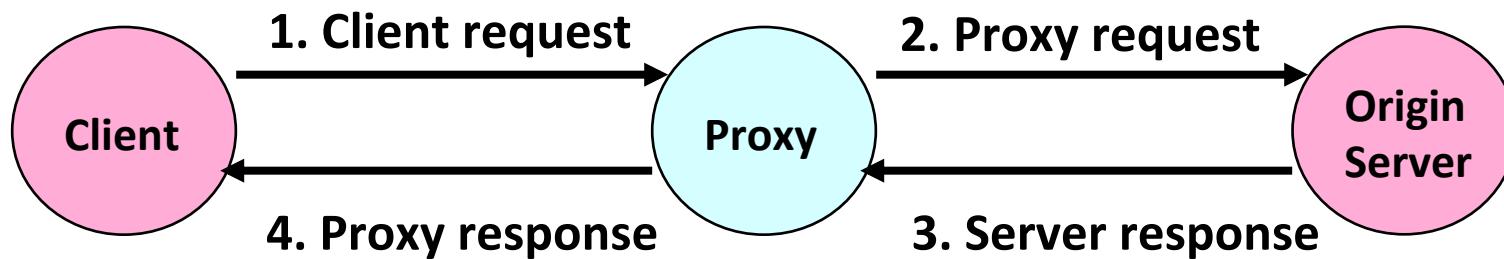
- Break into blocks
- Prefix each block with number of bytes (Hex coded)

Chunked Encoding Example

```
HTTP/1.1 200 OK\nDate: Sun, 31 Oct 2010 20:47:48 GMT\nServer: Apache/1.3.41 (Unix)\nKeep-Alive: timeout=15, max=100\nConnection: Keep-Alive\nTransfer-Encoding: chunked\nContent-Type: text/html\n\r\nd75\r\n First Chunk: 0xd75 = 3445 bytes\n<html>\n<head>\n    <link href="http://www.cs.cmu.edu/style/calendar.css" rel="stylesheet"\n          type="text/css">\n</head>\n<body id="calendar_body">\n\n    <div id='calendar'><table width='100%' border='0' cellpadding='0'\n        cellspacing='1' id='cal'>\n\n        . . .\n    </body>\n</html>\n\r\n0\r\n Second Chunk: 0 bytes (indicates last chunk)\n\r\n
```

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

