TCP and Connections

TCP provides reliability by tracking and retrying lost packets

⇒ needs an explicit ***connection*** between processes

⇒ needs explicit notions of client and server

Server side has two sockets:

A ***listener*** to receive clients

A per-client socket to communicate with the client

Each client has a single socket

Listening for Connections

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

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

In the background, allow TCP connections via **`socket`**

`socket` must be bound to an address already

Clients connect to that address

`backlog` indicates how many not-yet-accepted connections to allow in waiting

Accepting Connections

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

int accept(int socket,
           struct sockaddr *addr, socklen_t *addr_len);
```

Accepts a connection from **`socket`** and returns it as a new socket

`socket` must be previously passed to **`listen`**

`addr` and **`addr_len`** are filled with the client's address

... but a server doesn't usually care

Making Connections

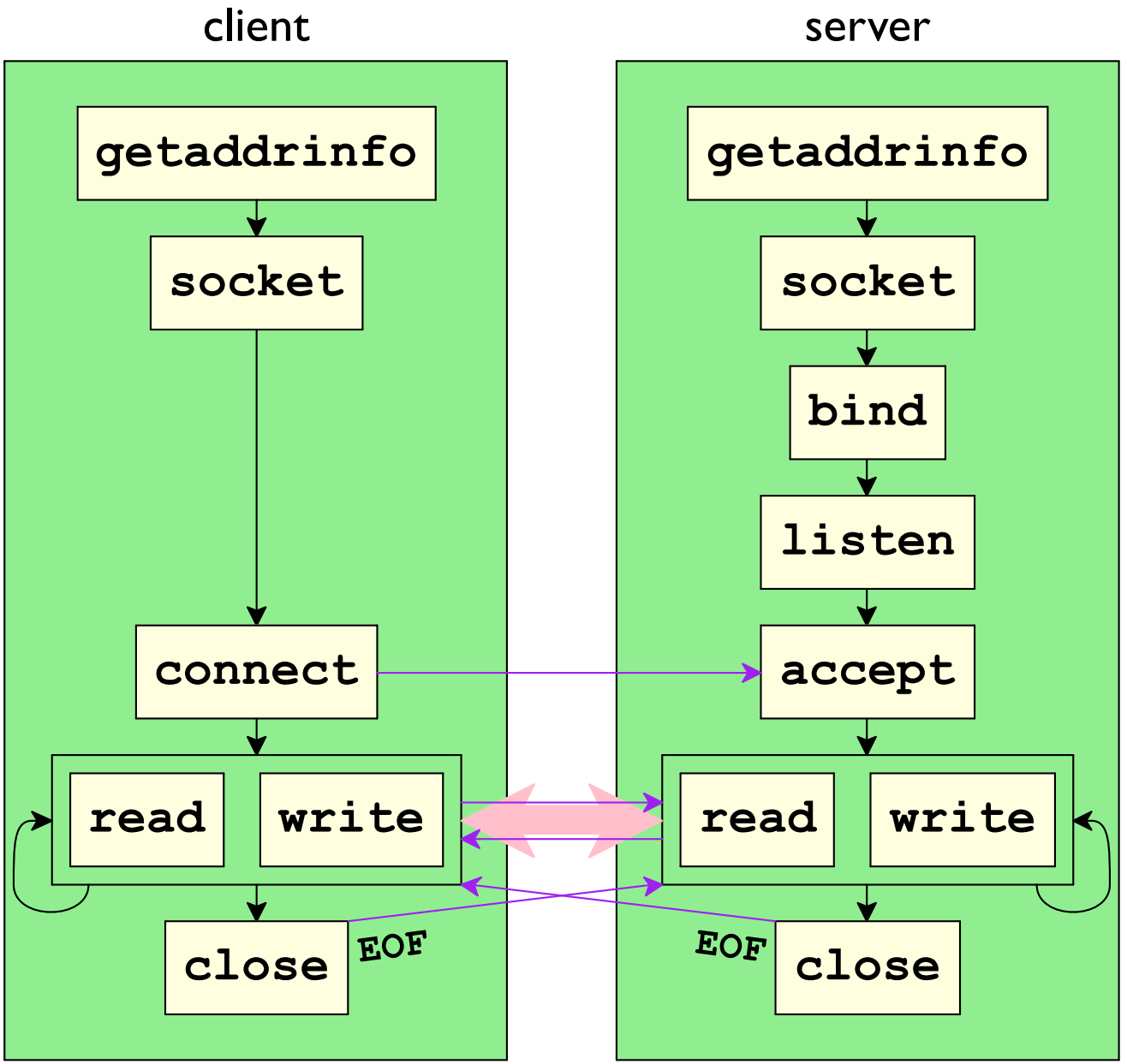
```
#include <sys/types.h>
#include <sys/socket.h>

int connect(int socket,
            struct sockaddr *addr, socklen_t addr_len);
```

Binds **`socket`** to a TCP connection as a client

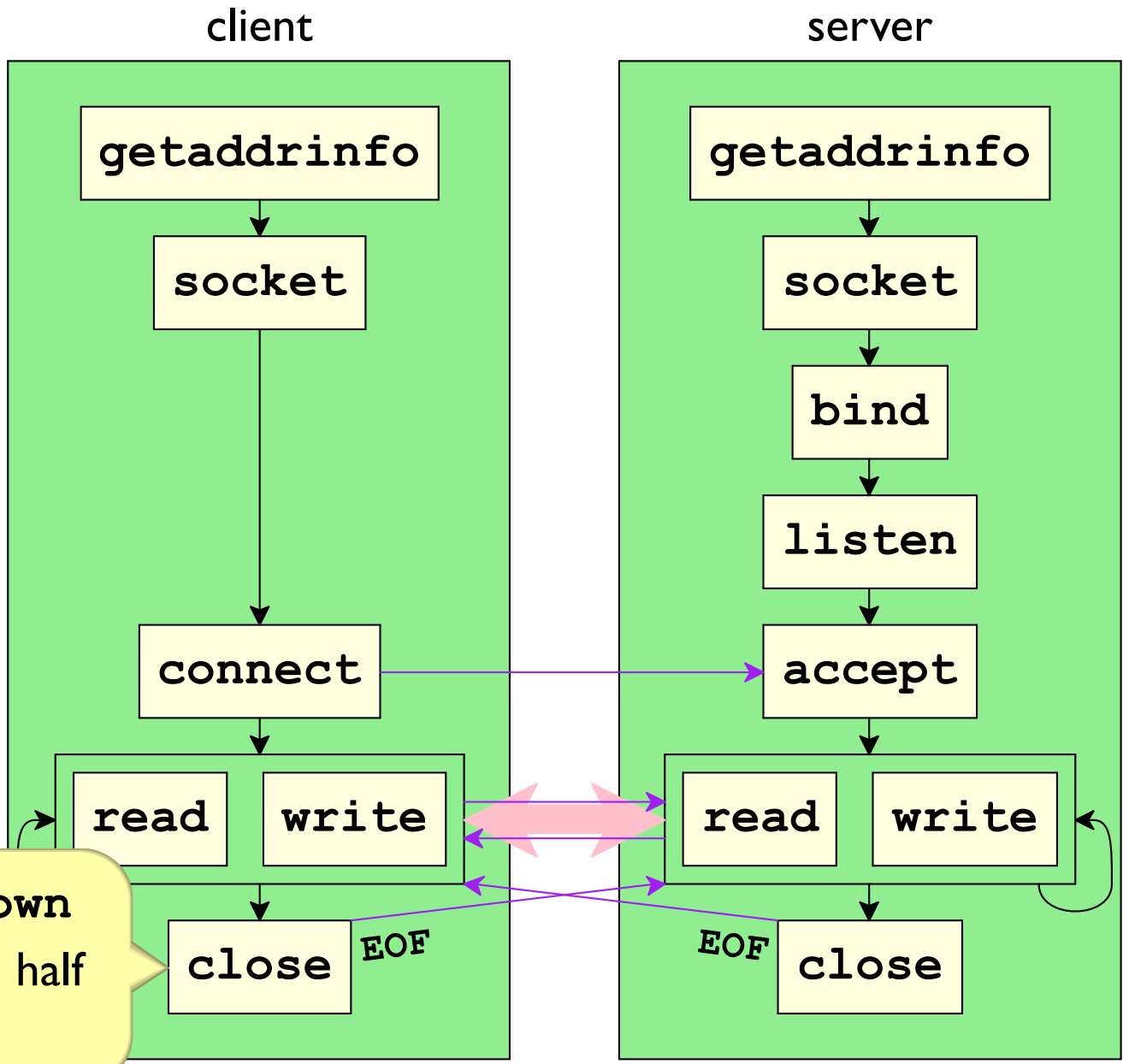
`addr` and **`addr_len`** are the server's address

The server sees the connection when it calls **`accept`**

Using TCP

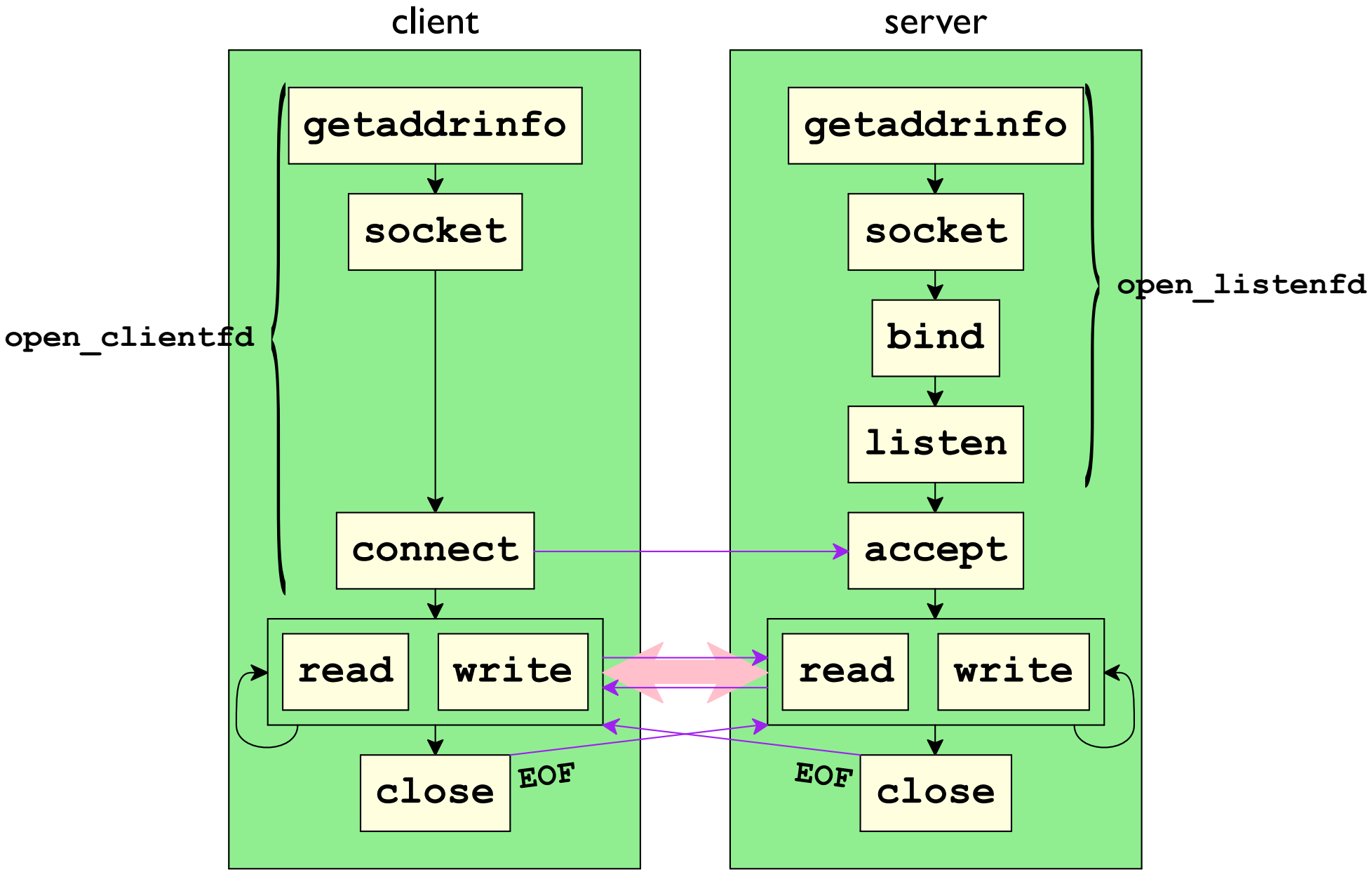

client
server
getaddrinfo
socket
connect
read
write
close
EOF
getaddrinfo
socket
bind
listen
accept
read
write
EOF
close

Using TCP

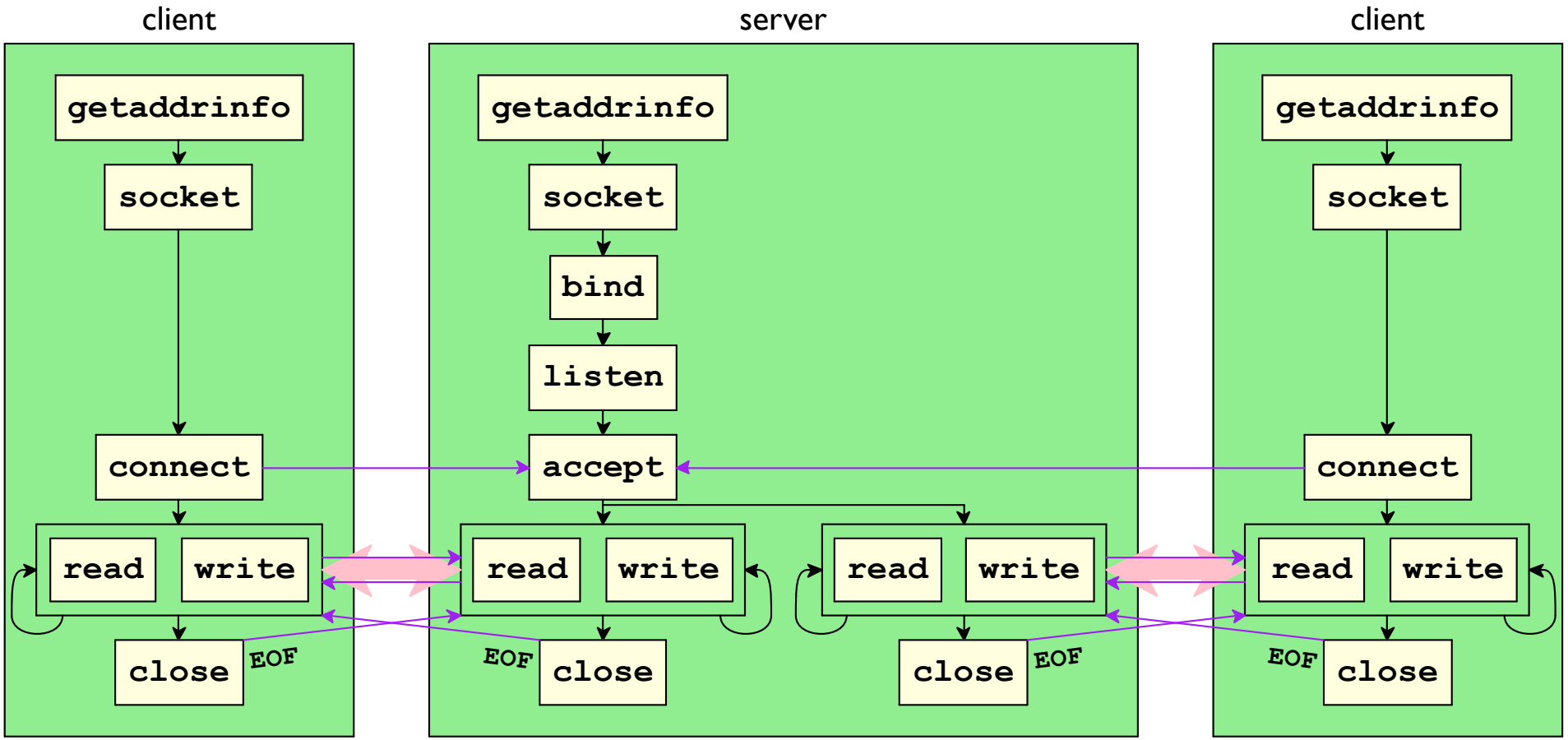


Use **shutdown** to leave read half open

Using TCP


client
server
getaddrinfo
socket
open_clientfd
connect
read
write
close
EOF
getaddrinfo
socket
bind
listen
open_listenfd
accept
read
write
EOF
close

Using TCP


client
server
client
getaddrinfo
socket
bind
listen
connect
accept
read
write
close
EOF

TCP Server

tcp_server.c

```
....
memset(&hints, 0, sizeof(struct addrinfo));
hints.ai_family = AF_INET;         /* Request IPv4 */
hints.ai_socktype = SOCK_STREAM;   /* Accept TCP connections */
hints.ai_flags = AI_PASSIVE;       /* ... on any IP address */
Getaddrinfo(NULL, portno, &hints, &addrs);

ls = Socket(addrs->ai_family, addrs->ai_socktype, addrs->ai_protocol);
Bind(ls, addrs->ai_addr, addrs->ai_addrlen);
Freeaddrinfo(addrs);
Listen(ls, 5);

while (1) {
  ....
  s = Accept(ls, (struct sockaddr *)&addr, &len);
  amt = Read(s, buffer, MAXBUF);
  write(1, buffer, amt);
  write(1, "\n", 1);
  write(s, &amt, sizeof(amt));
  Close(s);
}
....
```

TCP Client

tcp_client.c

```
....
memset(&hints, 0, sizeof(struct addrinfo));
hints.ai_family = AF_INET;         /* Request IPv4 */
hints.ai_socktype = SOCK_STREAM;  /* TCP connection */
Getaddrinfo(hostname, portno, &hints, &addrs);

s = Socket(addrs->ai_family, addrs->ai_socktype, addrs->ai_protocol);
Connect(s, addrs->ai_addr, addrs->ai_addrlen);
Freeaddrinfo(addrs);

copies = ((argc == 5) ? atoi(argv[4]) : 1);
len = strlen(argv[3]);
while (copies--) {
  amt = Write(s, argv[3], len);
  if (amt != len) app_error("incomplete write");
}

got = 0;
amt = Read(s, &got, sizeof(got));
printf("server got %ld\n", got);
Close(s);
....
```

Robust I/O

Provided by **`csapp.c`**:

```
ssize_t rio_readn(int fd, void *usrbuf, size_t n);
ssize_t rio_writen(int fd, void *usrbuf, size_t n);
```

Like **`read`** and **`write`**, but loops as needed for short counts and signal interruptions

Revised TCP Server

Robust I/O, wait for an EOF from clients:

tcp_server2.c

```
....
s = Accept(ls, (struct sockaddr *)&addr, &len);

while (1) {
  char buffer[MAXBUF];
  size_t amt = Rio_readn(s, buffer, MAXBUF);
  if (amt == 0) {
    printf("client is done\n");
    Rio_writen(s, &total_amt, sizeof(total_amt));
    break;
  } else {
    Rio_writen(1, buffer, amt);
    Rio_writen(1, "\n", 1);
    total_amt += amt;
  }
}

Close(s);
....
```

Revised TCP Client

tcp_client2.c

```
....

while (copies--)
  Rio_writen(s, argv[3], len);

Shutdown(s, SHUT_WR);

got = 0;
amt = Rio_readn(s, &got, sizeof(got));
if (amt != sizeof(got))
  app_error("response truncated");
printf("server got %ld\n", got);

Close(s);

....
```

Re-Revised TCP Server

Client can declare amount it will send

tcp_server3.c

```
....
s = Accept(ls, (struct sockaddr *)&addr, &len);

amt = Rio_readn(s, &total_amt, sizeof(total_amt));
if (amt != sizeof(total_amt))
  app_error("amount truncated");

buffer = malloc(total_amt);
amt = Rio_readn(s, buffer, total_amt);

Rio_writen(1, buffer, amt);
Rio_writen(1, "\n", 1);
free(buffer);

write(s, &amt, sizeof(amt));
Close(s);
....
```

Re-Revised TCP Client

tcp_client3.c

```
....

len = strlen(argv[3]);

amt = copies * len;
Rio_writen(s, &amt, sizeof(amt));

while (copies--)
  Rio_writen(s, argv[3], len);

got = 0;
amt = Rio_readn(s, &got, sizeof(got));
if (amt != sizeof(got))
  app_error("response truncated");

printf("server got %ld\n", got);

Close(s);

....
```

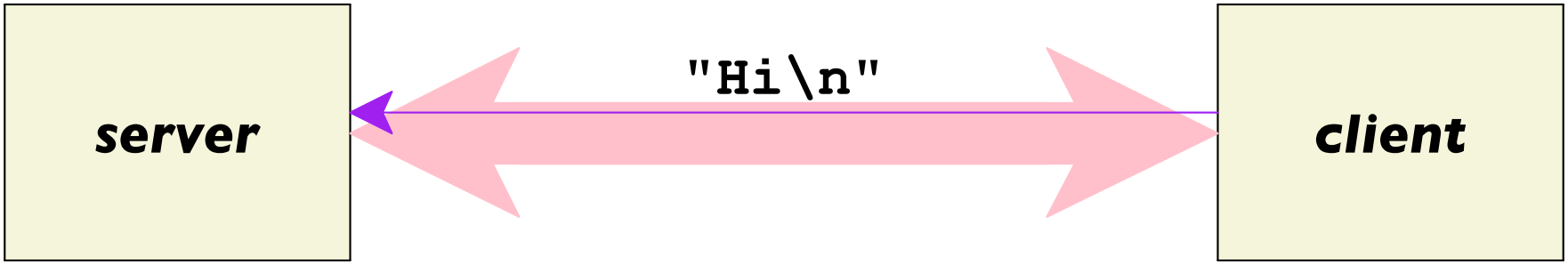
Echo Server

Another example: a server that echoes back every line


```
lnr = Open_listenfd(....);
fd = Accept(lnr, ....);          fd = Open_clientfd(....);
```

Echo Server

Another example: a server that echoes back every line

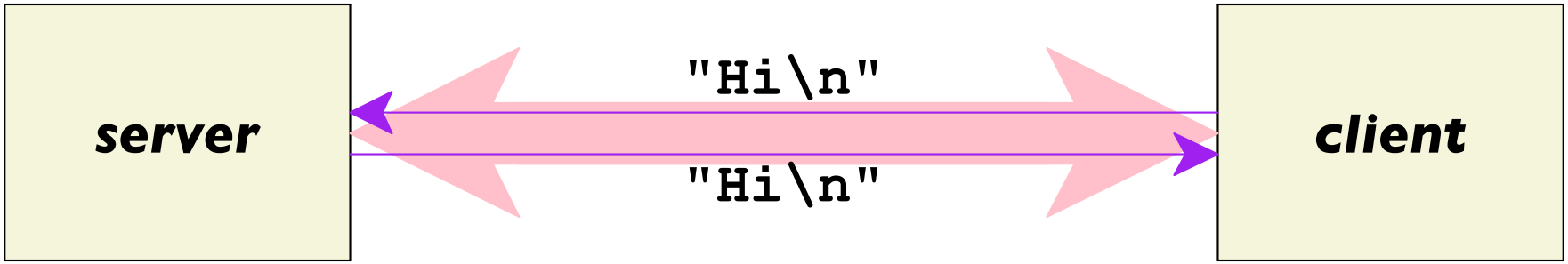



```
lnr = Open_listenfd(....);
fd = Accept(lnr, ....);
```

```
fd = Open_clientfd(....);

Rio_writen(fd, "Hi\n", 3);
```

Echo Server

Another example: a server that echoes back every line




```
lnr = Open_listenfd(....);
fd = Accept(lnr, ....);
```

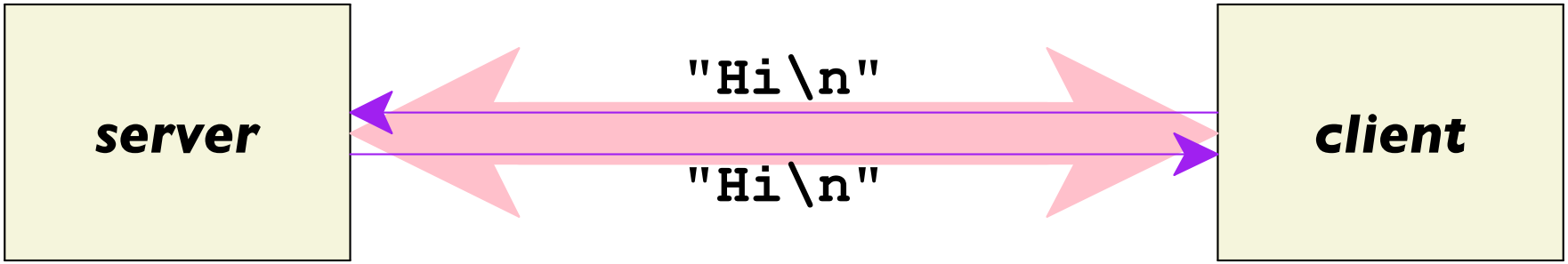
```
fd = Open_clientfd(....);
```

```
Rio_writen(fd, "Hi\n", 3);
```

```
Rio_writen(fd, ....);
```

Echo Server

Another example: a server that echoes back every line

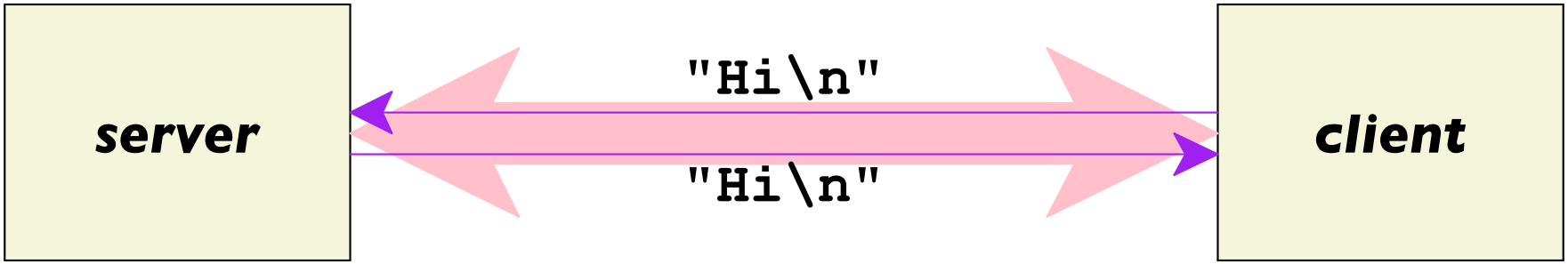



```
lnr = Open_listenfd(....);
fd = Accept(lnr, ....);

while (readline(fd, ....))
  Rio_writen(fd, ....);
```

```
fd = Open_clientfd(....);

Rio_writen(fd, "Hi\n", 3);

...
```

Echo Server

Another example: a server that echoes back every line




```
ln                                ....);
fd                                .);          fd = Open_clientfd(....);
```

Reading one byte at a time would be slow

```
while (readline(fd, ....))        Rio_writen(fd, "Hi\n", 3);
  Rio_writen(fd, ....);
                                  ...
```

Robust Buffered Reading

```
#include "csapp.h"

void rio_readinitb(rio_t *rp, int fd);
ssize_t rio_readlineb(rio_t *rp, void *buf, size_t maxlen);
ssize_t rio_readnb(rio_t *rp, void *buf, size_t n);
```

`rio_initb` initializes a buffer to hold bytes that are read but not yet consumed

`rio_readlineb` fills the buffer as needed and consumes bytes that make a line

`rio_readnb` is like **`rio_readn`**, but keeps using the buffer

Echo Server

echo.c

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

  listenfd = Open_listenfd(argv[1]);
  while (1) {
    socklen_t clientlen = sizeof(struct sockaddr_storage);
    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);
  }
}
.....
```

Echo Server

echo.c

```
....

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 %ld bytes\n", n);
    Rio_writen(connfd, buf, n);
  }
}
```

Telnet

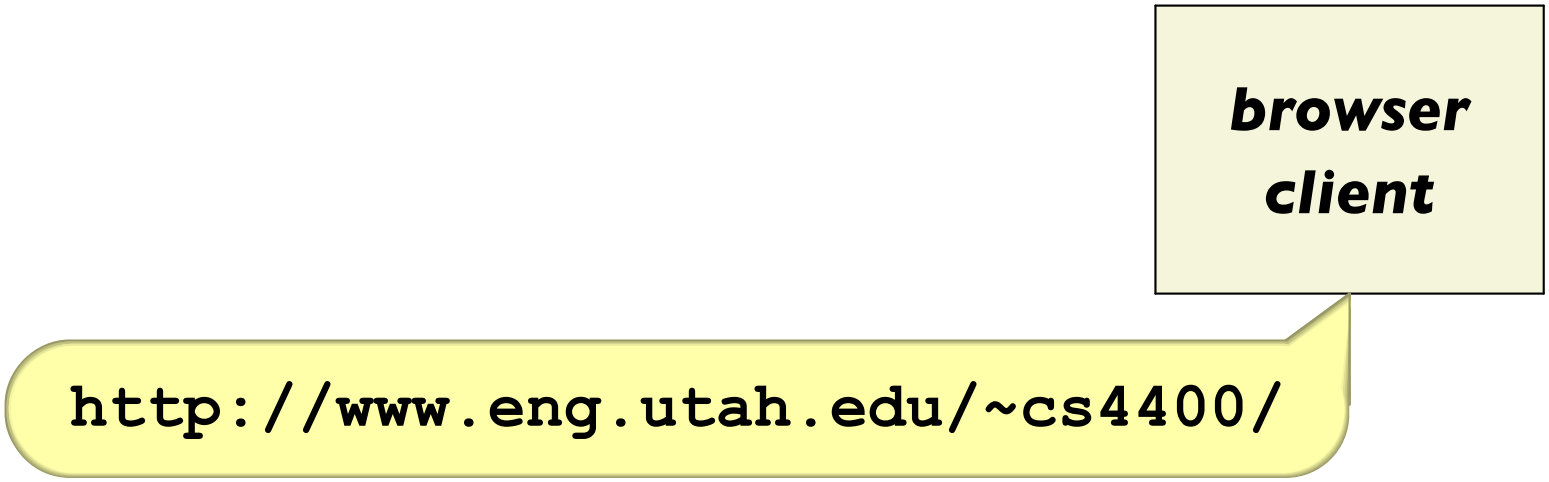
Instead of implementing an echo client, we can just use **`telnet`**

If the echo serever is at **`locahost`** on **`4567`**:

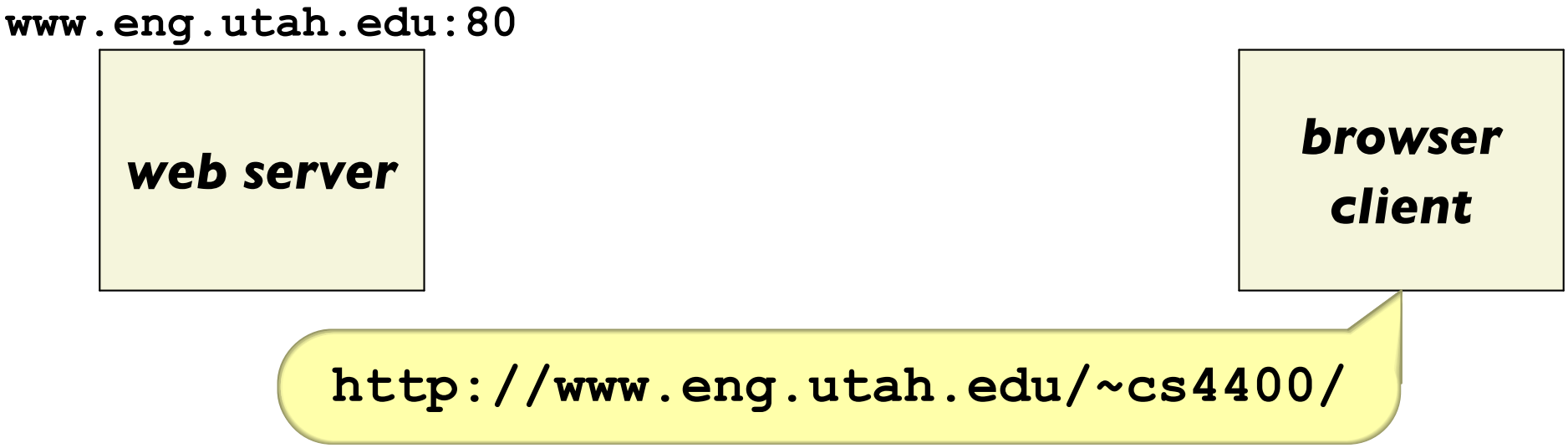
```
$ telnet localhost 4567
```

Use Ctl-] and then **`quit`** to stop

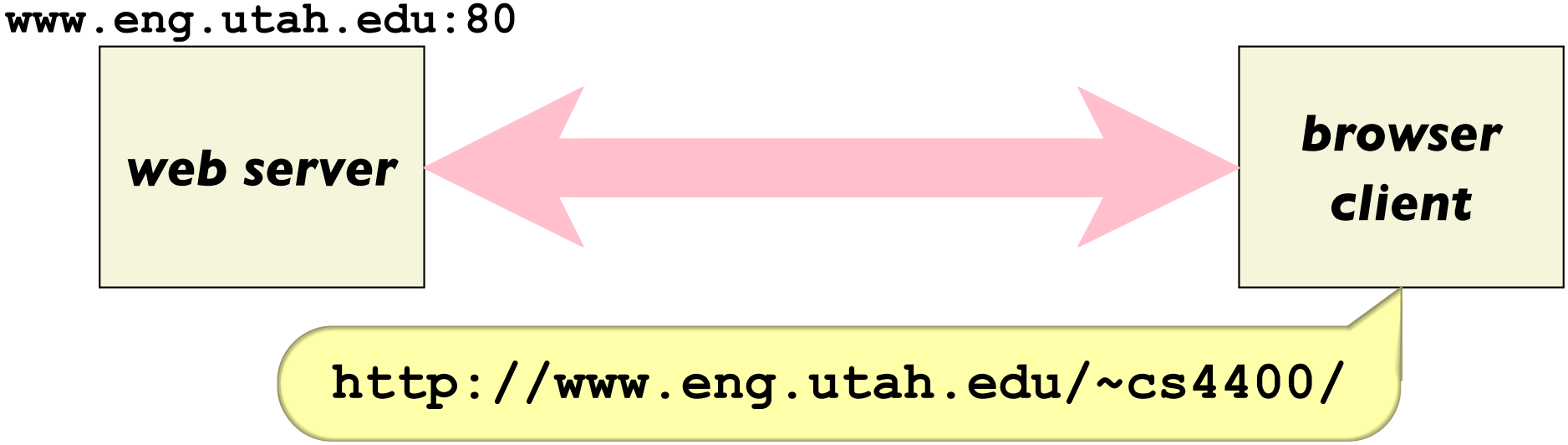
HTTP



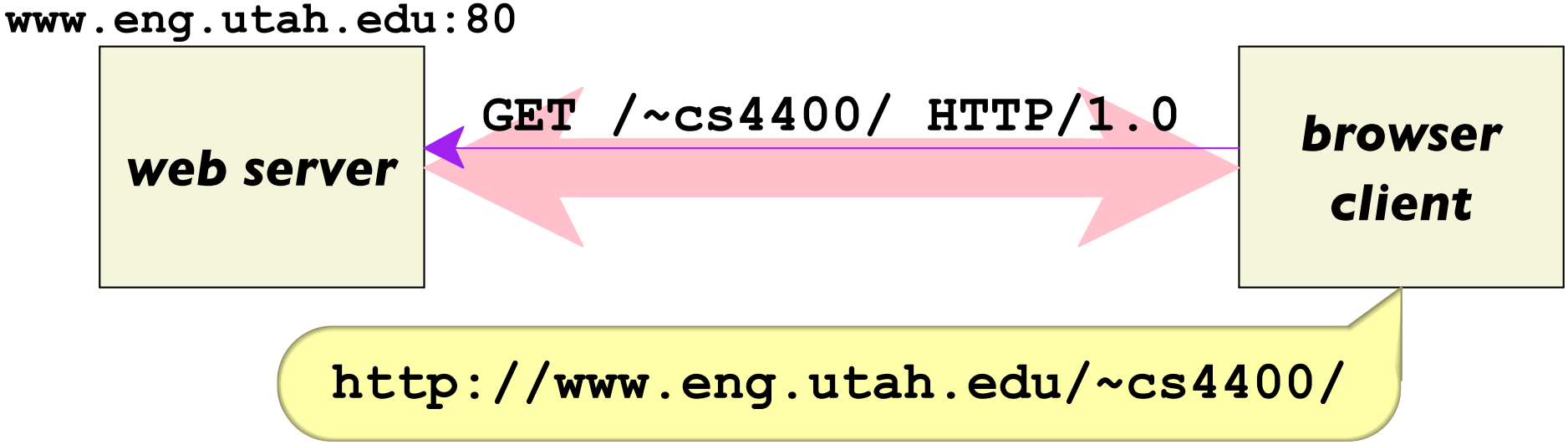
HTTP


www.eng.utah.edu:80
web server
browser client
http://www.eng.utah.edu/~cs4400/

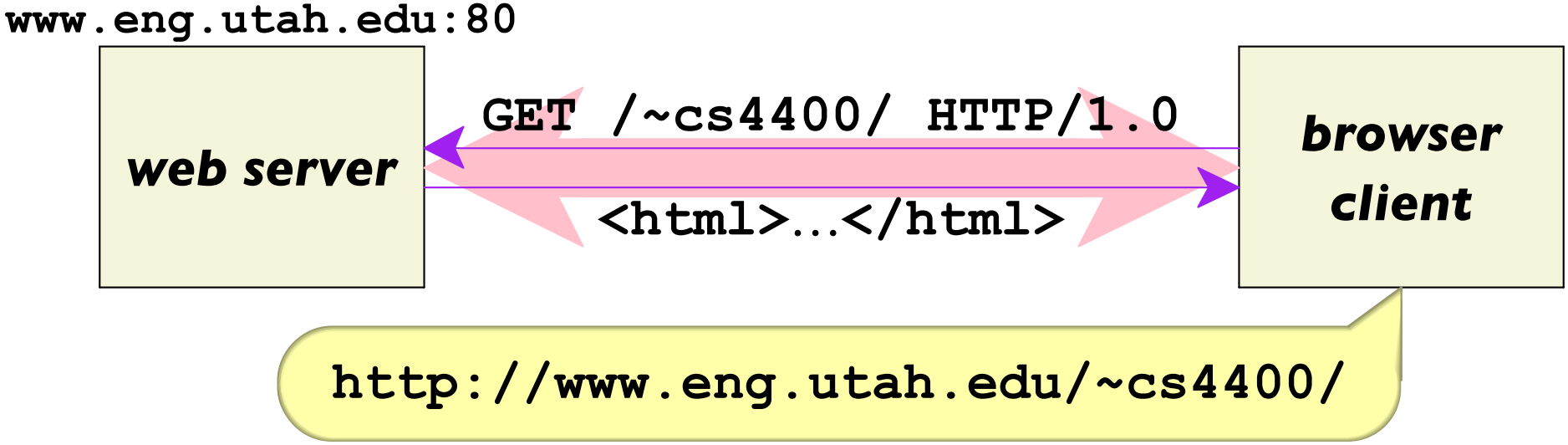
HTTP


www.eng.utah.edu:80
web server
browser client
http://www.eng.utah.edu/~cs4400/

HTTP


www.eng.utah.edu:80
web server
GET /~cs4400/ HTTP/1.0
browser client
http://www.eng.utah.edu/~cs4400/

HTTP

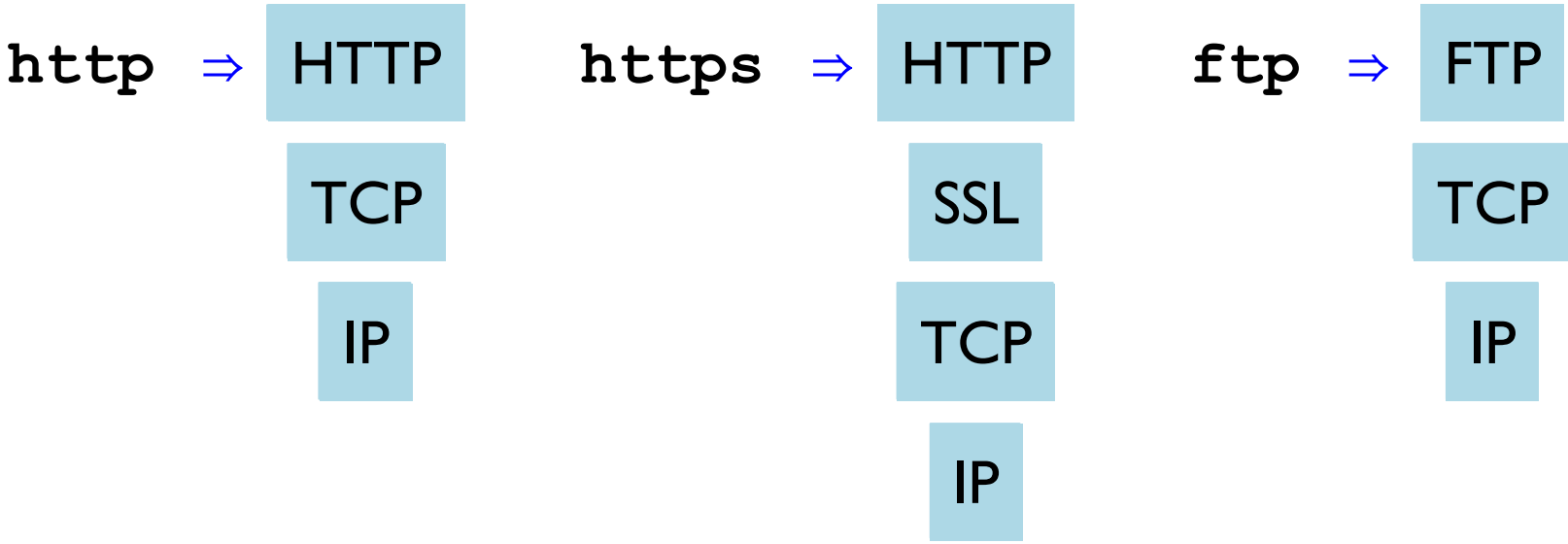

www.eng.utah.edu:80
web server
GET /~cs4400/ HTTP/1.0
<html>...</html>
browser client
http://www.eng.utah.edu/~cs4400/

URLs

scheme : / / *host* : *port* / *path* ? *query* # *fragment*

each color is optional

scheme — protocol to use



Assume **`http`** for the rest

URLs

scheme : / / *host* : *port* / *path* ? *query* # *fragment*

each color is optional

scheme — protocol to use

host — the server's host

`www.eng.utah.edu`

`google.com`

`127.0.0.1`

URLs

scheme : / / *host* : *port* / *path* ? *query* # *fragment*

each color is optional

scheme — protocol to use

host — the server's host

port — the server's port

defaults to 80

`http://localhost/` ⇒ port 80 on `localhost`

`http://localhost:8090/` ⇒ port 8090 on `localhost`

URLs

scheme : / / *host* : *port* / *path* ? *query* # *fragment*

each color is optional

scheme — protocol to use

host — the server's host

port — the server's port

path — item to get from the server, defaults to empty

Meaning of *path* is up to the server:

- could be a file
- could be a request to compute
- could be a request to change

URLs

scheme://*host*:*port*/*path*?*query*#*fragment*

each color is optional

scheme — protocol to use

host — the server's host

port — the server's port

path — item to get from the server, defaults to empty

`http://www.eng.utah.edu/~cs4400/network.pdf`

⇒ gets a file from the CADE filesystem

`https://goo.gl/om5FJq`

⇒ looks up redirection URL

URLs

scheme : / / *host* : *port* / *path* ? *query* # *fragment*

each color is optional

scheme — protocol to use

host — the server's host

port — the server's port

path — item to get from the server, defaults to empty

query — options related to *path*

Sequence of *key*=*value* separated by `&` or `;`

`http://www.youtube.com/watch?v=KFyuGneWhJ4`

`http://twitter.com/search?q=utah&src=typd`

Meaning of *query* is also up to the server

URLs

scheme : / / *host* : *port* / *path* ? *query* # *fragment*

each color is optional

scheme — protocol to use

host — the server's host

port — the server's port

path — item to get from the server, defaults to empty

query — options related to *path*

fragment — more options related to *path*

Use of *fragment* is up to the **client**

not sent to the server

`http://www.eng.utah.edu/~cs4400/#(part._staff)`

Encoding

scheme : / / *host* : *port* / *path* ? *query* # *fragment*

What if a *path* includes **?**?

What if a *query* includes **#**?

What if a *value* in a *query* includes **&**?

Percent encoding:

- Replace a character with **%***XX*
  - Each *X* is a hex digit
  - **0x***XX* is the character's value
- Replace a space with **+**

Access **lost+found** with **user** as **me&you**:

http://server.com/lost%2bfound?user=me%26you

HTTP

`http://`*host*`:`*port*`/`*path*`?`*query*`#`*fragment*

Client connects to *host*`:`*port* with TCP and sends...

Still more choices!

- **`GET`** mode — the default
- **`POST`** mode — better for sending data
- ...

HTTP

http://*host***:***port***/***path***?***query***#***fragment*

Client connects to *host*:*port* with TCP and sends...

GET /*path*?*query* **HTTP/1.0**CRLF

field: *value*CRLF ← zero or more as *header*

CRLF

where CRLF is a two-byte sequence:

- carriage return (CR) character, which is ASCII 13
- a linefeed (LF) character, which is ASCII 10

HTTP

http://*host*:*port*/*path*?*query*#*fragment*

Client connects to *host*:*p*... Or **HTTP/1.1**

GET /*path*?*query* **HTTP/1.0**CRLF

field: *value*CRLF ← zero or more as *header*

CRLF

where CRLF is a two-byte sequence:

- carriage return (CR) character, which is ASCII 13
- a linefeed (LF) character, which is ASCII 10

HTTP

http://*host*:*port*/*path*?*query*#*fragment*

Client connects to *host*:*port* with TCP and sends...

metadata for request
- wanted format
- ...

GET /*path*?*query* **HTTP/1.0**CRLF
field: *value*CRLF ← zero or more as *header*
CRLF

where CRLF is a two-byte sequence:

- carriage return (CR) character, which is ASCII 13
- a linefeed (LF) character, which is ASCII 10

HTTP

http://*host***:***port***/***path***?***query***#***fragment*

Client connects to *host*:*port* with TCP and sends...

GET /*path*?*query* **HTTP/1.0**CRLF

field: *value*CRLF ← zero or more as *header*

CRLF

Adjust **echo.c** to print received lines

and point a web browser at it

HTTP

http://*host***:***port***/***path***?***query***#***fragment*

Client connects to *host*:*port* with TCP and sends...

GET /*path*?*query* **HTTP/1.0**CRLF

field: *value*CRLF ← zero or more as *header*

CRLF

Server replies with

HTTP/1.0 *status* *status-message*CRLF

field: *value*CRLF ← zero or more as *header*

CRLF

data

HTTP

http://*host*:*port*/*path*?*query*#*fragment*

Client connects to *host*:*port* with TCP and sends...

GET /*path*?*query* **HTTP/1.0**CRLF

field: *value*CRLF ← zero or more as *header*

CRLF

Server replies with

HTTP/1.0 *status* *status-message*CRLF

field: *value*CRLF ← zero or more as *header*

CRLF

data

metadata for request
- data size
- data format
- ...

HTTP

http://*host***:***port***/***path***?***query***#***fragment*

Client connects to *host*:*port* with TCP and sends...

GET /*path*?*query* **HTTP/1.0**CRLF

field: *value*CRLF ← zero or more as *header*

CRLF

Server replies with

HTTP/1.0 *status* *status-message*CRLF

field: *value*CRLF

CRLF

data

status	*status-description*
200	OK
301	Moved permanently
400	Bad request
501	Not implemented

HTTP

http://*host***:***port***/***path***?***query***#***fragment*

Client connects to *host*:*port* with TCP and sends...

GET /*path*?*query* **HTTP/1.0**CRLF

field: *value*CRLF ← zero or more as *header*

CRLF

Server replies with

HTTP/1.0 *status* *status-message*CRLF

field: *value*CRLF ← zero or more as *header*

CRLF

data

telnet to a web server

HTTP

http://*host***:***port***/***path***?***query***#***fragment*

Client connects to *host*:*port* with TCP and sends...

POST /*path*?*query* **HTTP/1.0**CRLF

field: *value*CRLF ← zero or more as *header*

CRLF

data

Server reply is the same as for **GET**

Common Header Fields

`Content-Length` — length of response data or **`POST`** data

`Content-Type` — type response data or **`POST`** data

- **`text/html`**: HTML
- **`text/html; charset=utf-8`**: HTML with UTF-8 content
- **`application/x-www-form-urlencoded`**: POST data that uses the *query* format

`Connection` — **`close`** to get a single response

Field names are case-insensitive

TINY Web Server

The ***TINY Web Server*** is a useful web server in 250 lines of code

For each */path*`?`*query* request:

If */path* does not start **`/cgi-bin`**:

- Assume that *path* refers to a file
- Report **`Content-Length`** as file size
- Infer **`Content-Type`** from file extension
- Send file content as reply data

If */path* starts **`/cgi-bin`**:

- Assume that *path* refers to an executable
- Set **`QUERY_STRING`** environment variable to *query*
- Run executable to generate result

TINY Web Server — Main

tiny.c

```
int main(int argc, char **argv) {
  int listenfd, connfd;
  char hostname[MAXLINE], port[MAXLINE];
  struct sockaddr_storage clientaddr;

  listenfd = Open_listenfd(argv[1]);
  while (1) {
    socklen_t clientlen = sizeof(clientaddr);
    connfd = Accept(listenfd, (SA *)&clientaddr, &clientlen);

    Getnameinfo((SA *) &clientaddr, clientlen, hostname, MAXLINE,
                port, MAXLINE, 0);
    printf("Accepted connection from (%s, %s)\n", hostname, port);

    doit(connfd);

    Close(connfd);
  }
}
....
```

TINY Web Server — Handling a Connection

tiny.c

```
void doit(int fd) {
  int is_static;
  char buf[MAXLINE], method[MAXLINE], uri[MAXLINE], version[MAXLINE];
  char filename[MAXLINE], cgiargs[MAXLINE];
  rio_t rio;

  Rio_readinitb(&rio, fd);

  if (!Rio_readlineb(&rio, buf, MAXLINE))
    return;
  sscanf(buf, "%s %s %s", method, uri, version);

  read_requesthdrs(&rio);

  is_static = parse_uri(uri, filename, cgiargs);

  ....
}
```

TINY Web Server — Reading Headers

tiny.c

```
void read_requesthdrs(rio_t *rp) {
  char buf[MAXLINE];

  Rio_readlineb(rp, buf, MAXLINE);
  while (strcmp(buf, "\r\n"))
    Rio_readlineb(rp, buf, MAXLINE);
}
```

TINY Web Server — Parsing URLs

tiny.c

```
int parse_uri(char *uri, char *filename, char *cgiargs) {
  ....

  if (!strstr(uri, "cgi-bin")) {
    ....
    if (uri[strlen(uri)-1] == '/')
      strcat(filename, "home.html");
    ....
    return 1; /* => static content */
  } else {
    ....
    return 0; /* => dynamic content */
  }
}
```

TINY Web Server — Handling a Connection

tiny.c

```
void doit(int fd) {
  struct stat sbuf;

  ....
  if (stat(filename, &sbuf) < 0) {
    clienterror(fd, filename, "404", "Not found",
                ....);
    return;
  }

  if (is_static) {
    ....
    serve_static(fd, filename, sbuf.st_size);
  } else {
    ....
    serve_dynamic(fd, filename, cgiargs);
  }
}
```

TINY Web Server — Serving Files

tiny.c

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

  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));

  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 Web Server — Inferring a File Type

tiny.c

```
void get_filetype(char *filename, char *filetype) {
  if (strstr(filename, ".html"))
    strcpy(filetype, "text/html");
  else if (strstr(filename, ".gif"))
    strcpy(filetype, "image/gif");
  else if (strstr(filename, ".png"))
    strcpy(filetype, "image/png");
  else if (strstr(filename, ".jpg"))
    strcpy(filetype, "image/jpeg");
  else
    strcpy(filetype, "text/plain");
}
```

TINY Web Server — Serving Generated Content

tiny.c

```
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) {
   setenv("QUERY_STRING", cgiargs, 1);
   Dup2(fd, STDOUT_FILENO); /* Redirect stdout to client */
   Execve(filename, emptylist, environ);
 }
 Wait(NULL);
}
```