CS 43: Computer Networks

03: HTTP & Sockets

September 10, 2024

SWARTHMORE COLLEGE

Slides adapted from Kurose & Ross, Kevin Webb

Reading Quiz

Five-Layer Internet Model

Application: the application (e.g., the Web, Email)

Transport: end-to-end connections, reliability

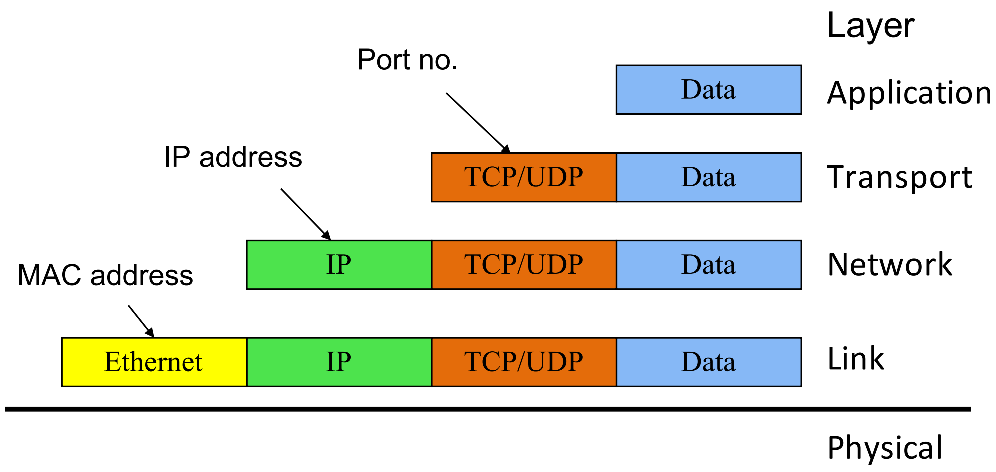
Network: routing

Link (data-link): framing, error detection

Physical: 1’s and 0’s/bits across a medium (copper, the air, fiber)

Application Layer
(HTTP, FTP, SMTP, Tiktok)

- Does whatever an application does!



Layer

Port no.

Data — Application

IP address

TCP/UDP | Data — Transport

MAC address

IP | TCP/UDP | Data — Network

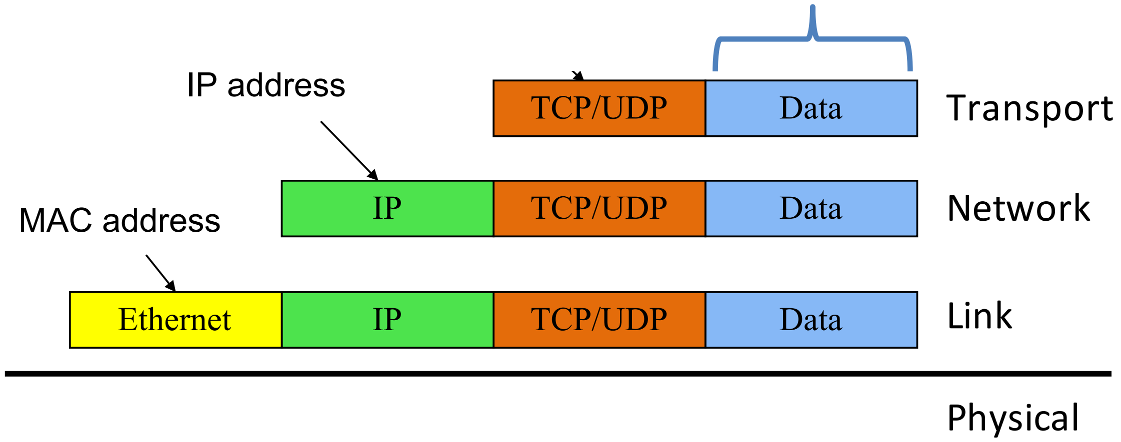
Ethernet | IP | TCP/UDP | Data — Link

Physical

Transport Layer (TCP, UDP)

- Provides
  - Ordering
  - Error checking
  - Delivery guarantee
  - Congestion control
  - Flow control

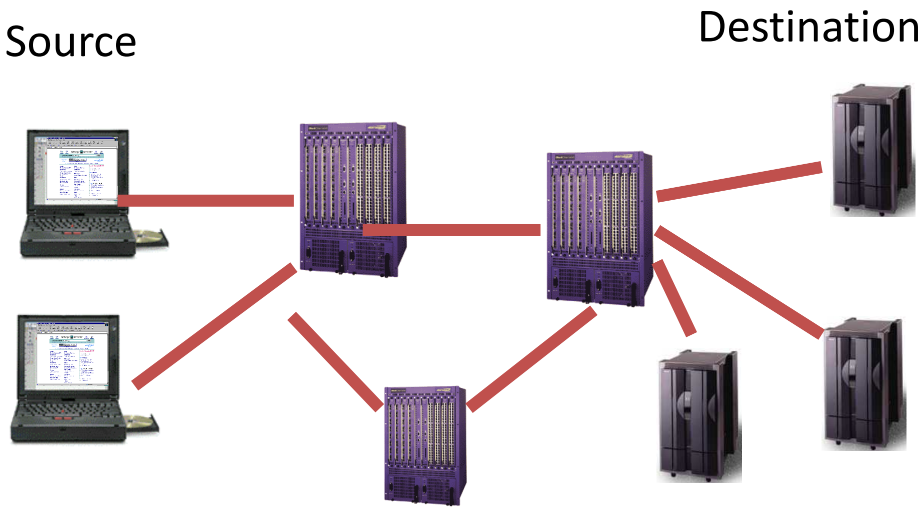
- Or doesn't!

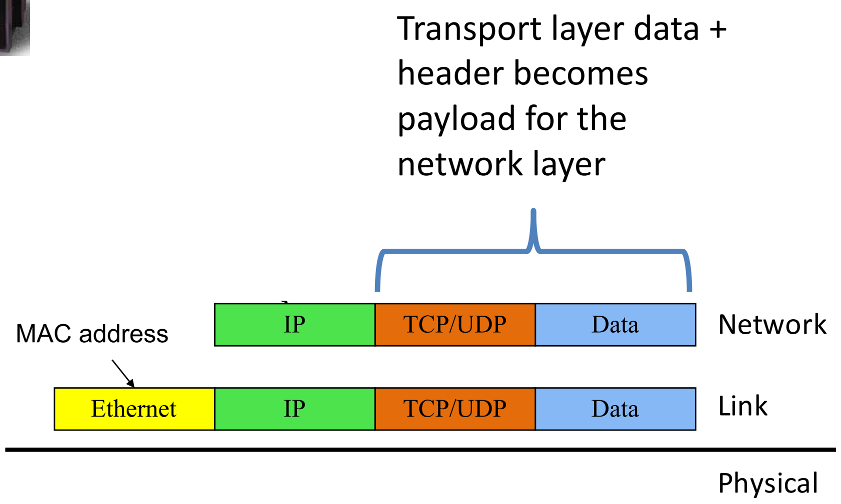


Application Layer Data becomes the payload for the transport layer

Network Layer (IP)

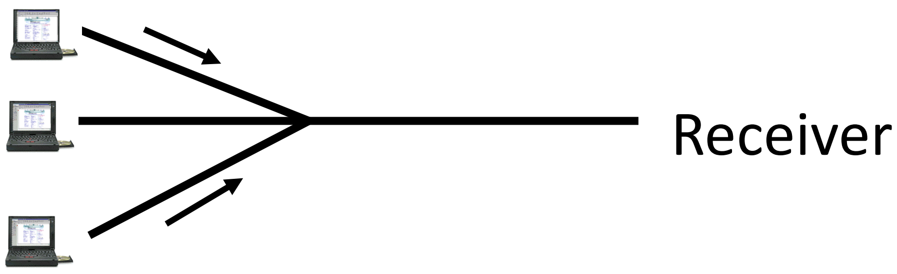
- **Routers**: choose paths through network





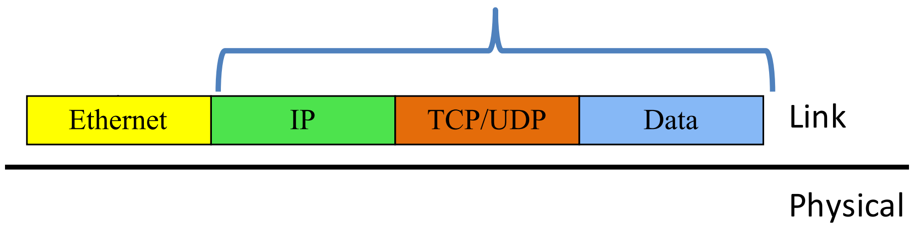
Link Layer (Ethernet, WiFi, Cable)

- Who’s turn is it to send right now?
- Break message into frames
- Media access: can it send the frame now?

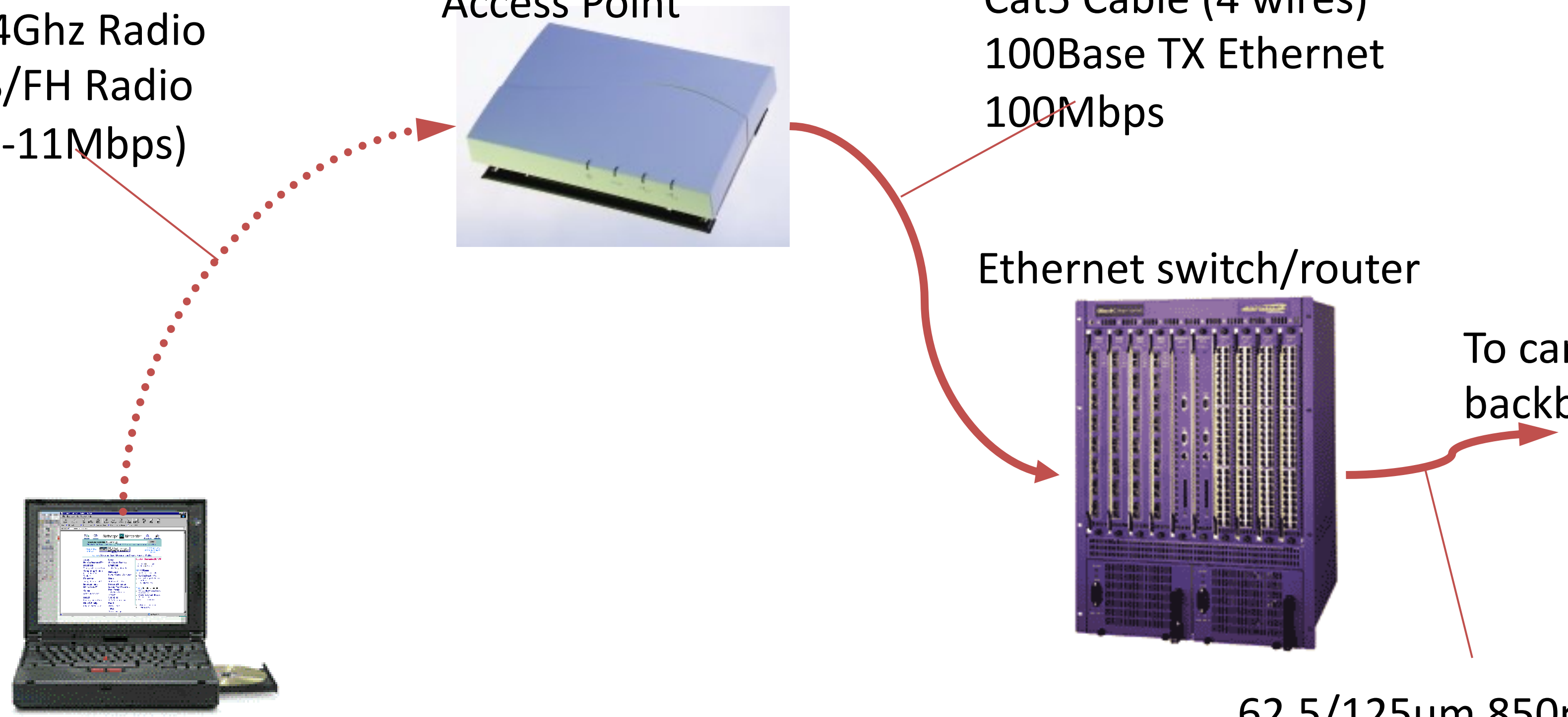


- Send frame, handle “collisions”

Network layer data + header becomes payload for the link layer



Physical layer – move actual bits! (Cat 5, Coax, Air, Fiber Optics)



2.4Ghz Radio
DS/FH Radio
(1-11Mbps)

802.11b Wireless
Access Point

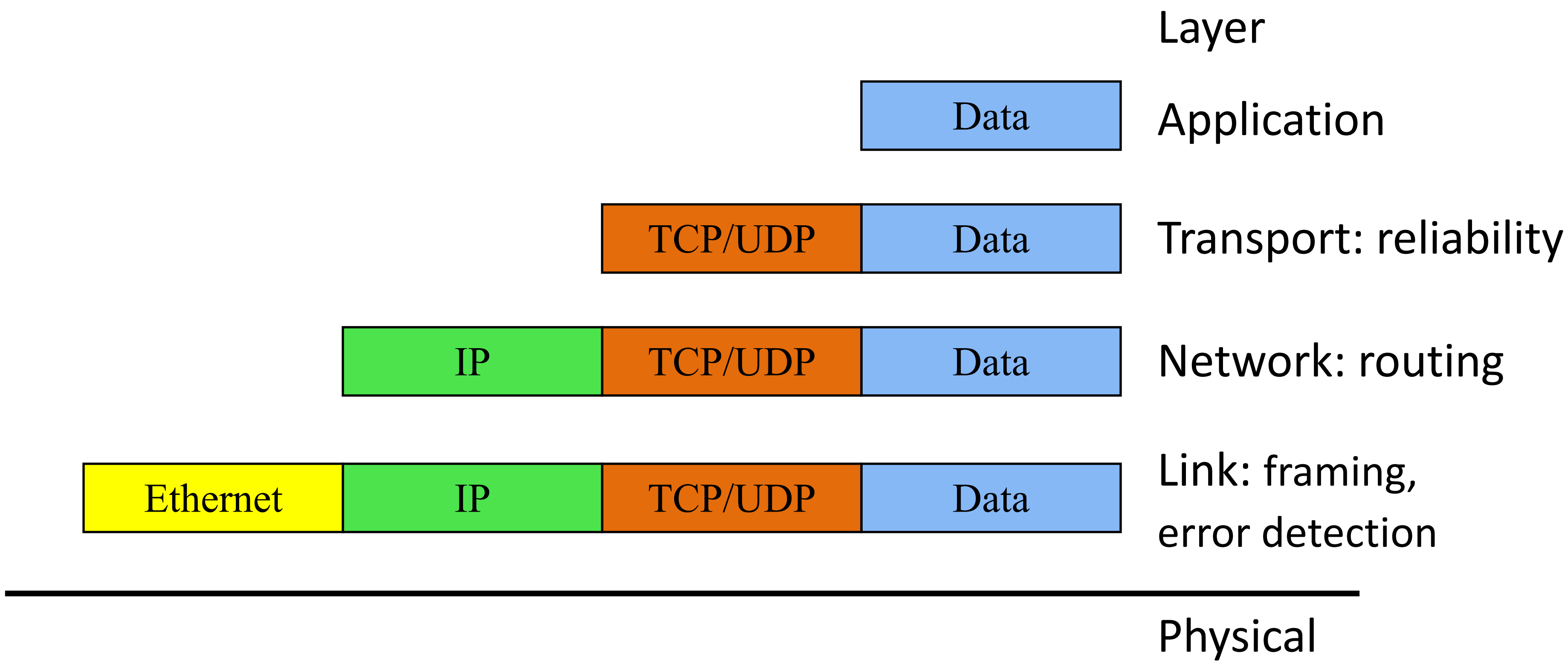
Cat5 Cable (4 wires)
100Base TX Ethernet
100Mbps

Ethernet switch/router

To campus
backbone

62.5/125um 850nm MMF
1000BaseSX Ethernet
1000Mbps

Layering and encapsulation



Layer

Data — Application

TCP/UDP | Data — Transport: reliability

IP | TCP/UDP | Data — Network: routing

Ethernet | IP | TCP/UDP | Data — Link: framing, error detection

Physical

Layering: Separation of Functions

- explicit structure allows identification, relationship of complex system’s pieces
  - layered reference model for discussion
  - reusable component design
- modularization eases maintenance
  - change of implementation of layer’s service transparent to rest of system,
  - e.g., change in postal route doesn’t effect delivery of lette

Abstraction!

- Hides the complex details of a process
- Use abstract representation of relevant properties make reasoning simpler
- Ex: Your knowledge of postal system:
  - Letters with addresses go in, come out other side

Five-Layer Internet Model

Application: the application (e.g., the Web, Email)

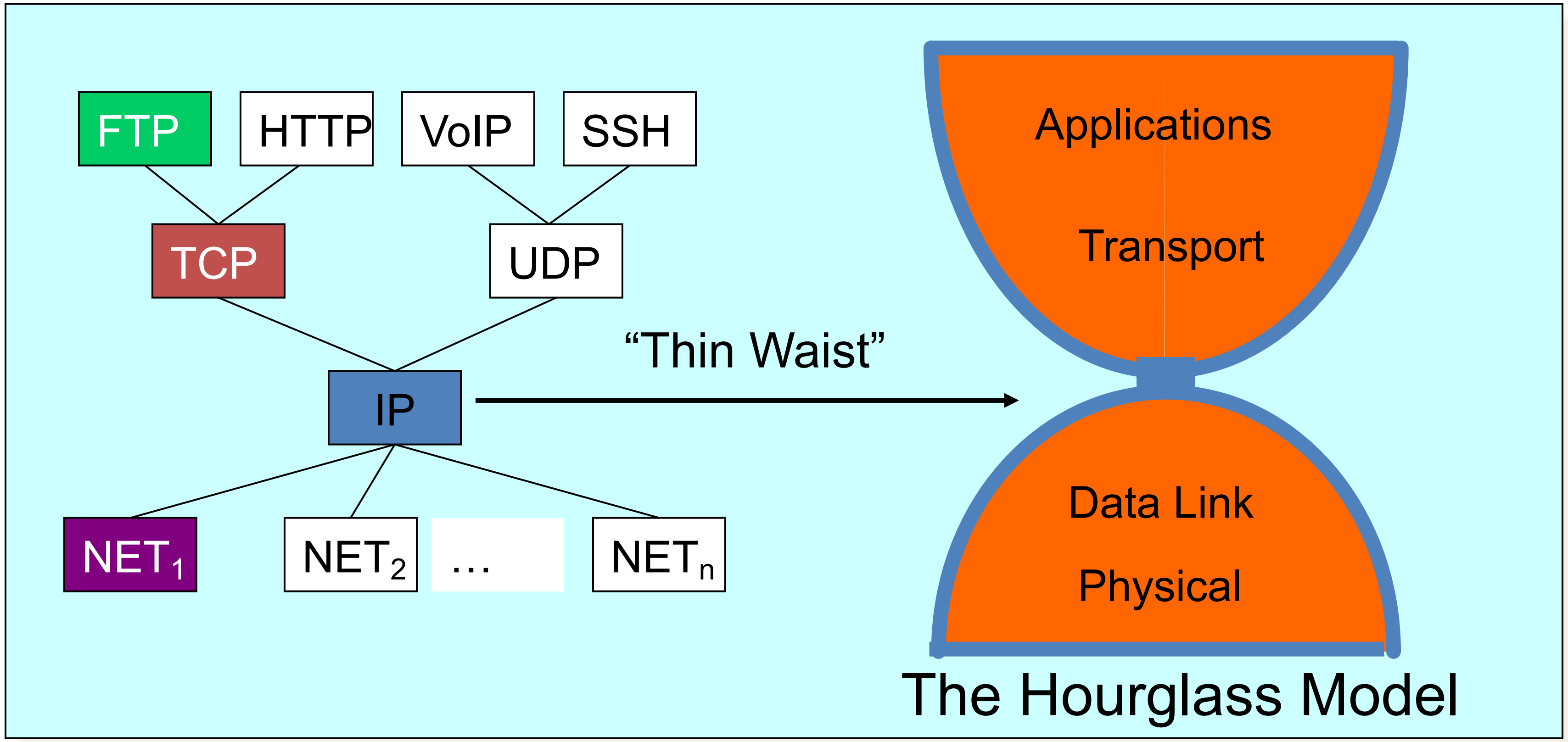
Transport: end-to-end connections, reliability

Network: routing

Link (data-link): framing, error detection

Physical: 1’s and 0’s/bits across a medium
(copper, the air, fiber)

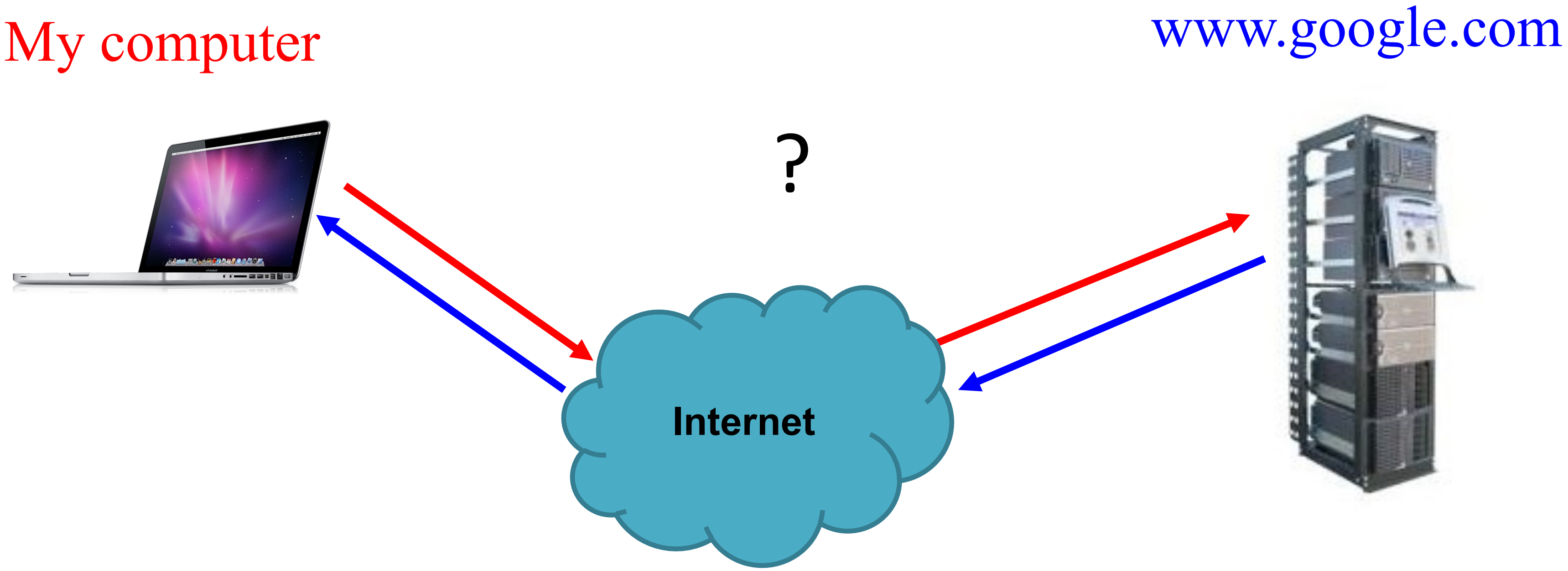
Internet Protocol Suite



The Hourglass Model

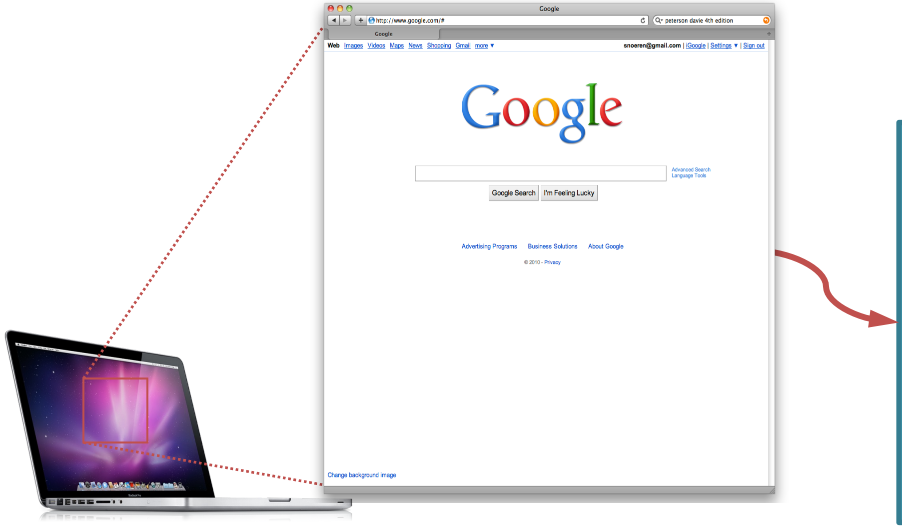
Putting this all together

- **ROUGHLY**, what happens when I click on a Web page from Swarthmore?



Application Layer: Web request (HTTP)

- Turn click into HTTP request



GET http://www.google.com/ HTTP/1.1
Host: www.google.com
…

Application Layer: Name resolution (DNS)

- Where is www.google.com?

My computer
(132.239.9.64)

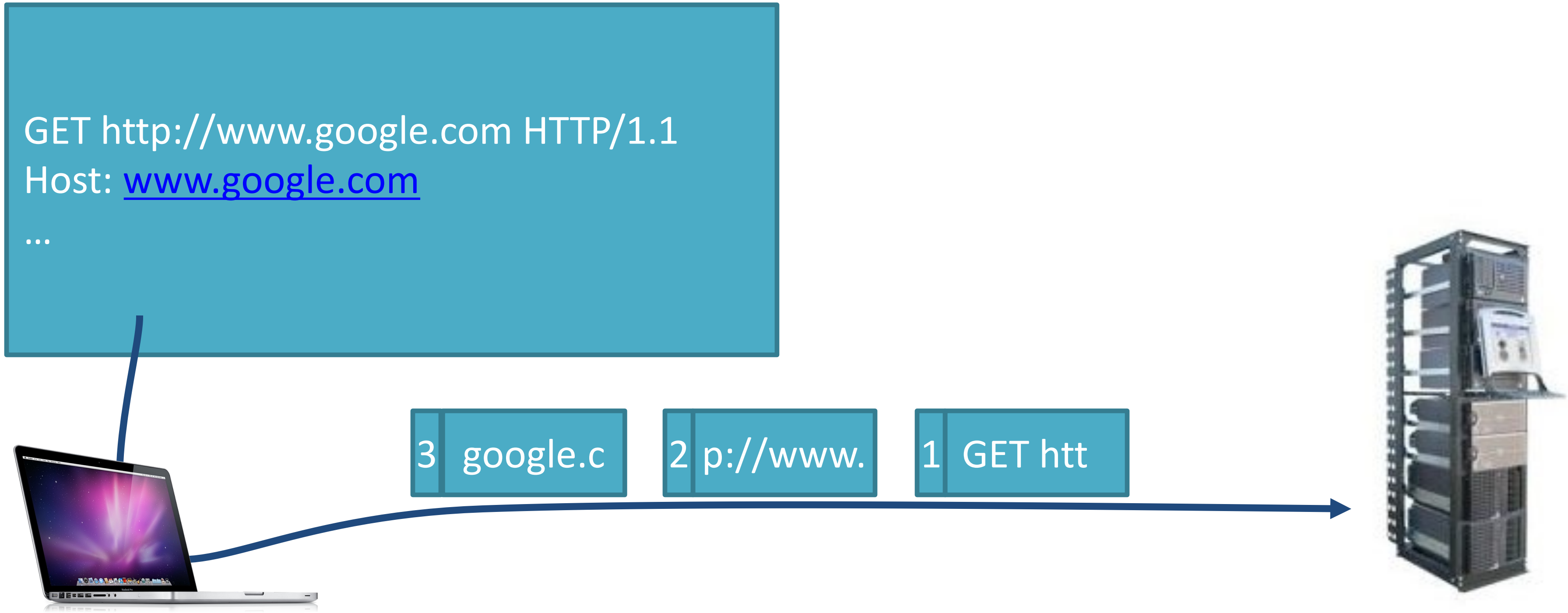
Local DNS server
(132.239.51.18)

What's the address for www.google.com

Oh, you can find it at 66.102.7.104

Transport Layer: TCP

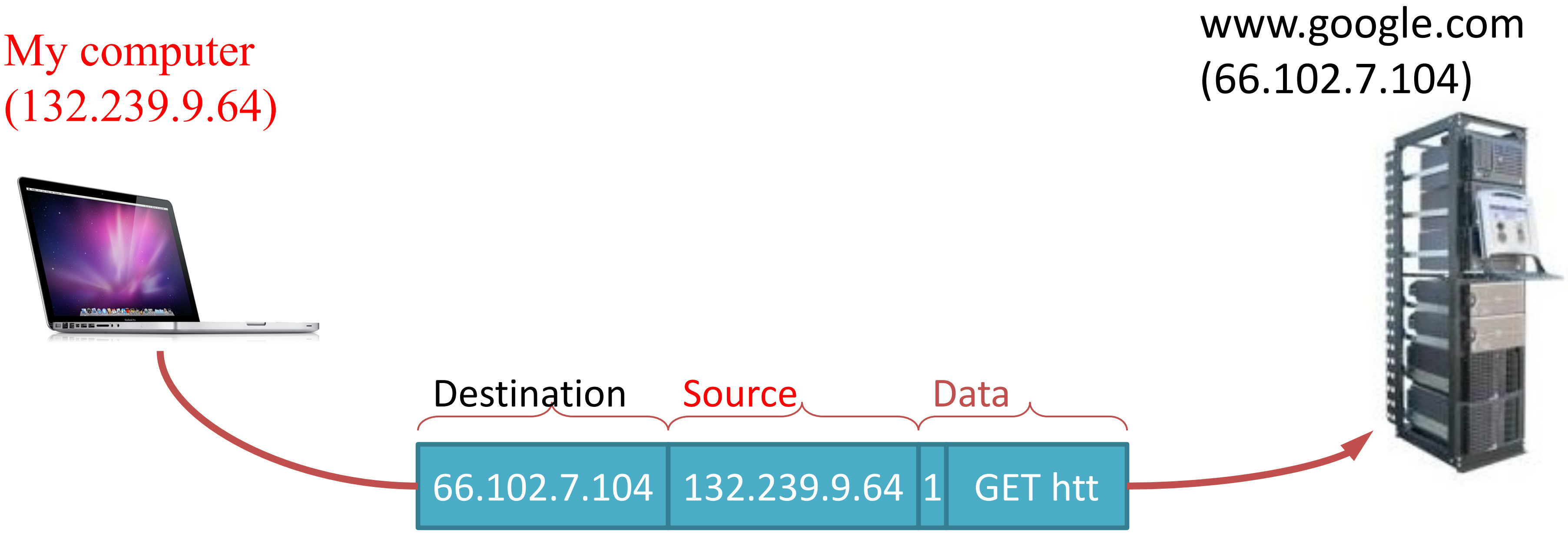
- Break message into packets (TCP segments)
- Should be delivered reliably & in-order



GET http://www.google.com HTTP/1.1
Host: www.google.com
…

Network Layer: Global Network Addressing

- Address each packet so it can traverse network and arrive at host



My computer
(132.239.9.64)

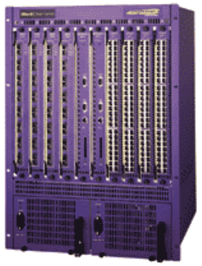
www.google.com
(66.102.7.104)

Destination Source Data

66.102.7.104 | 132.239.9.64 | 1 | GET htt

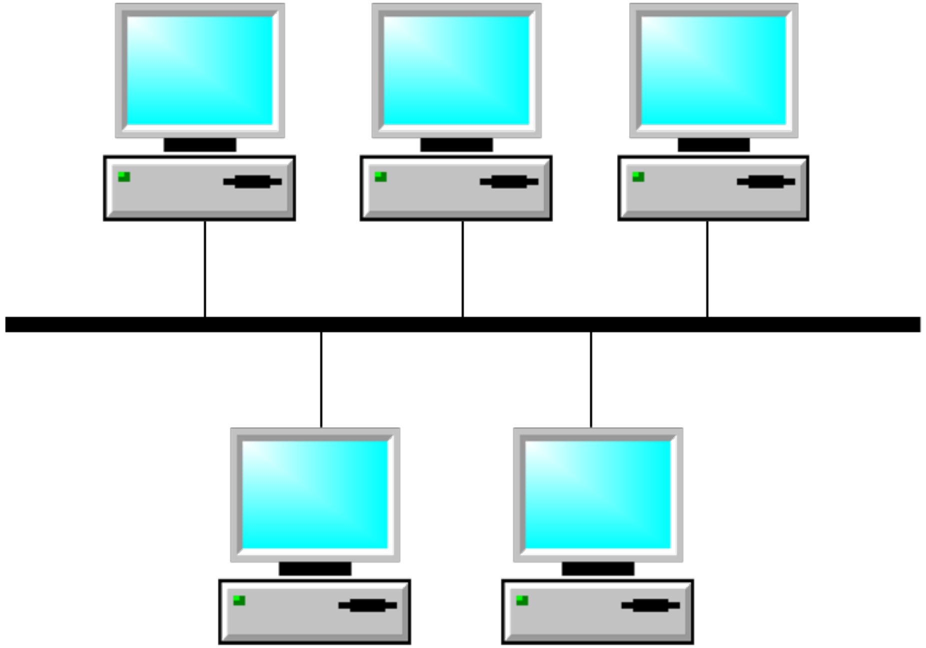
Network Layer: (IP) At Each Router

- Where do I send this to get it closer to Google?
- Which is the best route to take?

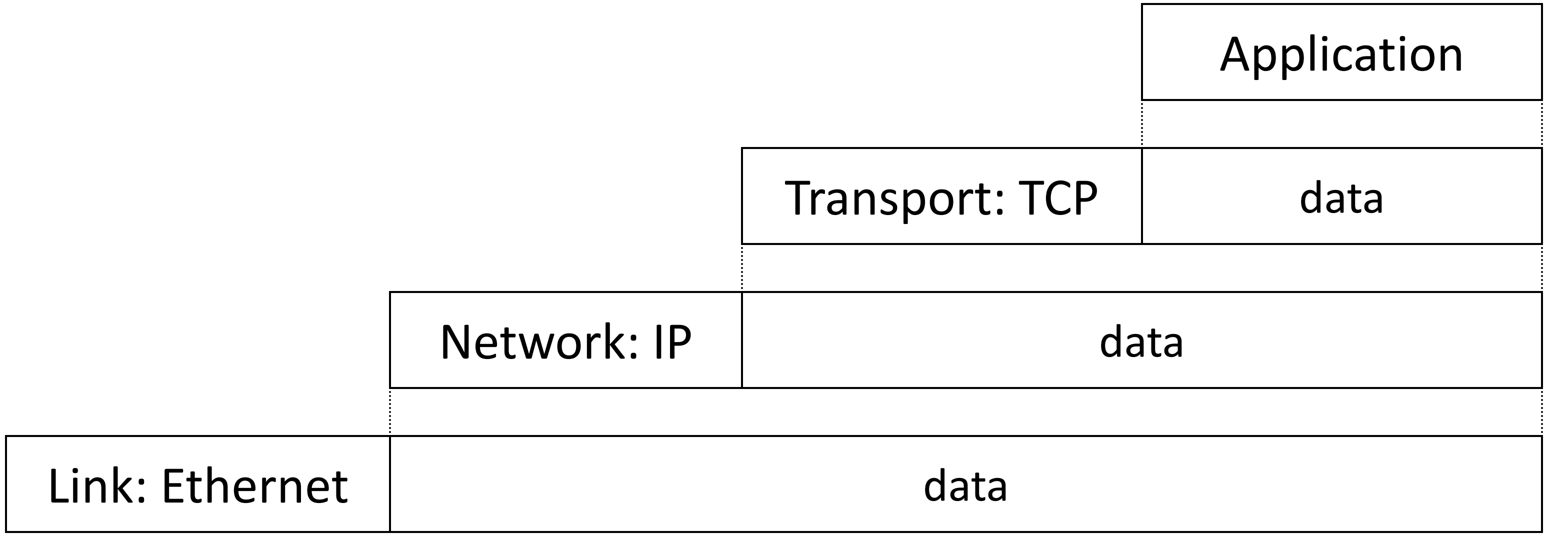


Link & Physical Layers (Ethernet)

- Forward to the next node!
- Share the physical medium.
- Detect errors.



Message Encapsulation



Application

Transport: TCP | data

Network: IP | data

Link: Ethernet | data

- Higher layer within lower layer
- Each layer has different concerns, provides abstract services to those above

Five-Layer Internet Model

Application: the application (e.g., the Web, Email)

Transport: end-to-end connections, reliability

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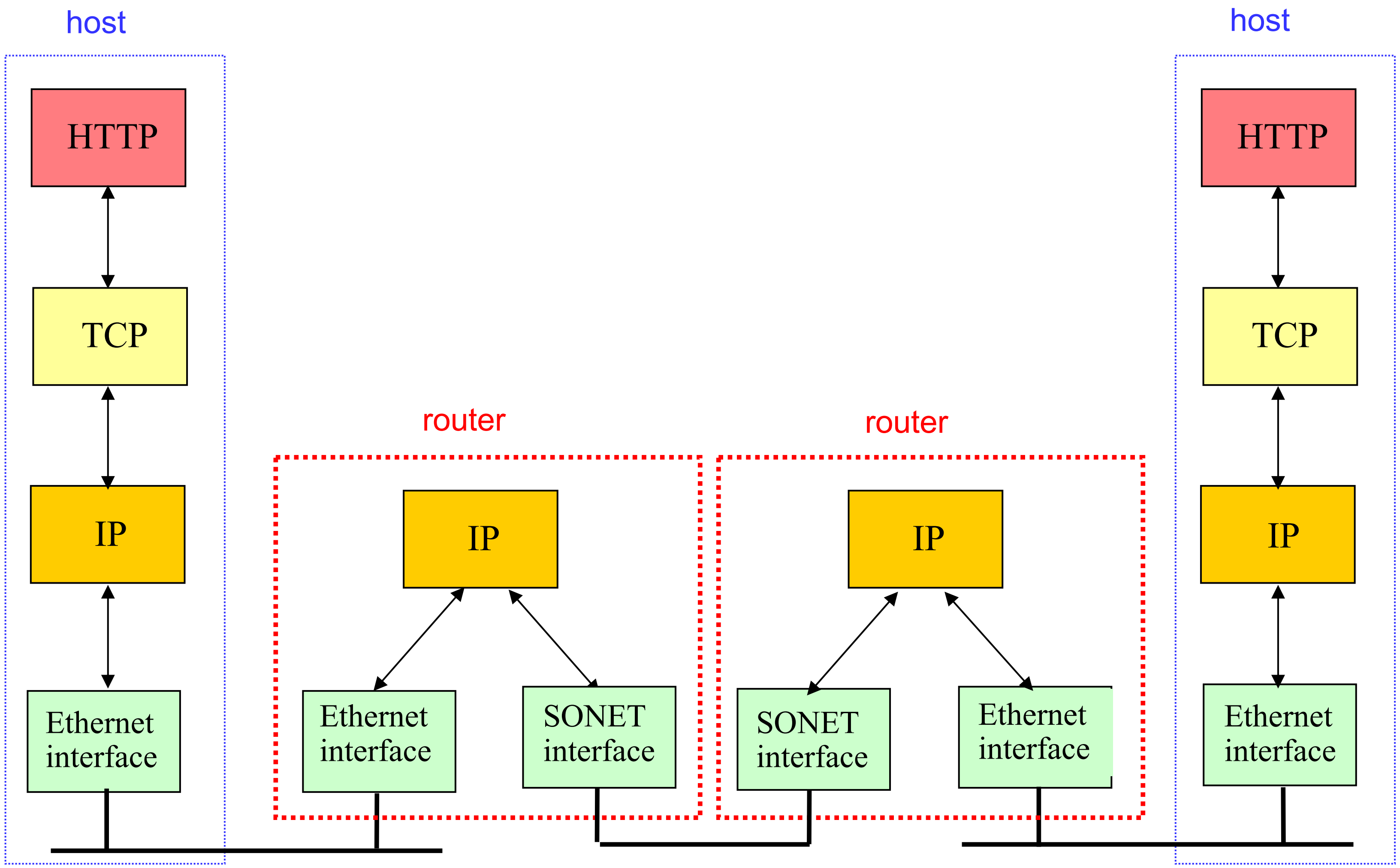
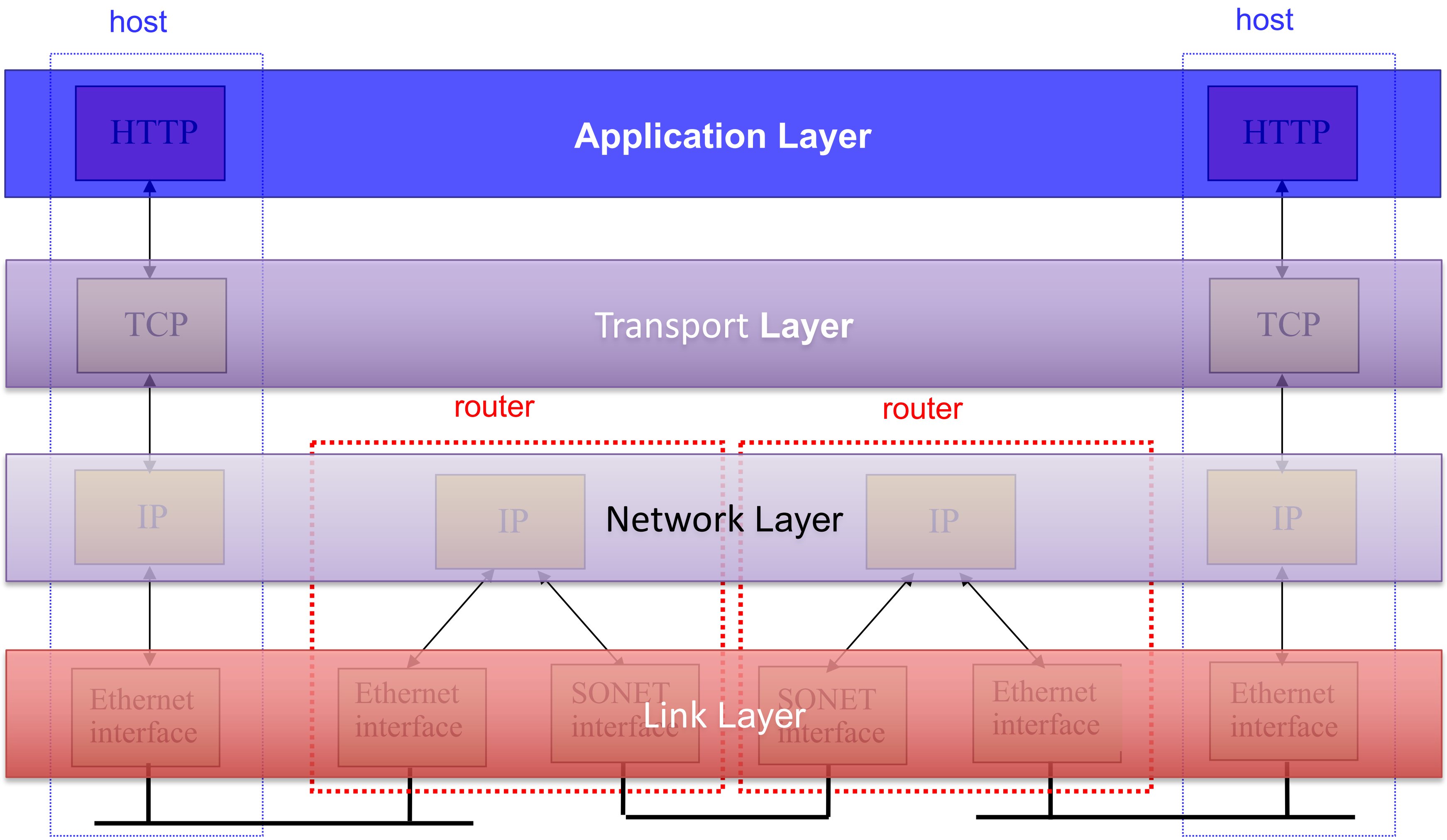
TCP/IP Protocol Stack



TCP/IP Protocol Stack



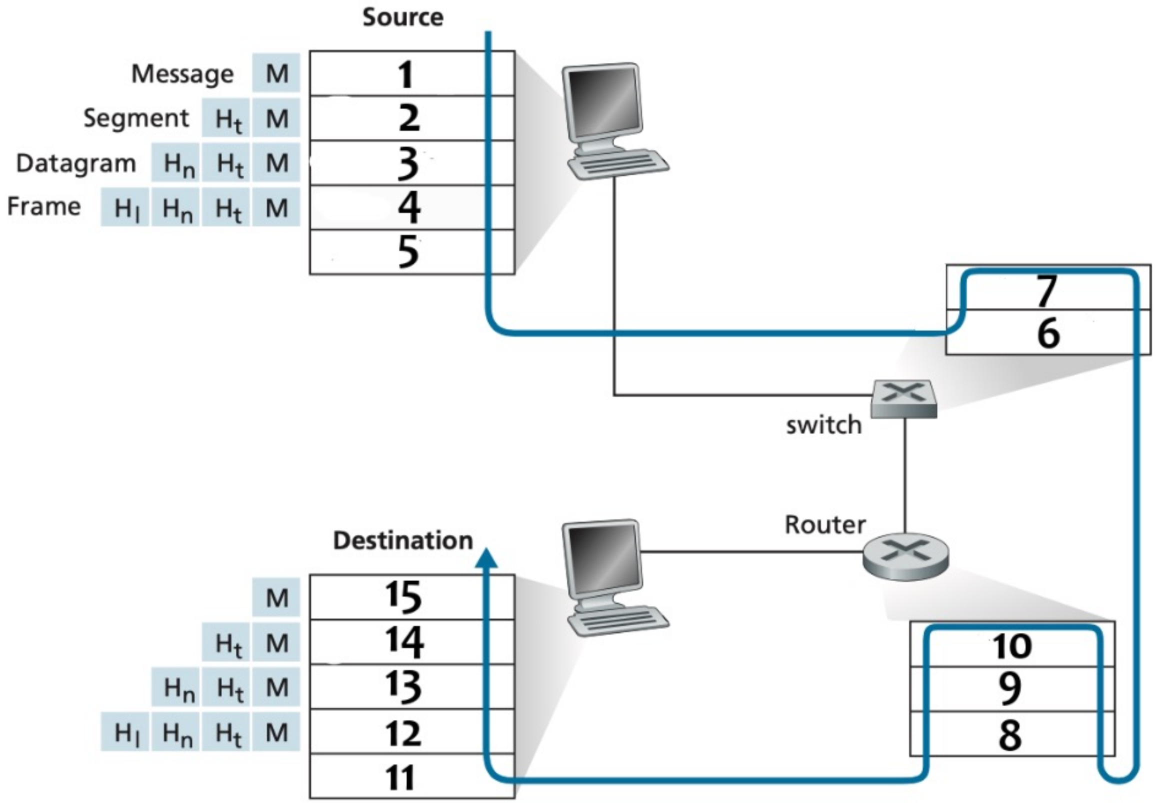
Worksheet

THE NETWORK PROTOCOL STACK AND PROTOCOL LAYERING

In the scenario below, imagine that you're sending an http request to another machine somewhere on the network.

- Application
- Transport
- Network
- Link
- Physical

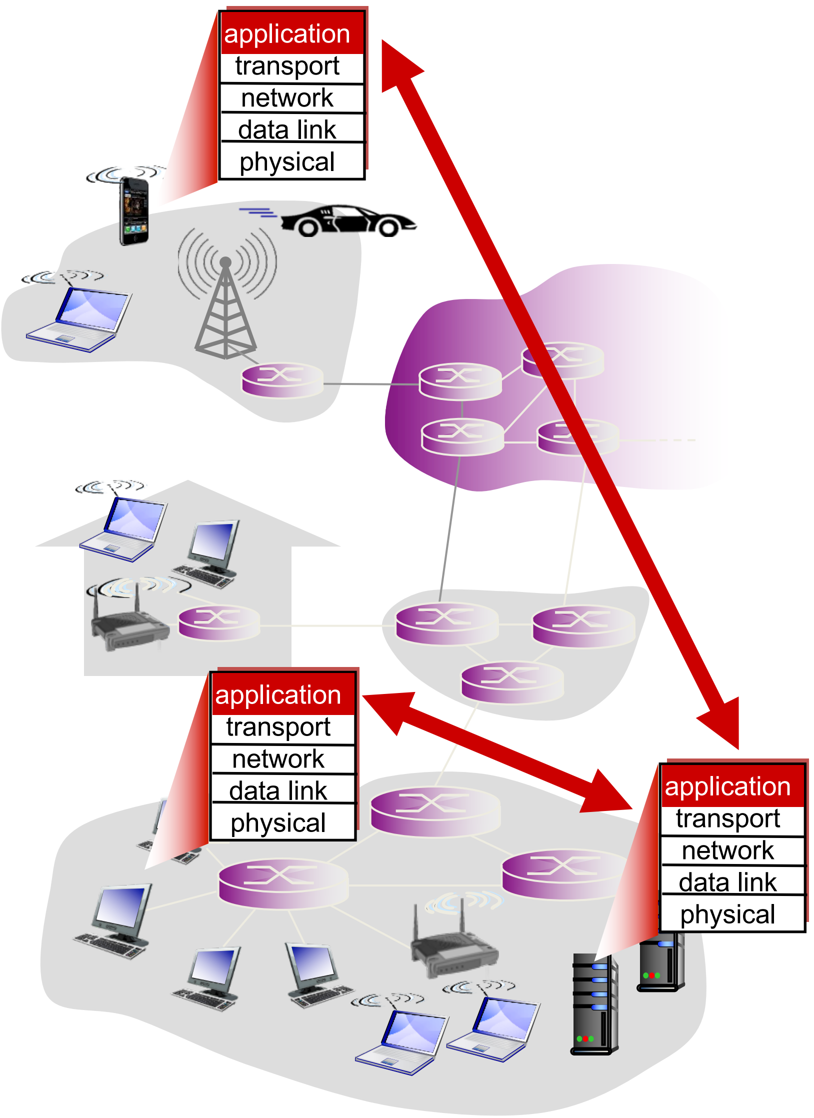
Five-layer Internet protocol stack



Creating a network app

write programs that:

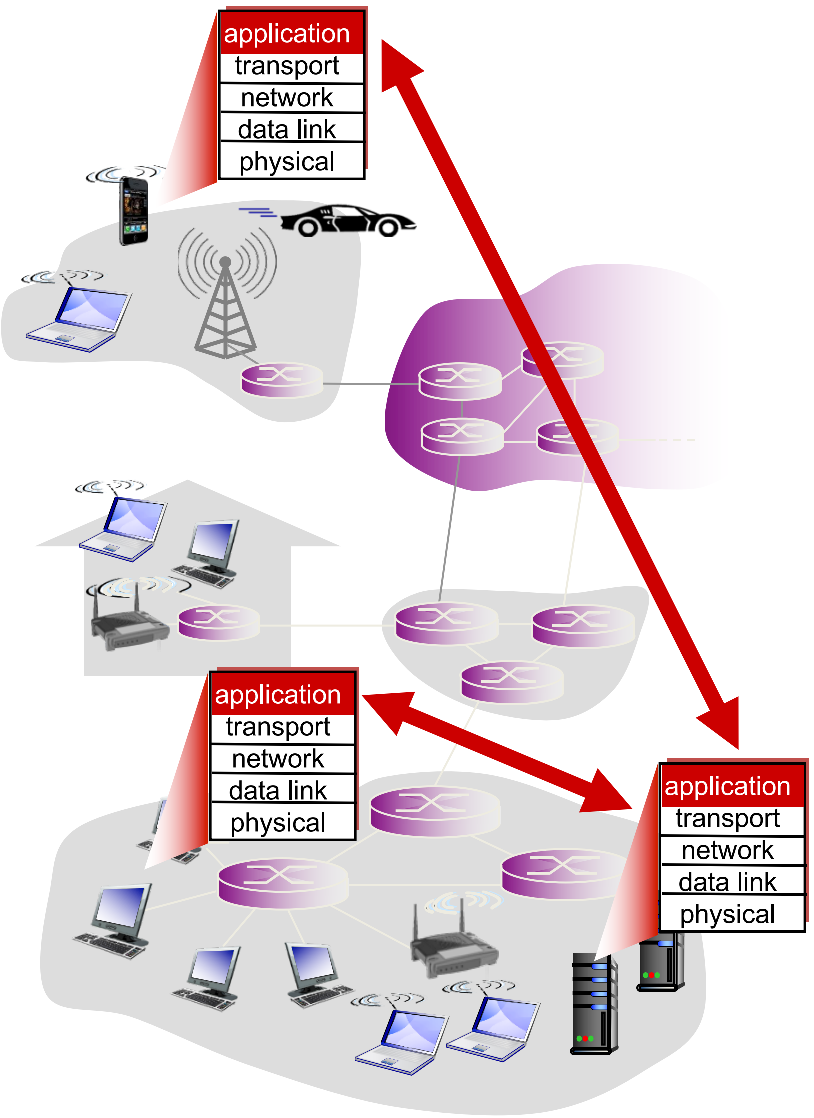
- run on (different) *end systems*
- communicate over network
- e.g., web server s/w communicates with browser software



Creating a network app

no need to write software for network-core devices!

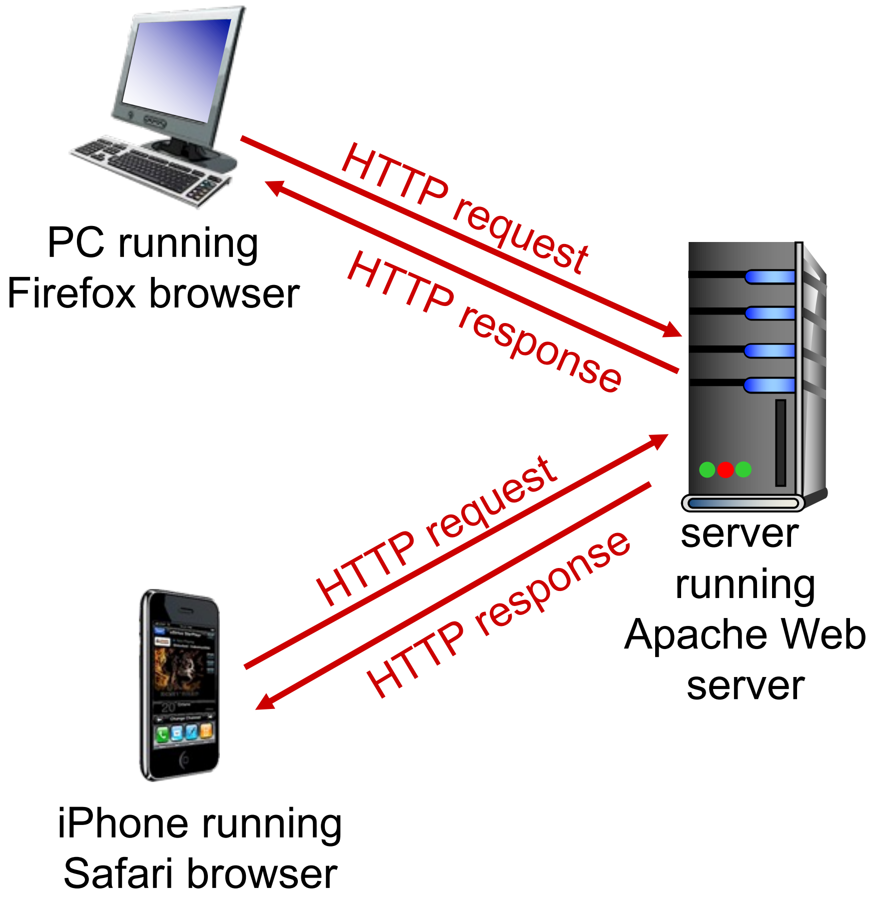
- network-core devices do not run user applications
- applications on end systems
  - rapid app development, propagation



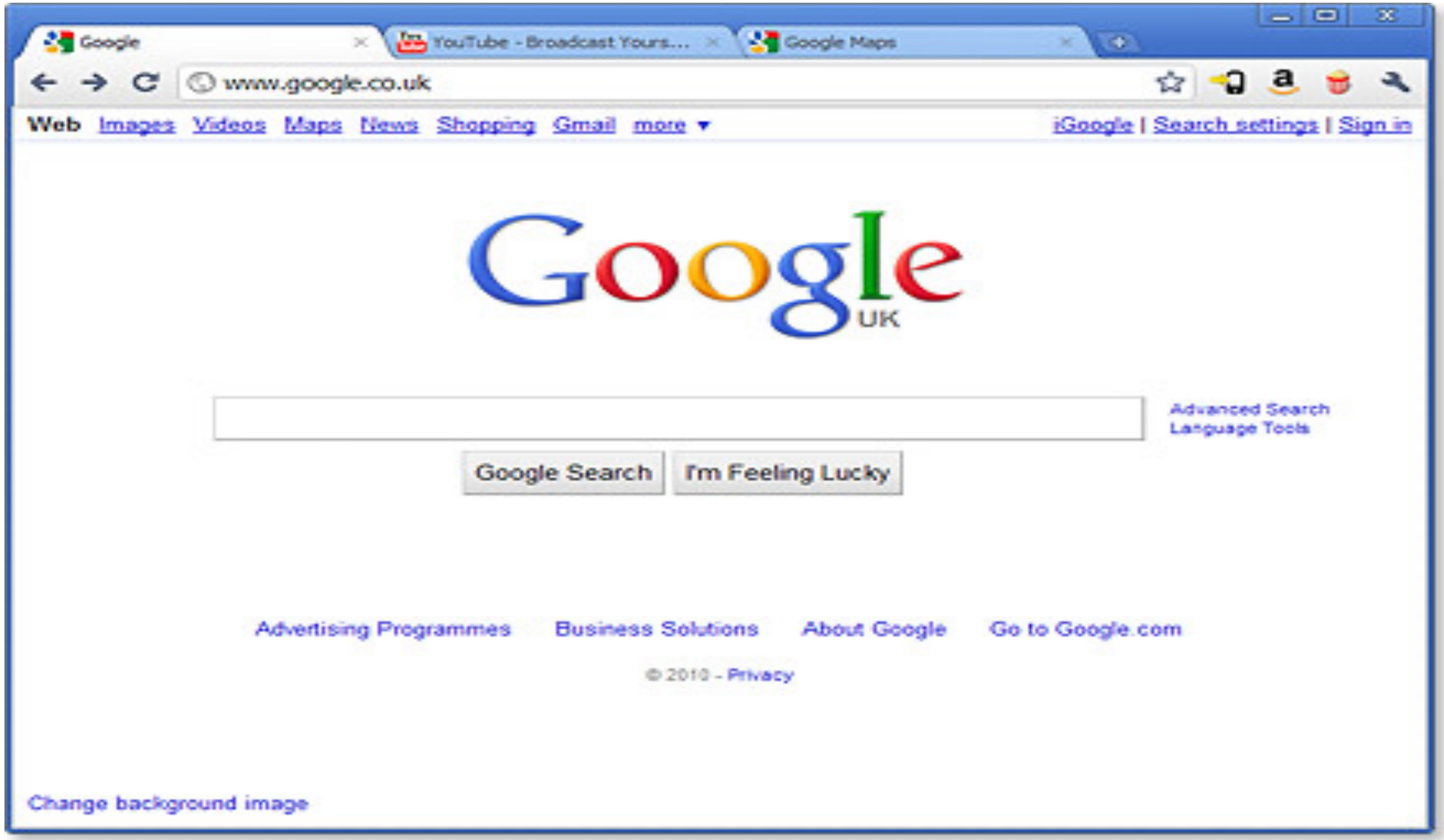
HTTP: HyperText Transfer Protocol

Client/Server model

- client: browser that uses HTTP to request, and receive Web objects.
- server: Web server that uses HTTP to respond with requested object.



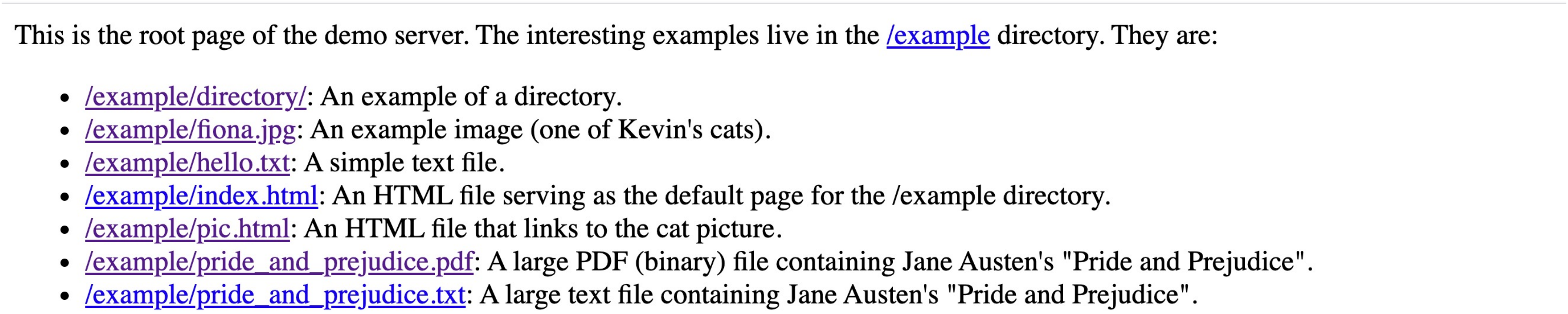
What IS A Web Browser?



HTTP and the Web

- web page consists of objects
- object can be: an HTML file (index.html)

demo.cs.swarthmore.edu/index.html

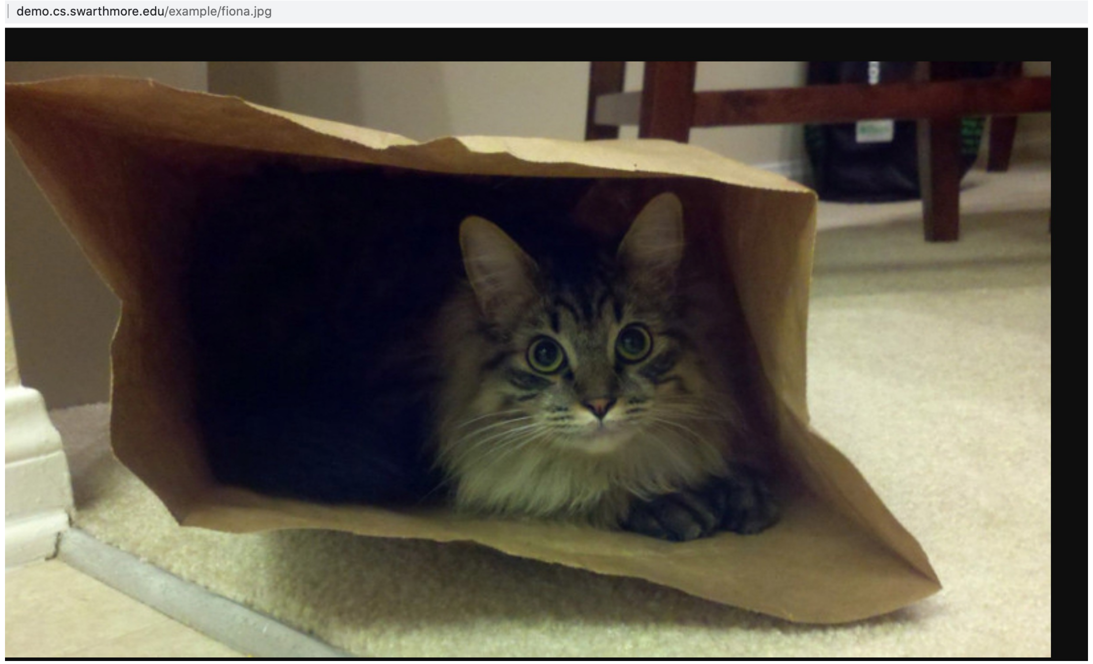


This is the root page of the demo server. The interesting examples live in the /example directory. They are:

- /example/directory/: An example of a directory.
- /example/fiona.jpg: An example image (one of Kevin's cats).
- /example/hello.txt: A simple text file.
- /example/index.html: An HTML file serving as the default page for the /example directory.
- /example/pic.html: An HTML file that links to the cat picture.
- /example/pride_and_prejudice.pdf: A large PDF (binary) file containing Jane Austen's "Pride and Prejudice".
- /example/pride_and_prejudice.txt: A large text file containing Jane Austen's "Pride and Prejudice".

Web objects

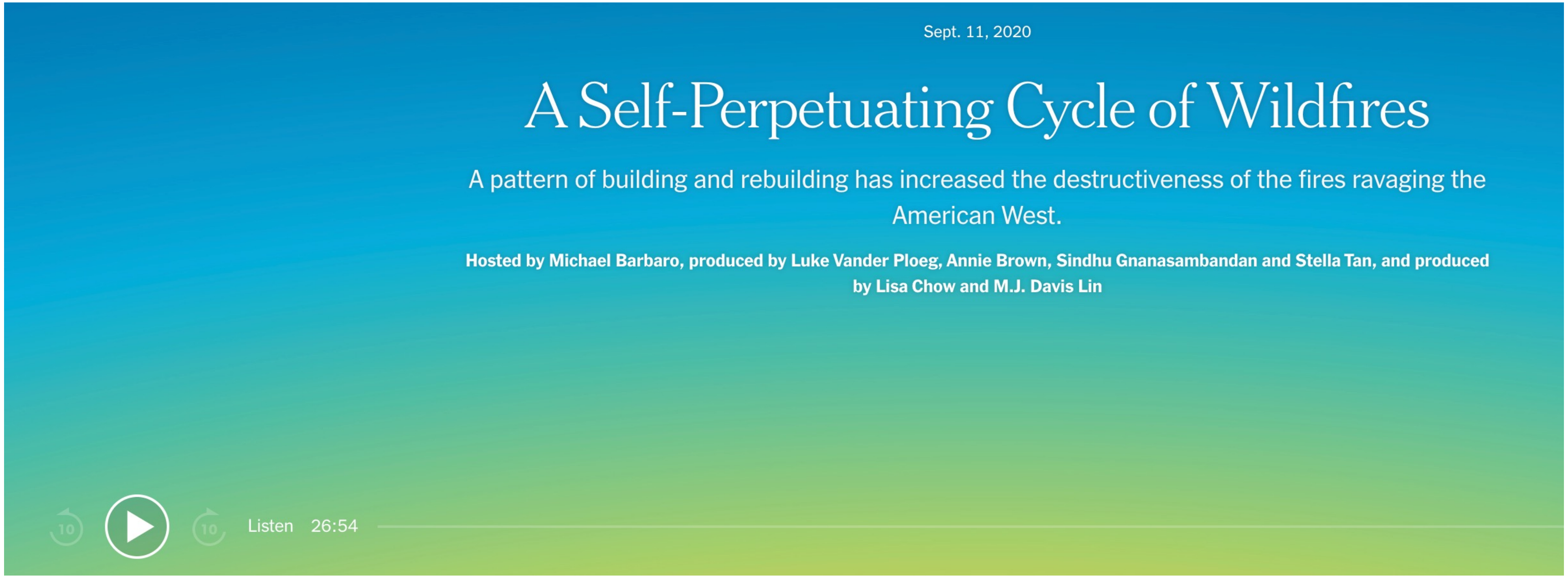
- web page consists of objects
- object can be: JPEG image



demo.cs.swarthmore.edu/example/fiona.jpg

Web objects

- web page consists of objects
- object can be: audio file



Sept. 11, 2020

A Self-Perpetuating Cycle of Wildfires

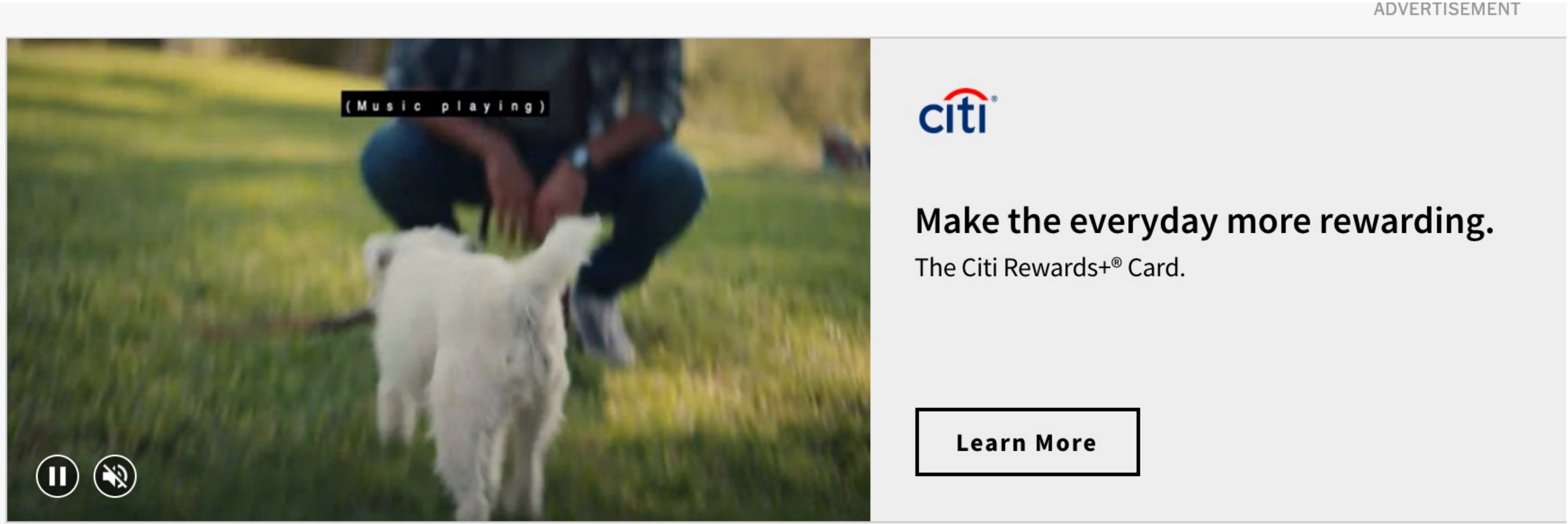
A pattern of building and rebuilding has increased the destructiveness of the fires ravaging the American West.

Hosted by Michael Barbaro, produced by Luke Vander Ploeg, Annie Brown, Sindhu Gnanasambandan and Stella Tan, and produced by Lisa Chow and M.J. Davis Lin

Courtesy: New York Times

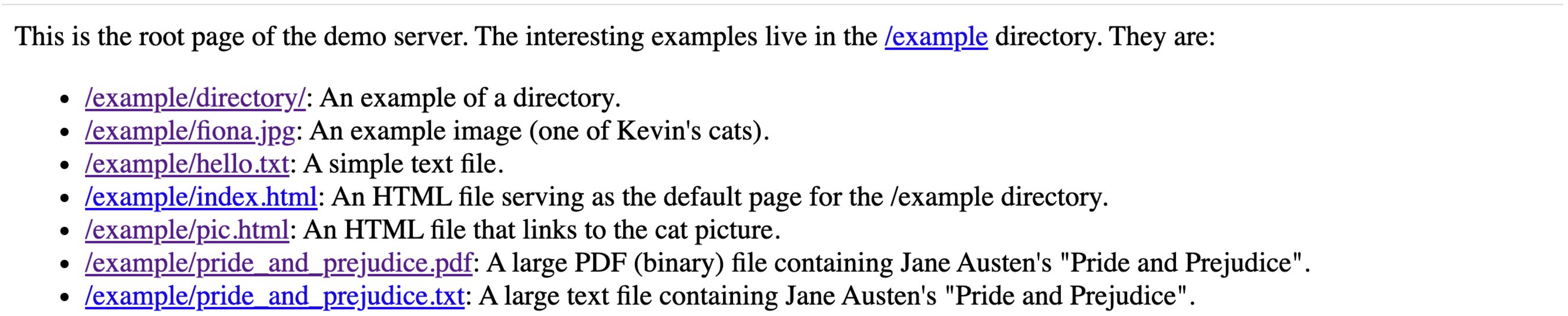
Web objects

- web page consists of objects
- object can be: video, java applets, etc.



HTTP and the Web

- a web page consists of base HTML-file which includes several referenced objects
- each object is addressable by a URL, e.g.,



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- /example/pride_and_prejudice.txt: A large text file containing Jane Austen's "Pride and Prejudice".

$$\underbrace{\texttt{demo.cs.swarthmore.edu}}_{\text{host name}}\texttt{/}\underbrace{\texttt{example/pic.html}}_{\text{path name}}$$

HTTP Overview

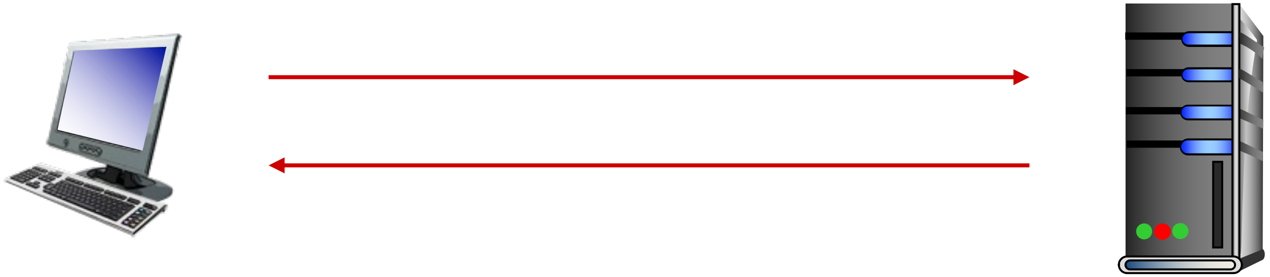
1. User types in a URL.

http://some.host.name.tld/directory/name/file.ext

host name

path name

HTTP Overview



2. Browser establishes connection with server using the Sockets API.

    Calls socket()   // create a socket
    Looks up "some.host.name.tld" (DNS: getaddrinfo)
    Calls connect() // connect to remote server
    Ready to call send() // Can now send HTTP requests

HTTP Overview

3. Browser requests data the user asked for

GET /directory/name/file.ext HTTP/1.0

Host: some.host.name.tld

Required fields

[other optional fields, for example:]

User-agent: Mozilla/5.0 (Windows NT 6.1; WOW64)

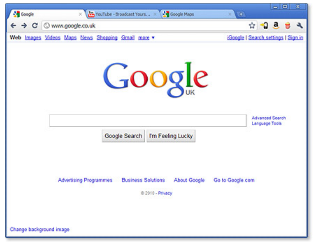
Accept-language: en

HTTP Overview

4. Server responds with the requested data.

HTTP/1.0 200 OK
Content-Type: text/html
Content-Length: 1299
Date: Sun, 01 Sep 2013 21:26:38 GMT
[Blank line]
(Data data data data...)

HTTP Overview



5. Browser renders the response, fetches any additional objects, and closes the connection.

HTTP Overview

1. User types in a URL.
2. Browser establishes connection with server.
3. Browser requests the corresponding data.
4. Server responds with the requested data.
5. Browser renders the response, fetches other objects, and closes the connection.

It's a document retrieval system, where documents point to (link to) each other, forming a "web".

HTTP Overview (Lab 1)

1. User types in a URL.
2. Browser establishes connection with server.
3. Browser requests the corresponding data.
4. Server responds with the requested data.
5. ~~Browser renders the response, fetches other objects,~~ Save the file and close the connection.

It’s a document retrieval system, where documents point to (link to) each other, forming a “web”.

Trying out HTTP (client side) for yourself

1. Telnet to your favorite Web server:

```
telnet demo.cs.swarthmore.edu 80
```

Opens TCP connection to port 80 (default HTTP server port) at example server.

Anything typed is sent to server on port 80 at demo.cs.swarthmore.edu

Trying out HTTP (client side) for yourself

2. Type in a GET HTTP request:

(Hit carriage
return twice) This
is a minimal, but complete,
GET request to the HTTP
server.

```
GET / HTTP/1.1
Host: demo.cs.swarthmore.edu
(blank line)
```

3. Look at response message sent by HTTP server!

Example

```
$ telnet demo.cs.swarthmore.edu 80
Trying 130.58.68.26...
Connected to demo.cs.swarthmore.edu.
Escape character is '^]'.
GET / HTTP/1.1
Host: demo.cs.swarthmore.edu

HTTP/1.1 200 OK
Vary: Accept-Encoding
Content-Type: text/html
Accept-Ranges: bytes
ETag: "316912886"
Last-Modified: Wed, 04 Jan 2017 17:47:31 GMT
Content-Length: 1062
Date: Wed, 05 Sep 2018 17:27:34 GMT
Server: lighttpd/1.4.35
```

Response headers

Example

```
$ telnet demo.cs.swarthmore.edu 80
Trying 130.58.68.26...
Connected to demo.cs.swarthmore.edu.
Escape character is '^]'.
GET / HTTP/1.1
Host: demo.cs.swarthmore.edu
```

Response
headers

```
<html><head><title>Demo Server</title></head>
<body>
.....
</body>
</html>
```

Response
body
(This is what you
should be saving in
lab 1.)

HTTP request message

- two types of HTTP messages: **request, response**
- **HTTP request message:** ASCII (human-readable format)

carriage return character

line-feed character

request line (GET, POST, HEAD, etc. commands)

variable # header lines

two carriage return, line feed characters

```
GET /index.html HTTP/1.0\r\n
Host: web.cs.swarthmore.edu\r\n
User-Agent: Firefox/3.6.10\r\n
Accept: text/html,application/xhtml+xml\r\n
Accept-Language: en-us,en;q=0.5\r\n
Accept-Encoding: gzip,deflate\r\n
Accept-Charset: ISO-8859-1,utf-8;q=0.7\r\n
Keep-Alive: 115\r\n
Connection: keep-alive\r\n
\r\n
```

HTTP response message

```
HTTP/1.1 200 OK\r\n
Date: Sun, 26 Sep 2010 20:09:20 GMT\r\n
Server: Apache/2.0.52 (CentOS)\r\n
Last-Modified: Tue, 30 Oct 2007 17:00:02 GMT\r\n
ETag: "17dc6-a5c-bf716880"\r\n
Accept-Ranges: bytes\r\n
Content-Length: 2652\r\n
Keep-Alive: timeout=10, max=100\r\n
Connection: Keep-Alive\r\n
Content-Type: text/html; charset=ISO-8859-1\r\n
\r\n
data data data data data ...
```

status line
(protocol
status code
status phrase)

variable #
header
lines

two carriage return,
line feed characters

data, e.g., requested HTML file: may not be text!

HTTP response status codes

Status code appears in first line of server-to-client response message.

200 OK

- Request succeeded, requested object later in this msg

301 Moved Permanently

- Requested object moved, new location specified later in this msg (Location:)

400 Bad Request

  - Request msg not understood by server

403 Forbidden

  - You don’t have permission to read the object

404 Not Found

  - Requested document not found on this server

505 HTTP Version Not Supported

HTTP response status codes

Status code appears in first line of server-to-client response message.

Many others! Search “list of HTTP status codes”

420 Enhance Your Calm (twitter)

- Slow down, you’re being rate limited

451 Unavailable for Legal Reasons

- Censorship?

418 I’m a Teapot

- Response from a teapot requested to brew a beverage (announced Apr 1)

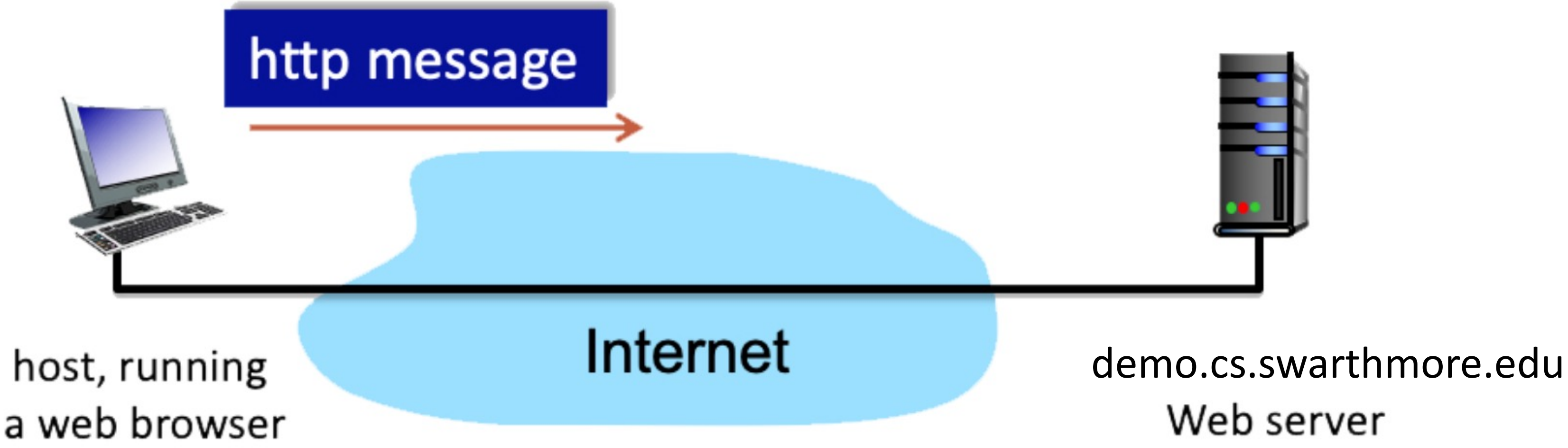
Client-Server communication

- Client:
  - initiates communication
  - must know the address and port of the server
  - active socket
- Server:
  - passively waits for and responds to clients
  - passive socket

Worksheet

THE HTTP GET MESSAGE

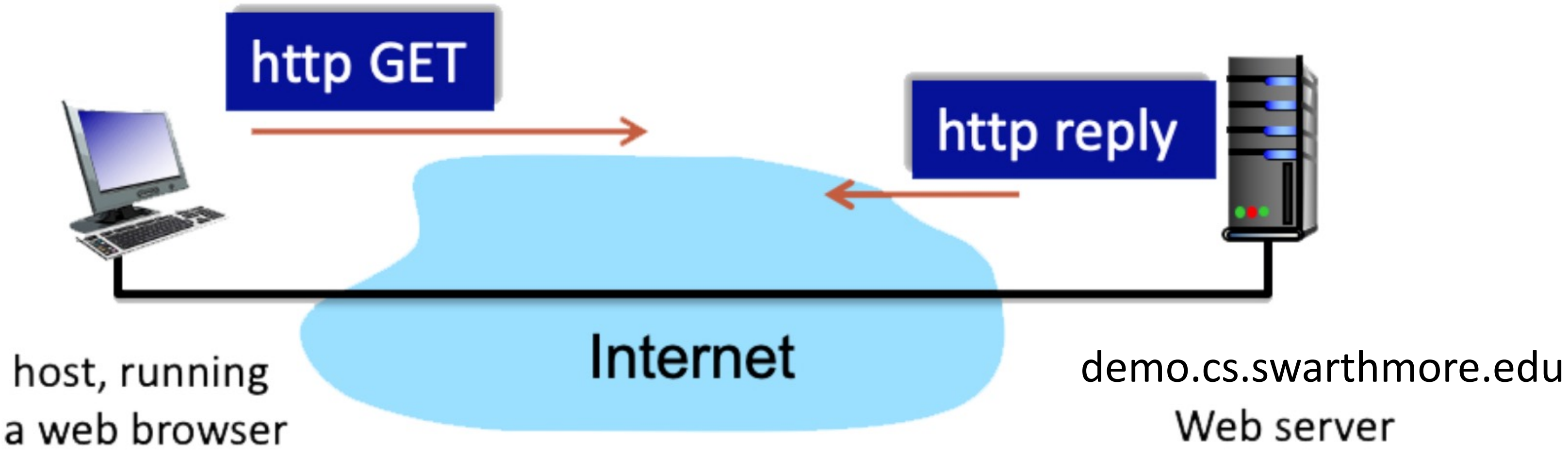
Consider the figure below, where a client is sending an HTTP GET message to a web server, gaia.cs.umass.edu



Worksheet

THE HTTP RESPONSE MESSAGE

Consider the figure below, where the server is sending a HTTP RESPONSE message back the client.



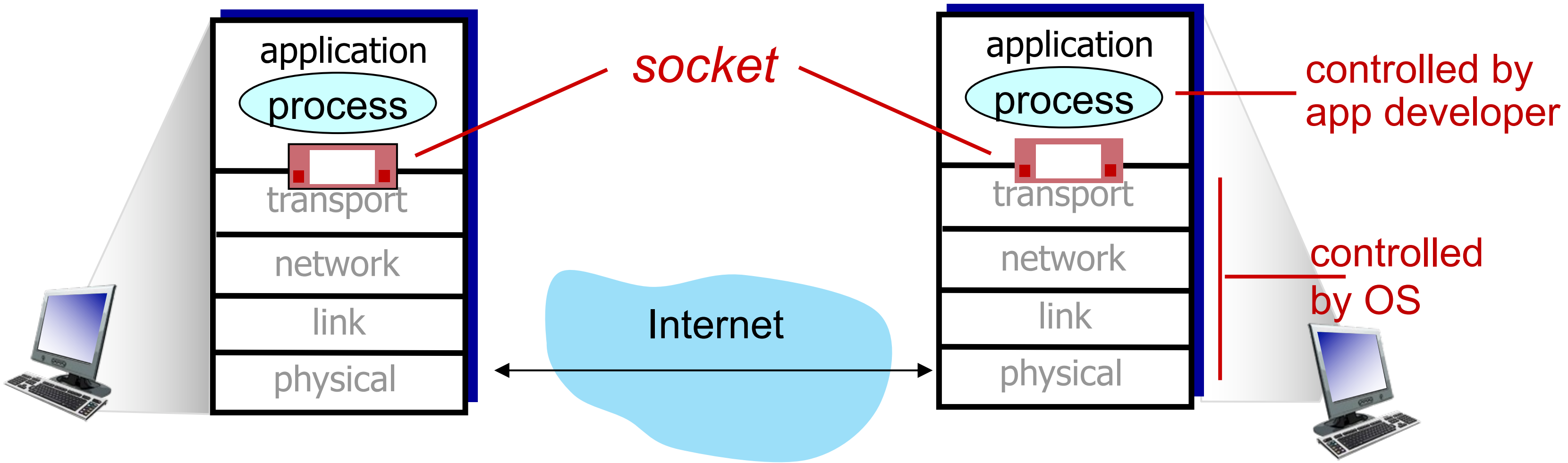
What is a socket?

An abstraction through which an application may send and receive data,

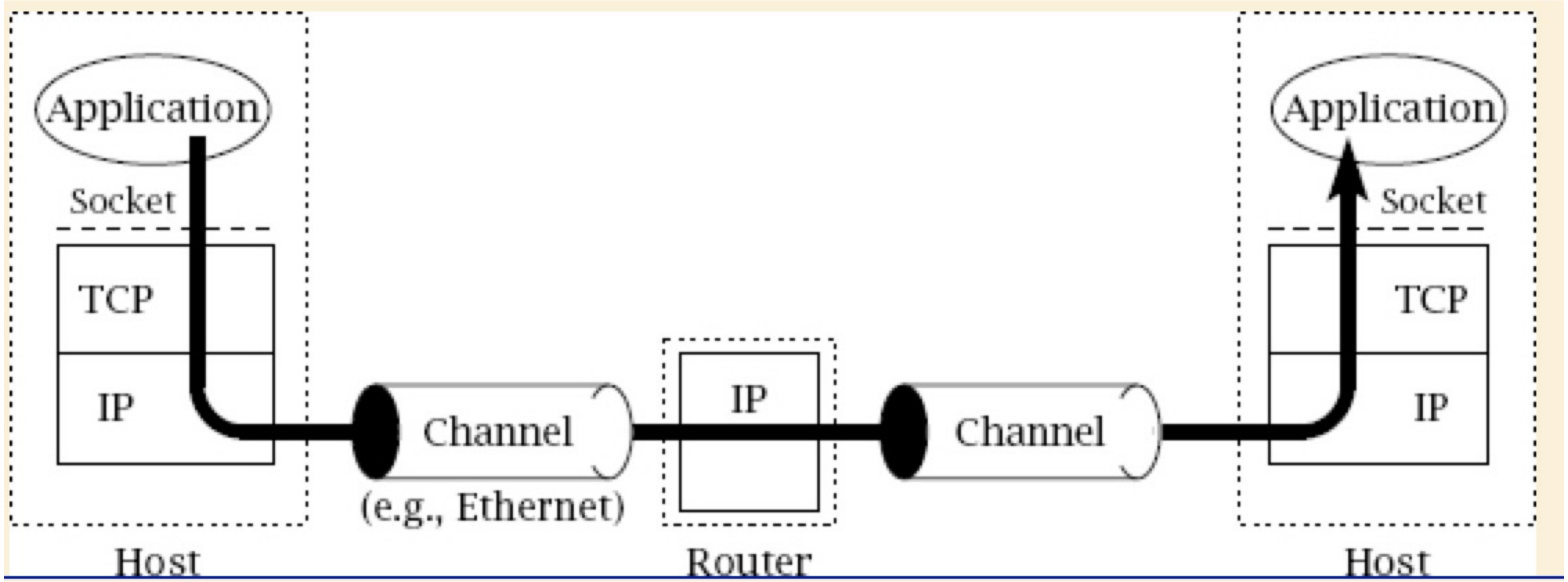
in the same way as a open-file handle allows an application to read and write data to storage.

Sockets

- process sends/receives messages to/from its socket
- socket analogous to door
  - sending process shoves message out door
  - sending process relies on transport infrastructure on other side of door to deliver message to socket at receiving process
  - two sockets involved: one on each side

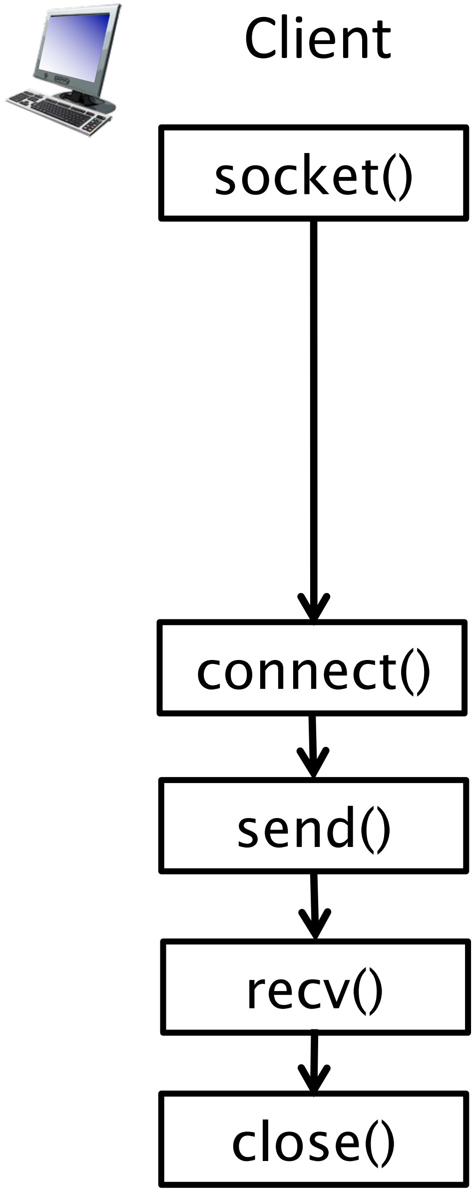


Socket Programming



Adapted from: Donahoo, Michael J., and Kenneth L. Calvert. TCP/IP sockets in C: practical guide for programmers. Morgan Kaufmann, 2009.

TCP Socket Procedures: Client



create a new communication endpoint

actively attempt to establish a connection

send some data over a connection

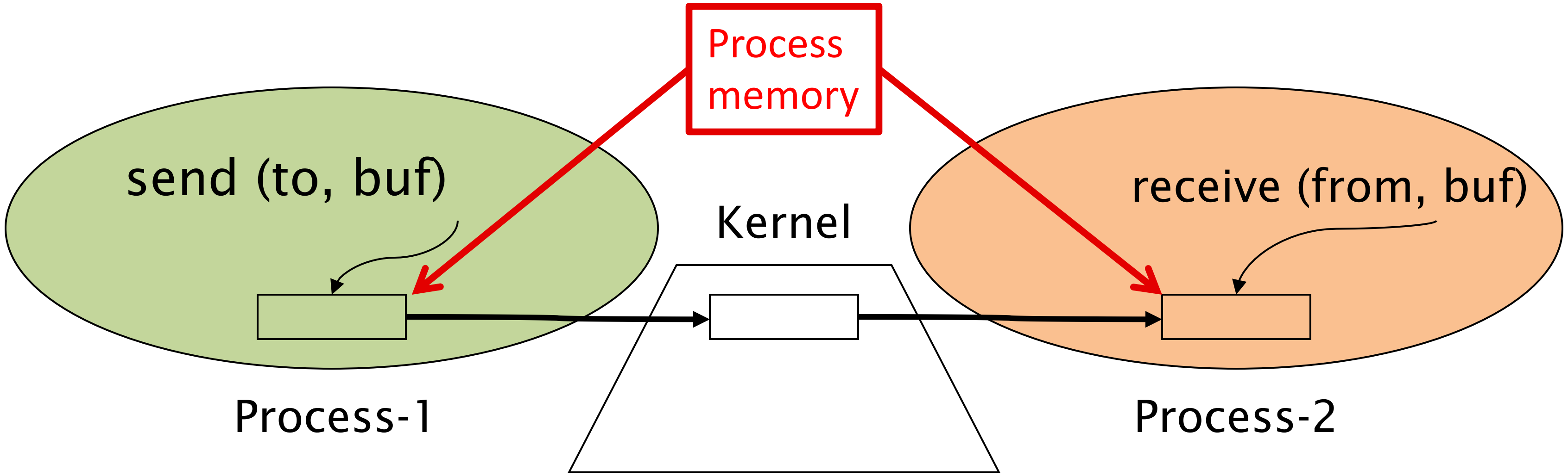
receive some data over a connection

release the connection

Recall Inter-process Communication (IPC)

- Processes must communicate to cooperate
- Must have two mechanisms:
  - Data transfer
  - Synchronization
- On a single machine:
  - Threads (shared memory)
  - Message passing

Message Passing (local)



- Operating system mechanism for IPC
  - send (destination, message_buffer)
  - receive (source, message_buffer)
- Data transfer: in to and out of kernel message buffers
- Synchronization

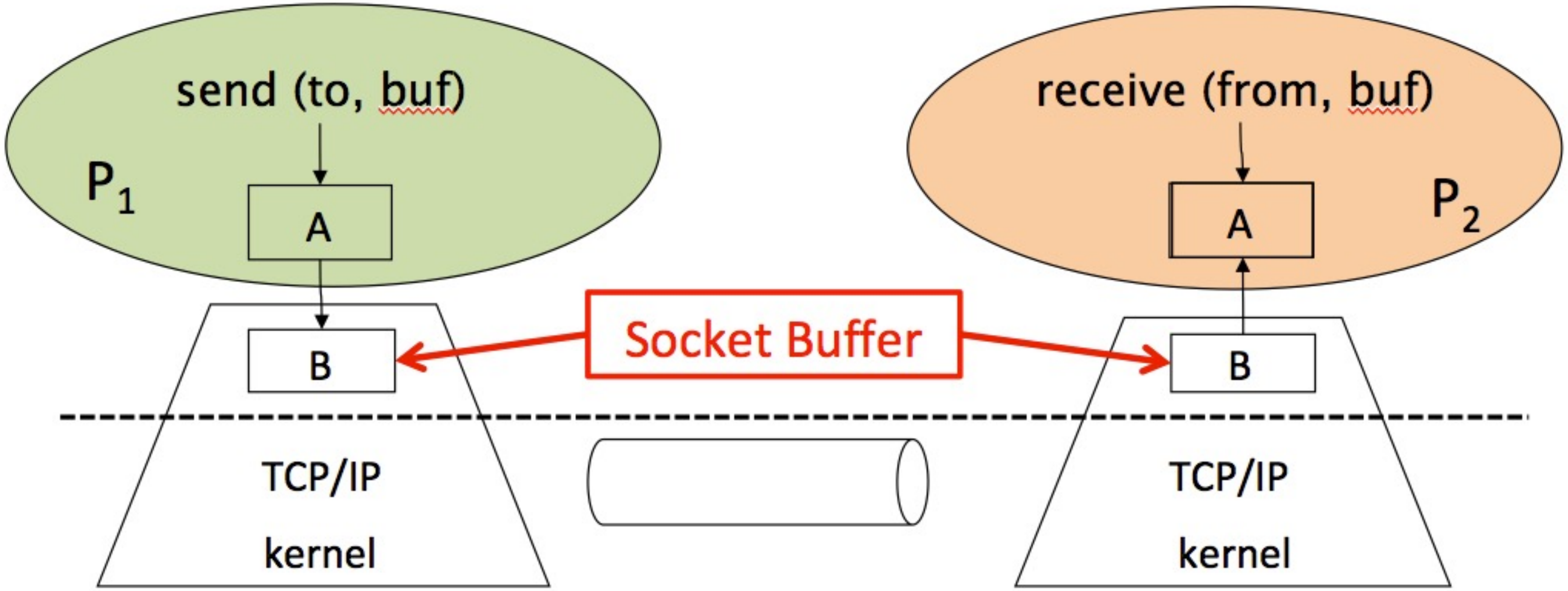
Interprocess Communication (non-local)

- Processes must communicate to cooperate

- Must have two mechanisms:
  - Data transfer
  - Synchronization

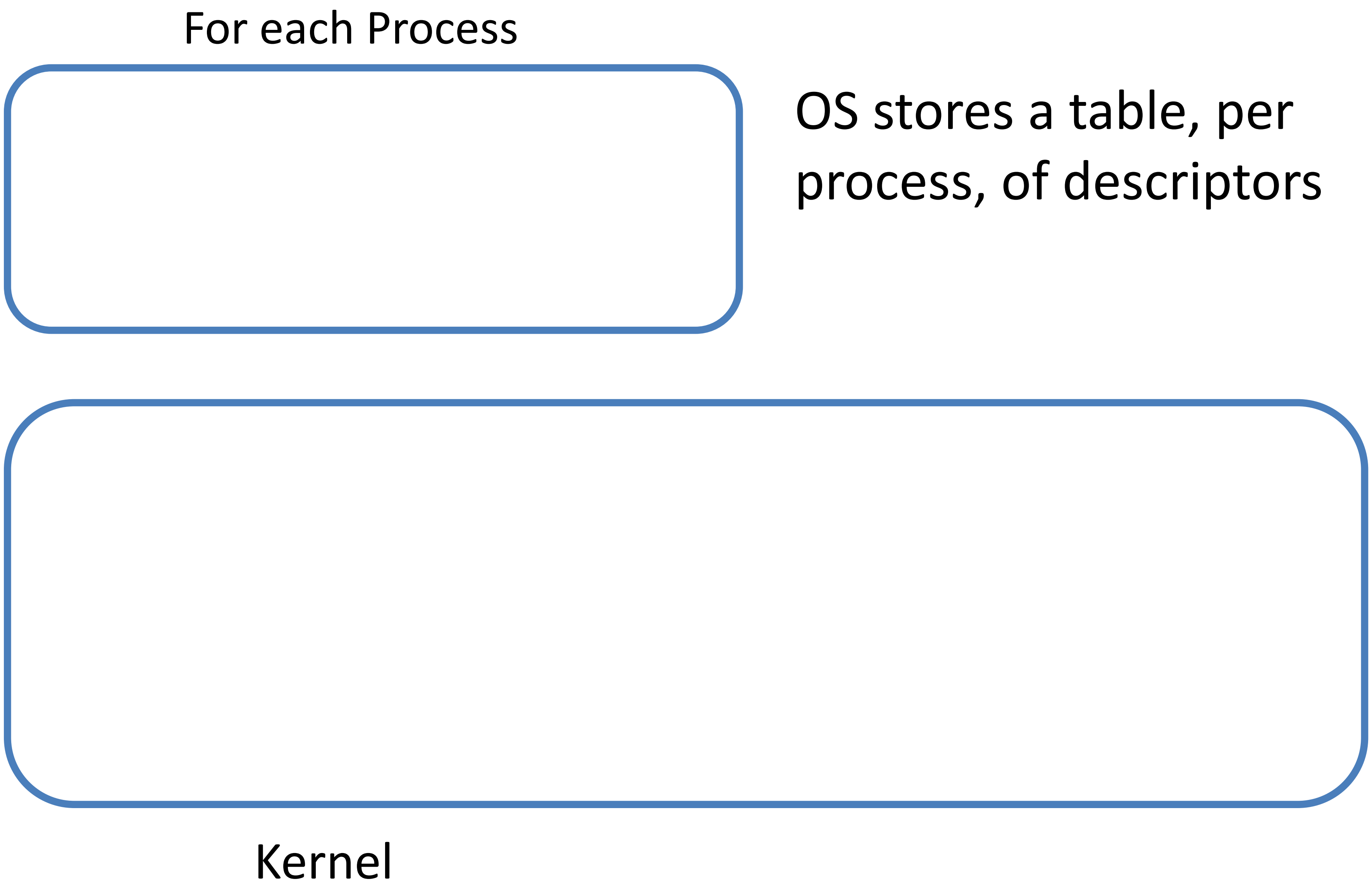
- Across a network:
  - Threads (shared memory) <u>NOT AN OPTION</u>!
  - Message passing

Message Passing (network)



- Same synchronization
- Data transfer
  - Copy to/from OS socket buffer
  - Extra step across network: hidden from applications

Descriptor Table

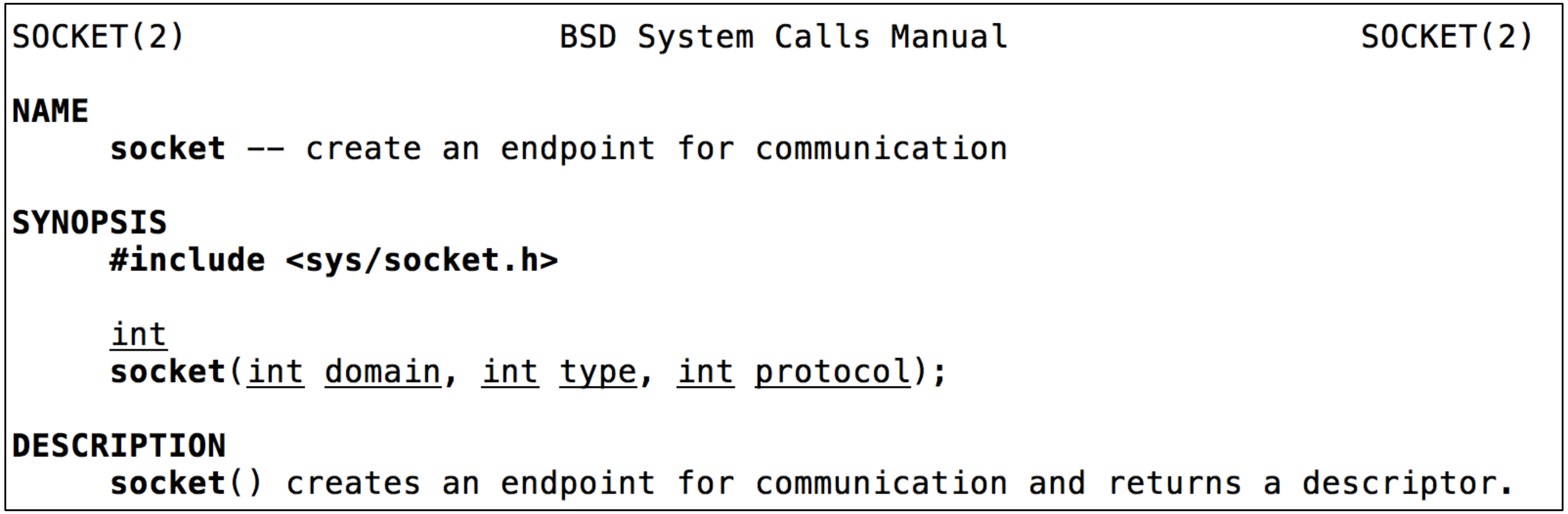


For each Process

Kernel

OS stores a table, per process, of descriptors

Descriptors



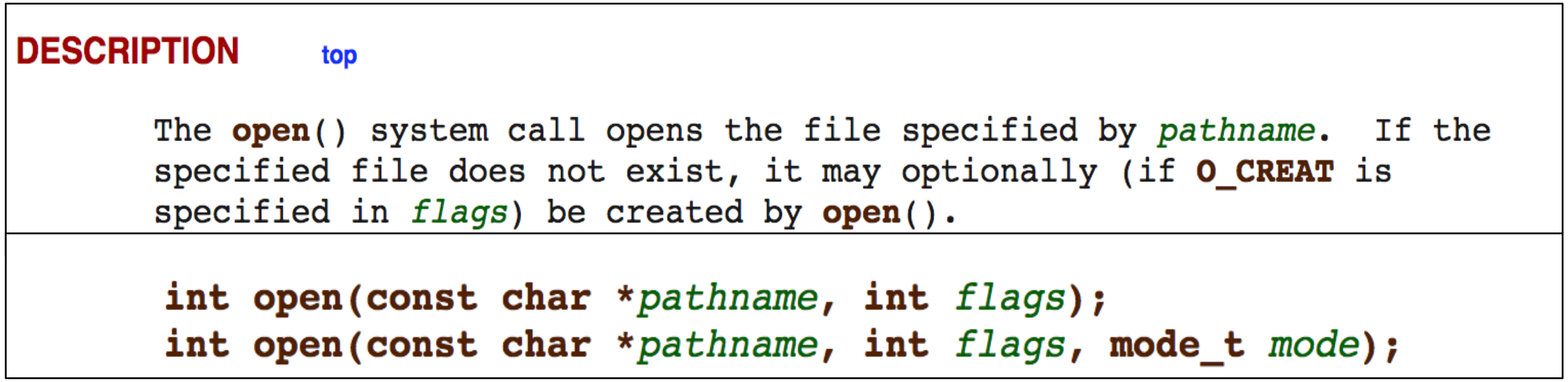
```
SOCKET(2)                 BSD System Calls Manual                SOCKET(2)

NAME
     socket -- create an endpoint for communication

SYNOPSIS
     #include <sys/socket.h>

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

DESCRIPTION
     socket() creates an endpoint for communication and returns a descriptor.
```

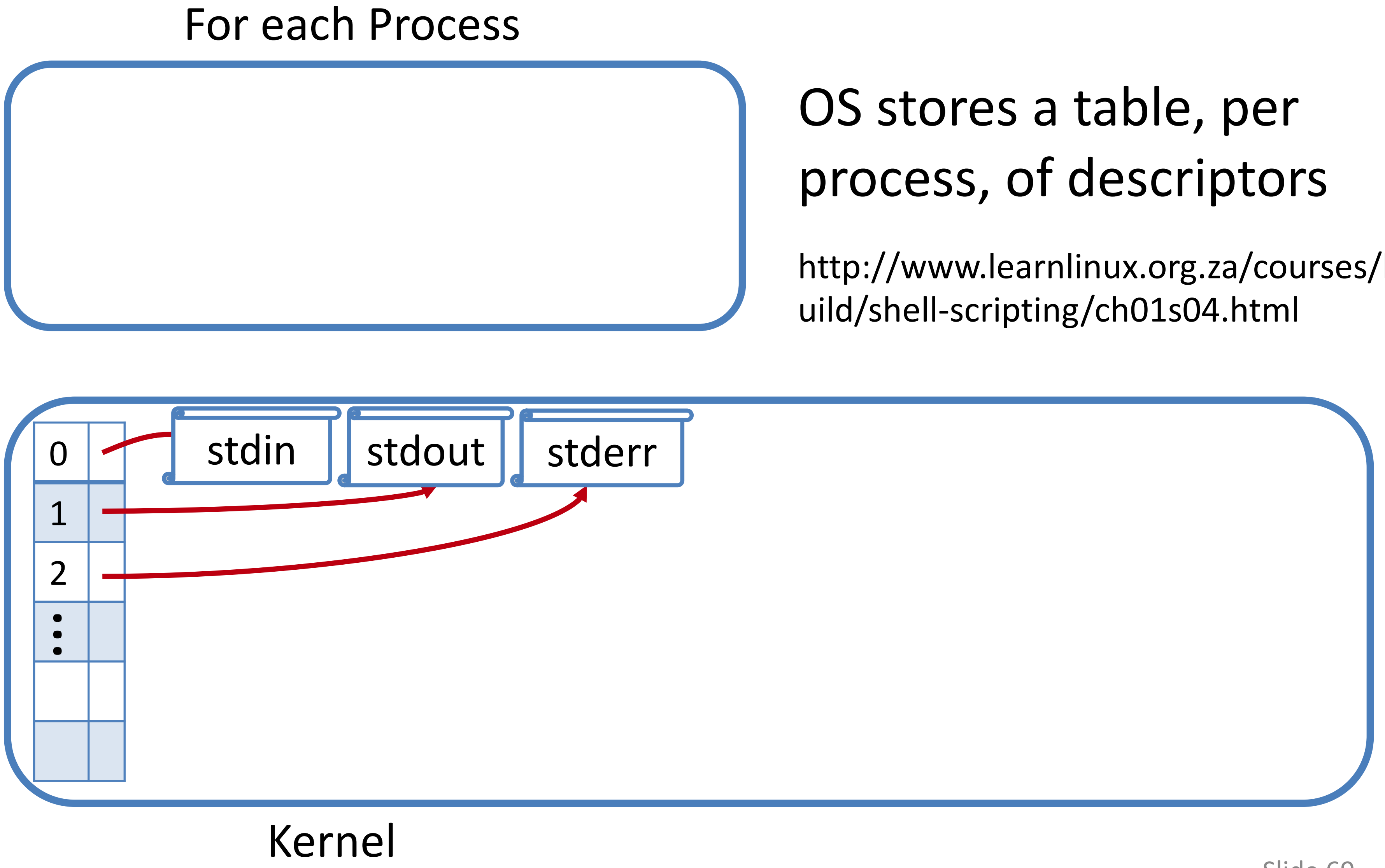


```
DESCRIPTION       top

       The open() system call opens the file specified by pathname.  If the
       specified file does not exist, it may optionally (if O_CREAT is
       specified in flags) be created by open().

        int open(const char *pathname, int flags);
        int open(const char *pathname, int flags, mode_t mode);
```

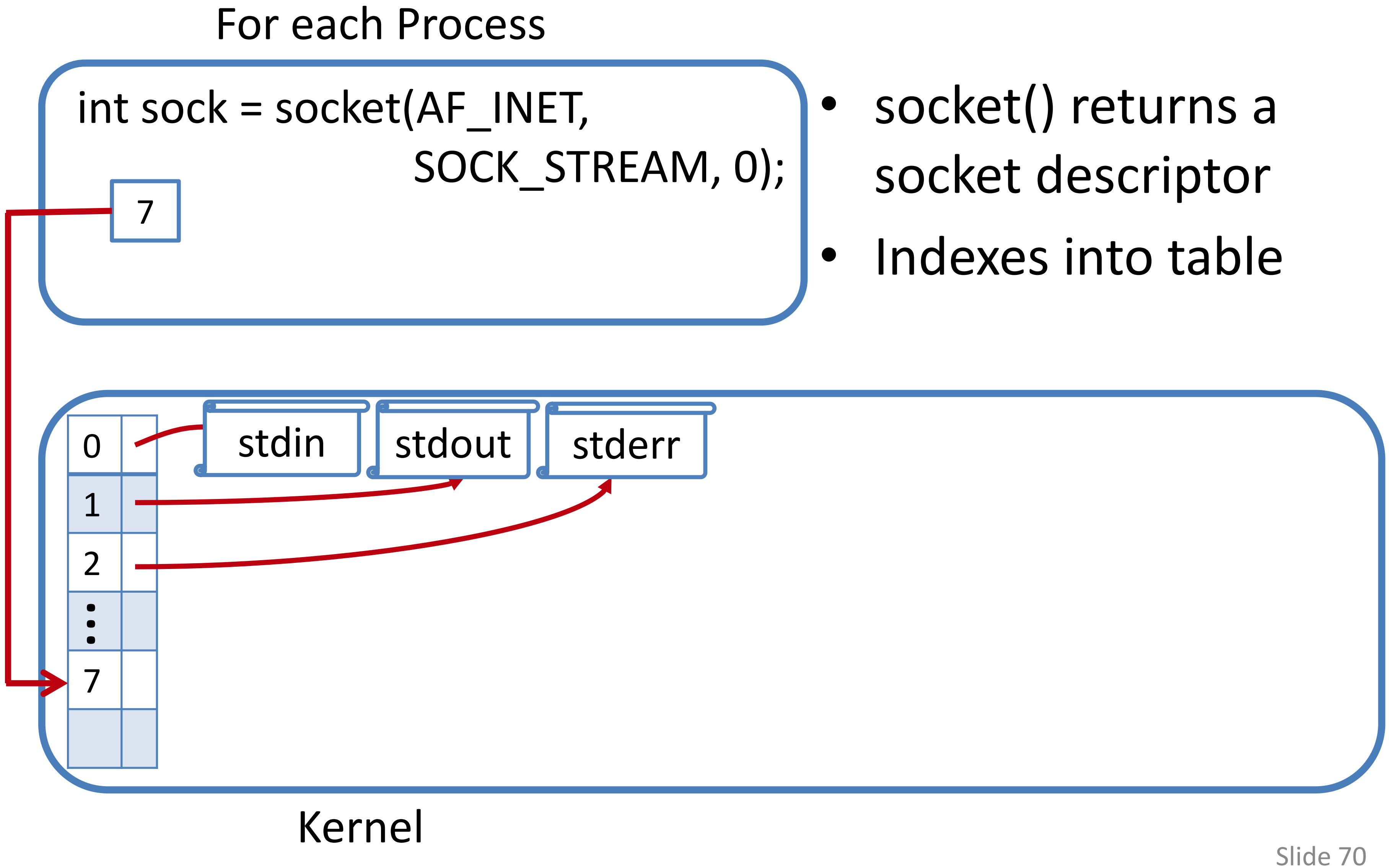
Descriptor Table



OS stores a table, per process, of descriptors

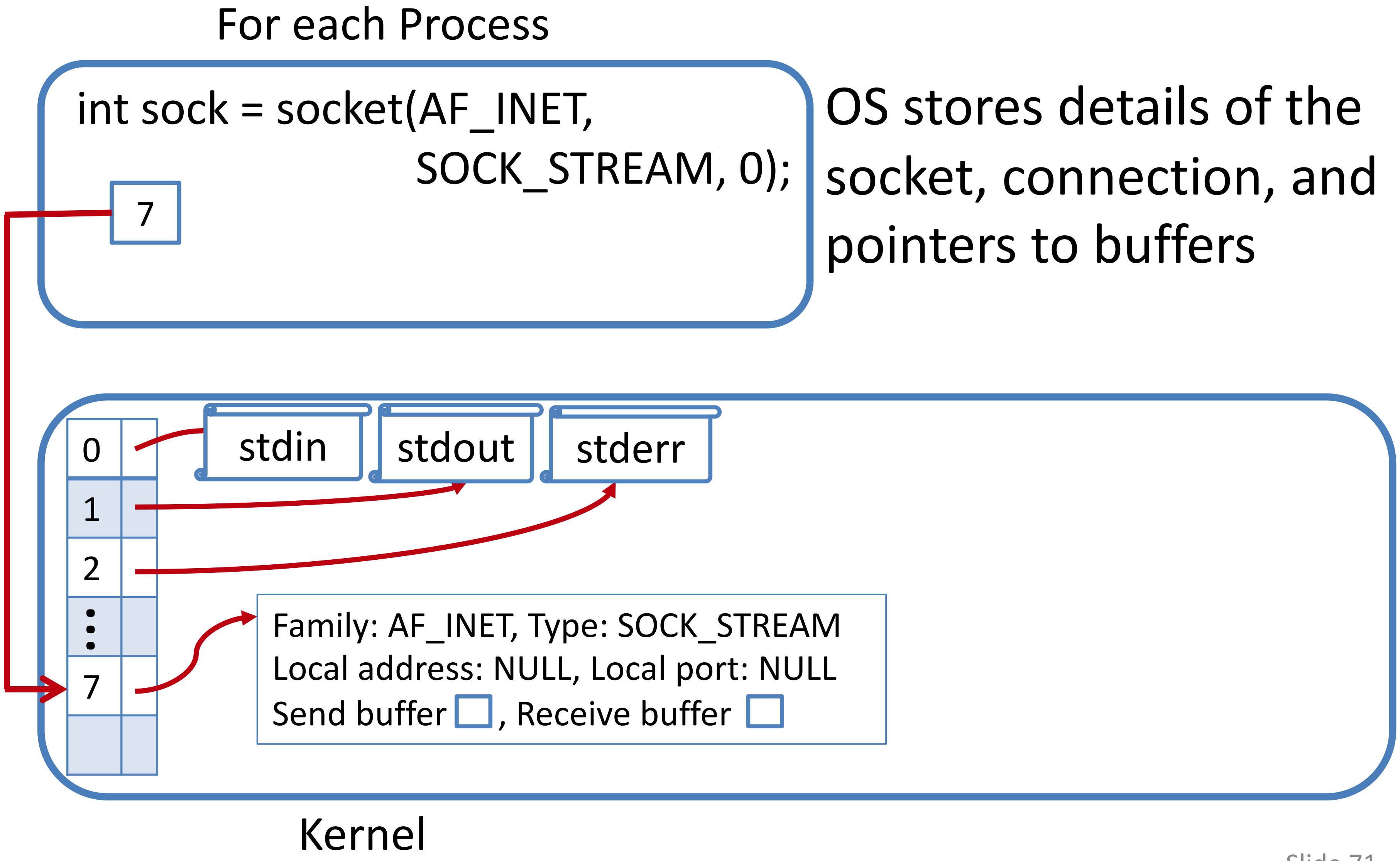
http://www.learnlinux.org.za/courses/build/shell-scripting/ch01s04.html

socket()



- socket() returns a socket descriptor
- Indexes into table

socket()



For each Process

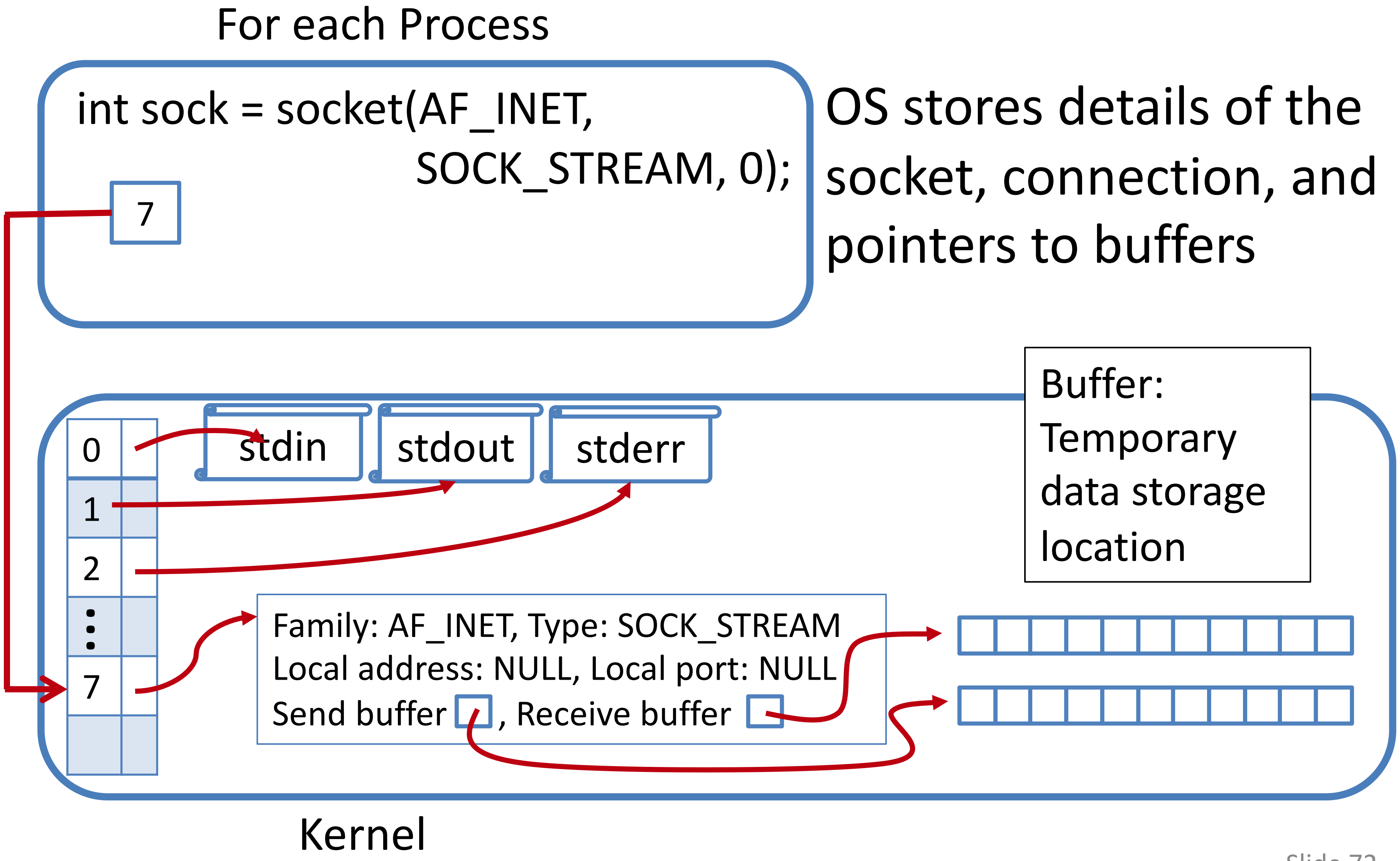
```
int sock = socket(AF_INET,
                  SOCK_STREAM, 0);
```

Family: AF_INET, Type: SOCK_STREAM
Local address: NULL, Local port: NULL
Send buffer ☐, Receive buffer ☐

Kernel

OS stores details of the socket, connection, and pointers to buffers

socket()



For each Process

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```

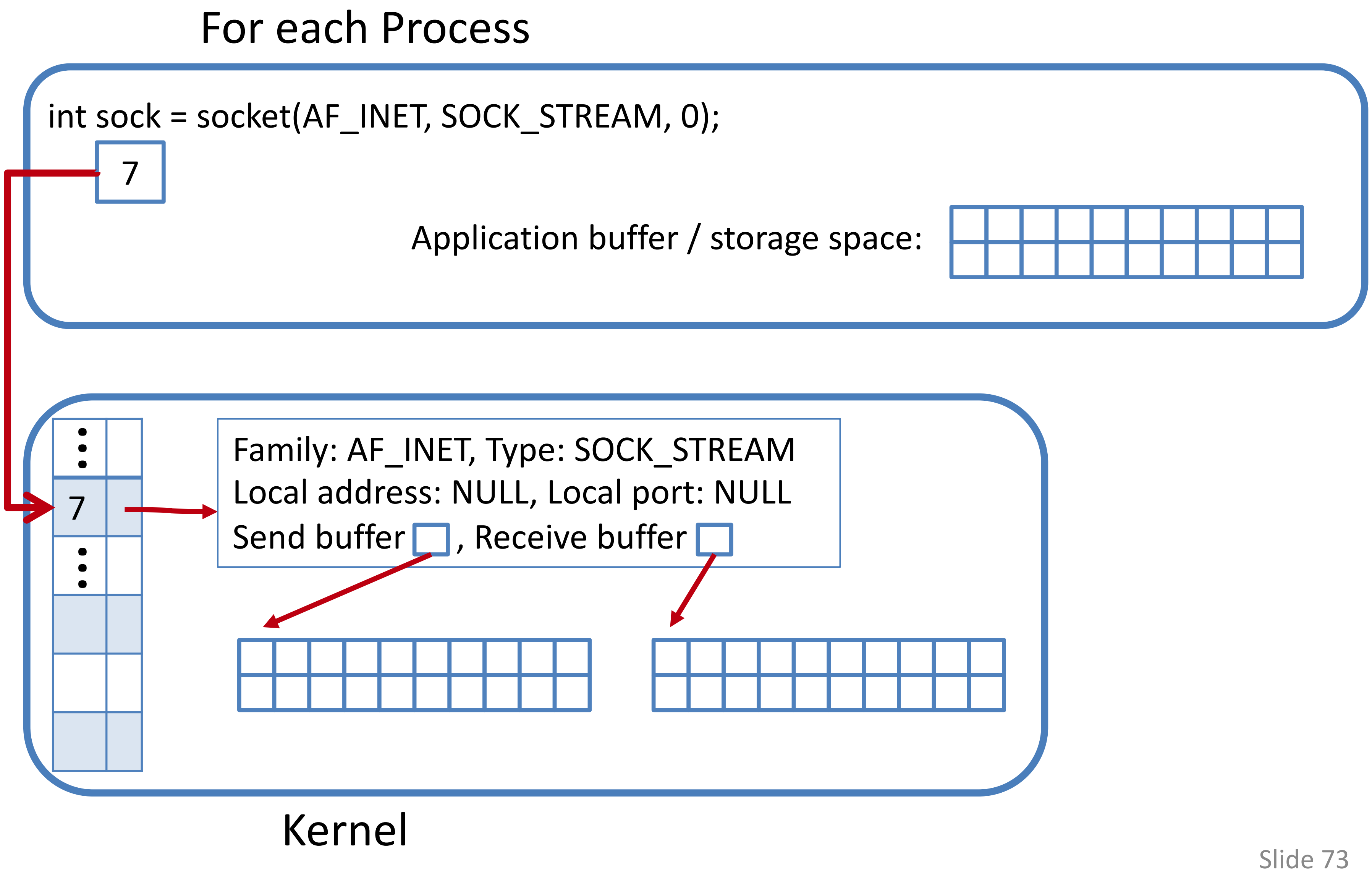
Family: AF_INET, Type: SOCK_STREAM
Local address: NULL, Local port: NULL
Send buffer ☐, Receive buffer ☐

Kernel

OS stores details of the socket, connection, and pointers to buffers

Buffer: Temporary data storage location

Socket Buffers



For each Process

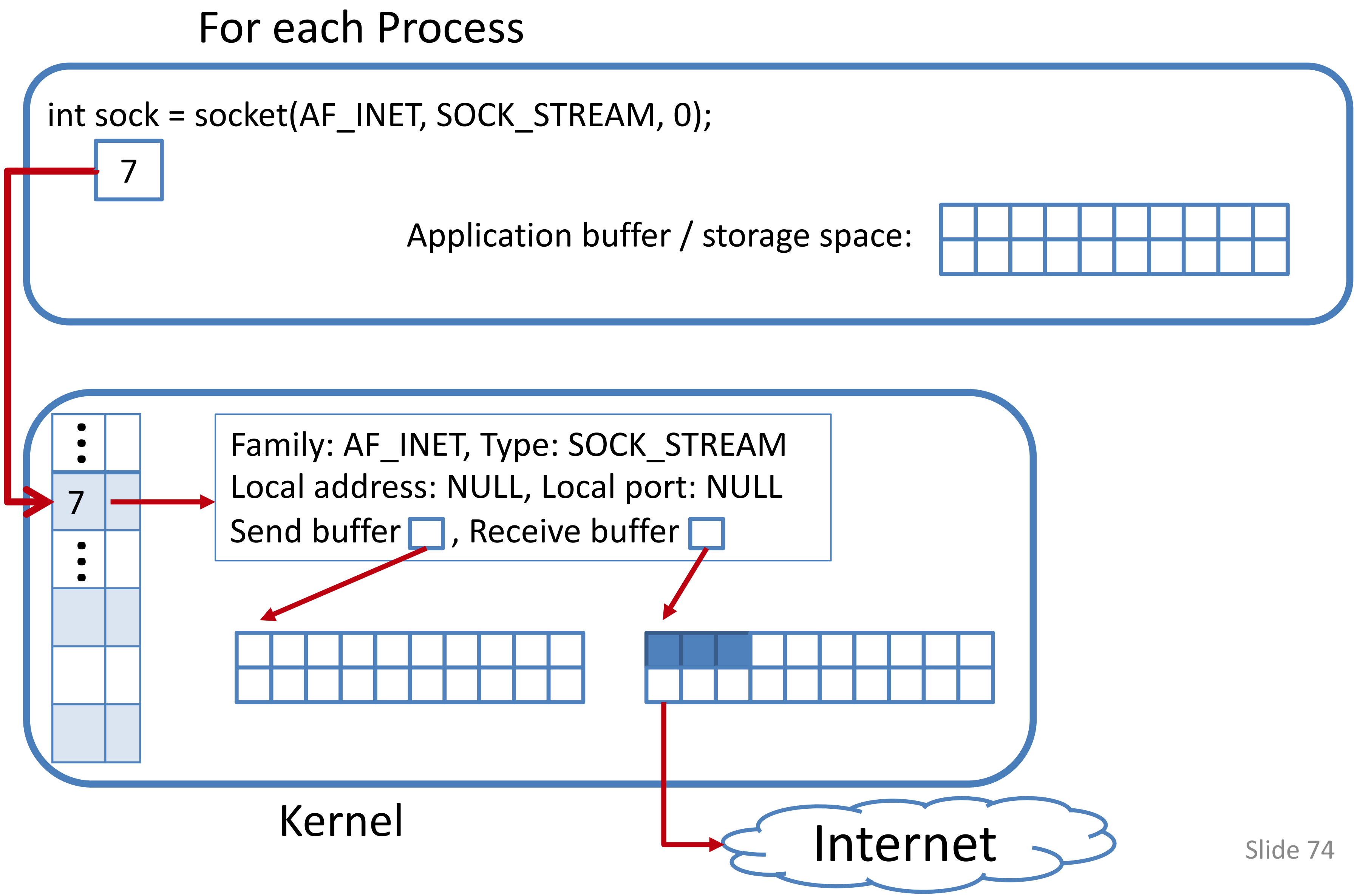
```
int sock = socket(AF_INET, SOCK_STREAM, 0);
```

Application buffer / storage space:

Family: AF_INET, Type: SOCK_STREAM
Local address: NULL, Local port: NULL
Send buffer ☐, Receive buffer ☐

Kernel

Socket Buffers



For each Process

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Application buffer / storage space:

Family: AF_INET, Type: SOCK_STREAM
Local address: NULL, Local port: NULL
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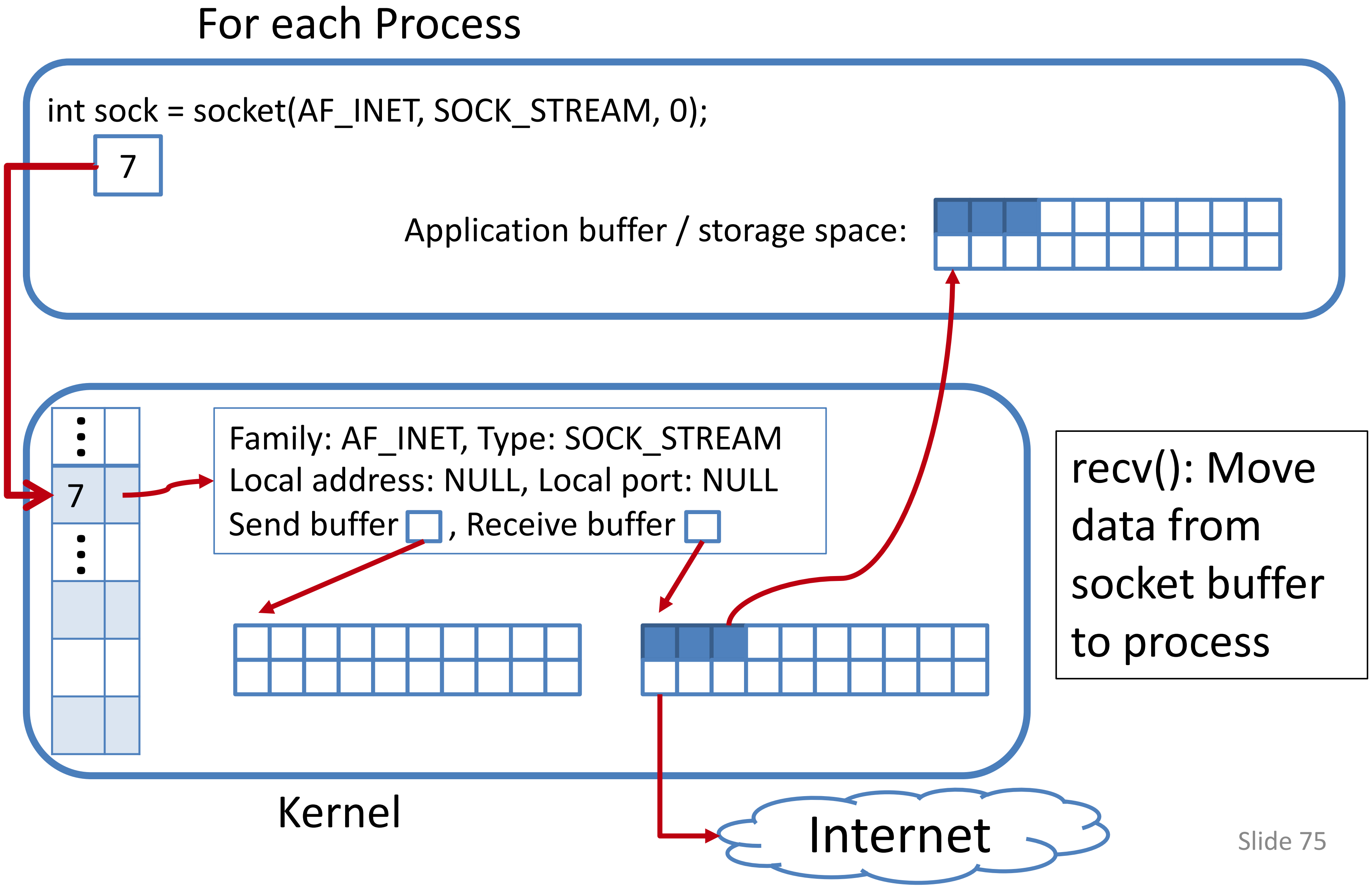
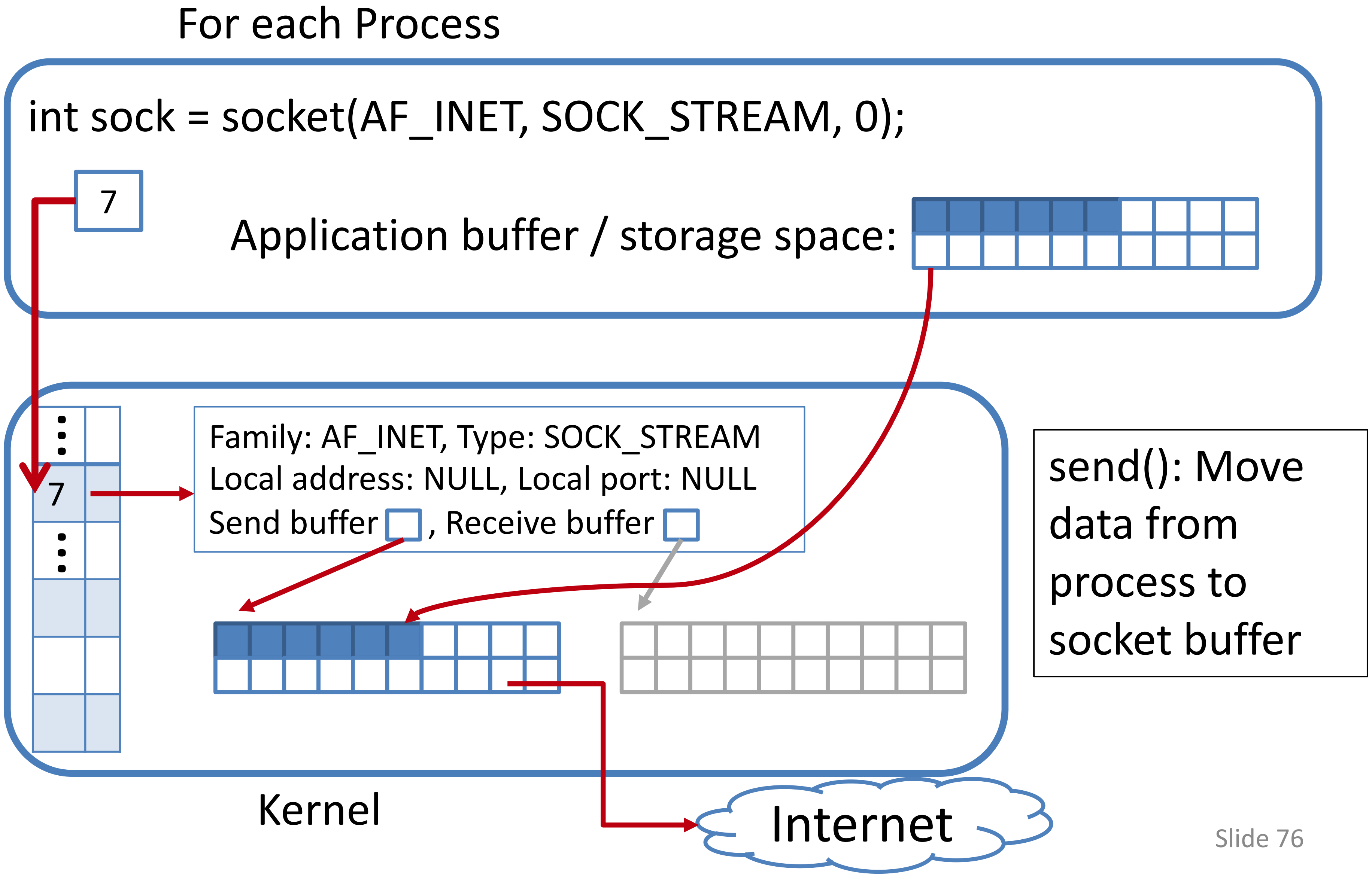
Socket Buffers



recv(): Move data from socket buffer to process

Socket Buffers



For each Process

int sock = socket(AF_INET, SOCK_STREAM, 0);

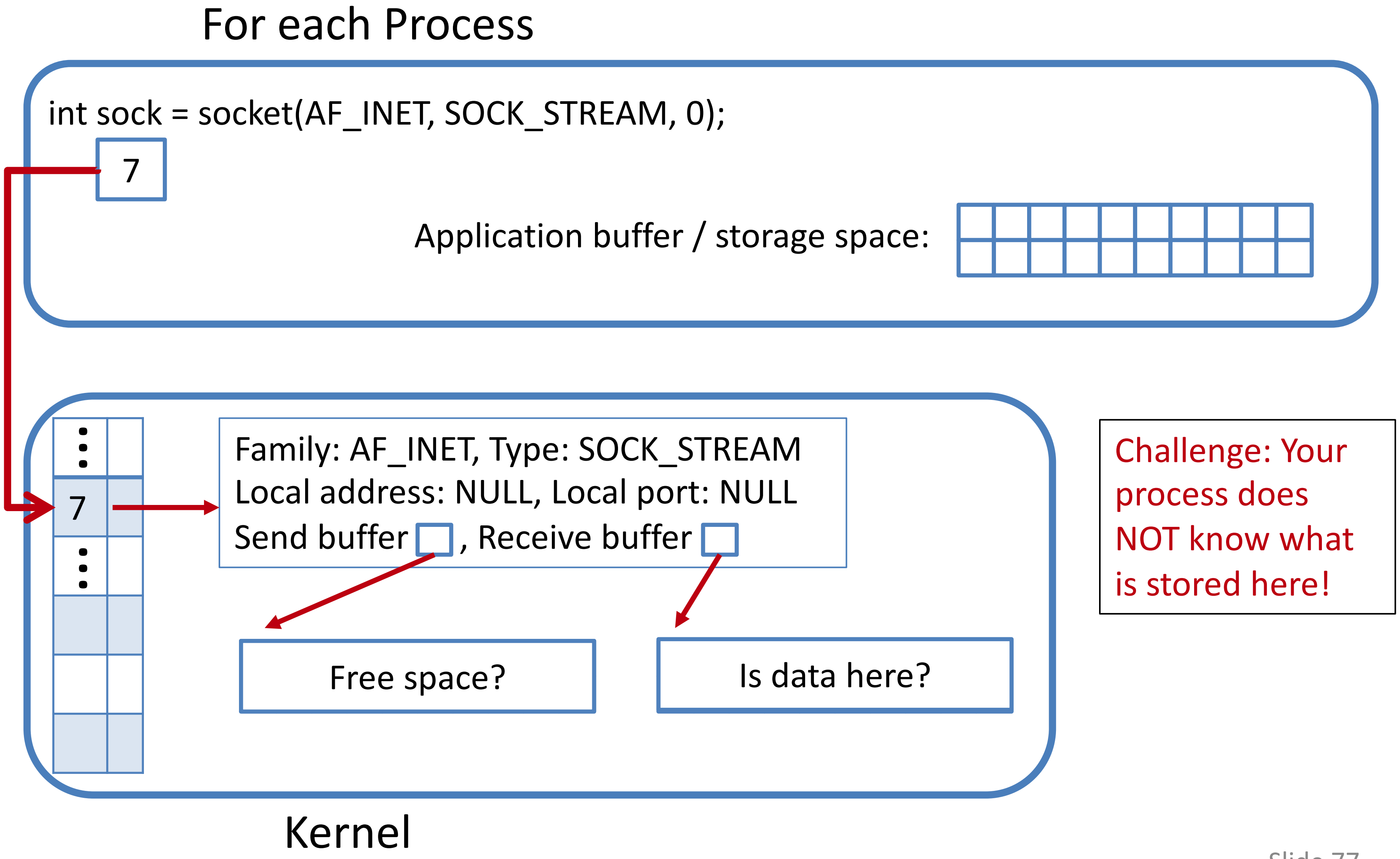
Application buffer / storage space:

Family: AF_INET, Type: SOCK_STREAM
Local address: NULL, Local port: NULL
Send buffer ☐, Receive buffer ☐

send(): Move data from process to socket buffer

Kernel

Socket Buffers



For each Process

int sock = socket(AF_INET, SOCK_STREAM, 0);

Application buffer / storage space:

Family: AF_INET, Type: SOCK_STREAM
Local address: NULL, Local port: NULL
Send buffer ☐, Receive buffer ☐

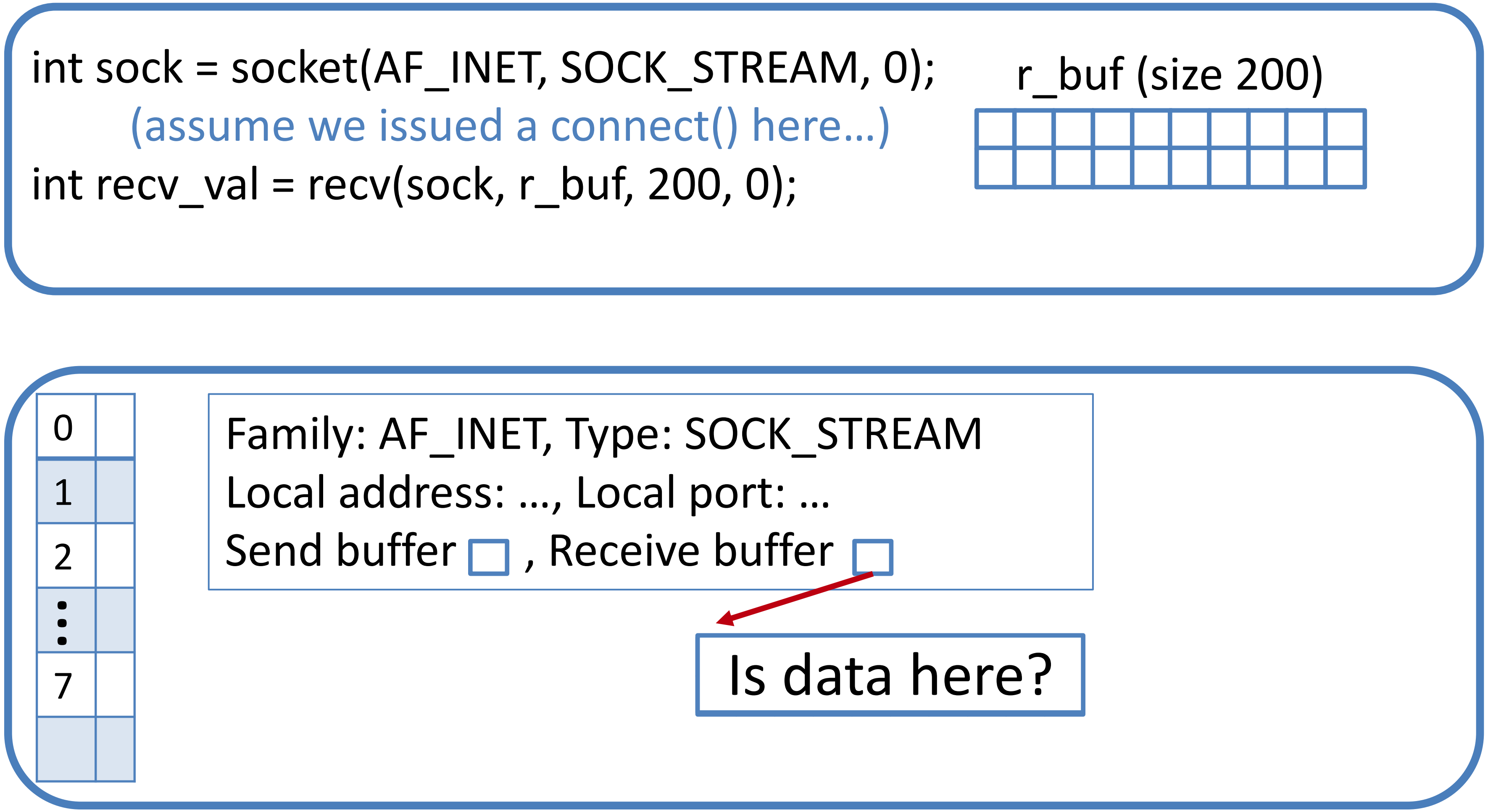
Free space?

Is data here?

Kernel

Challenge: Your process does NOT know what is stored here!

recv()



For each Process

```
int sock = socket(AF_INET, SOCK_STREAM, 0);
```

(assume we issued a connect() here…)

```
int recv_val = recv(sock, r_buf, 200, 0);
```

r_buf (size 200)

Family: AF_INET, Type: SOCK_STREAM
Local address: …, Local port: …
Send buffer ☐ , Receive buffer ☐

Is data here?

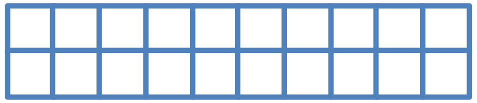
Kernel

What should we do if the receive socket buffer is empty? If it has 100 bytes?

For each Process

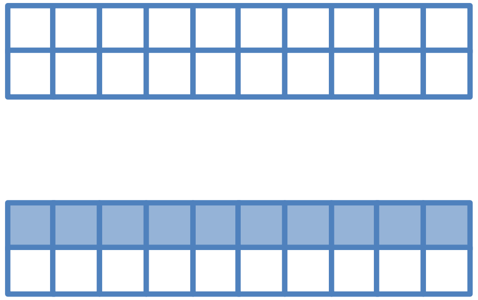
```
int sock = socket(AF_INET, SOCK_STREAM, 0);
        (assume we connect()ed here…)
int recv_val = recv(sock, r_buf, 200, 0);
```

r_buf (size 200)



Two Scenarios:

Socket buffer



Kernel

What should we do if the receive socket buffer is empty? If it has 100 bytes?

For each Process

```
int sock = socket(AF_INET, SOCK_STREAM, 0);
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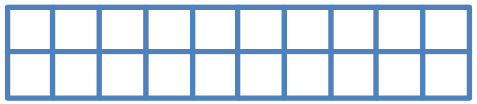
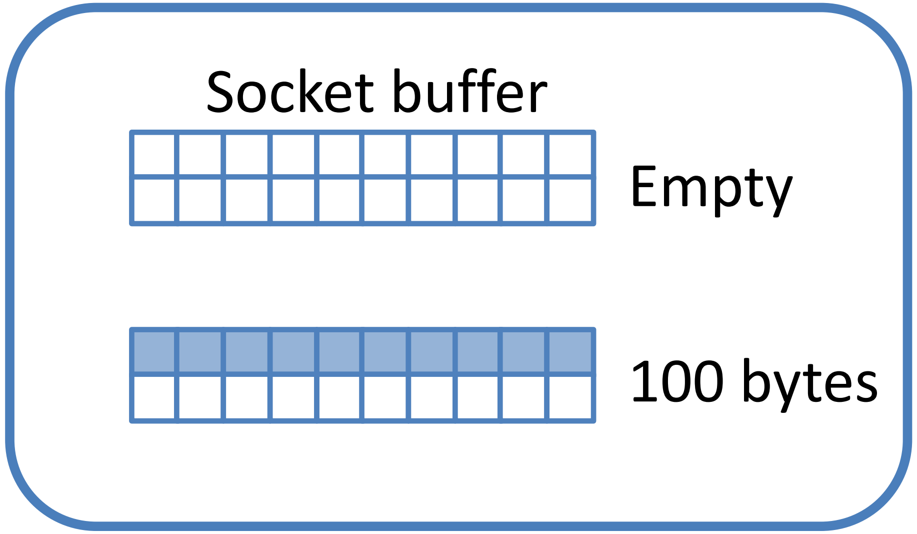
int recv_val = recv(sock, r_buf, 200, 0);
```

r_buf (size 200)



Two Scenarios:

	Empty	100 Bytes
A	**Block**	**Block**
B	**Block**	**Copy 100 bytes**
C	**Copy 0 bytes**	**Block**
D	**Copy 0 bytes**	**Copy 100 bytes**
E	**Something else**	



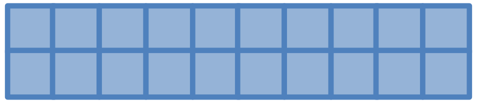
Kernel

What should we do if the send socket buffer is full?
If it has 100 bytes?

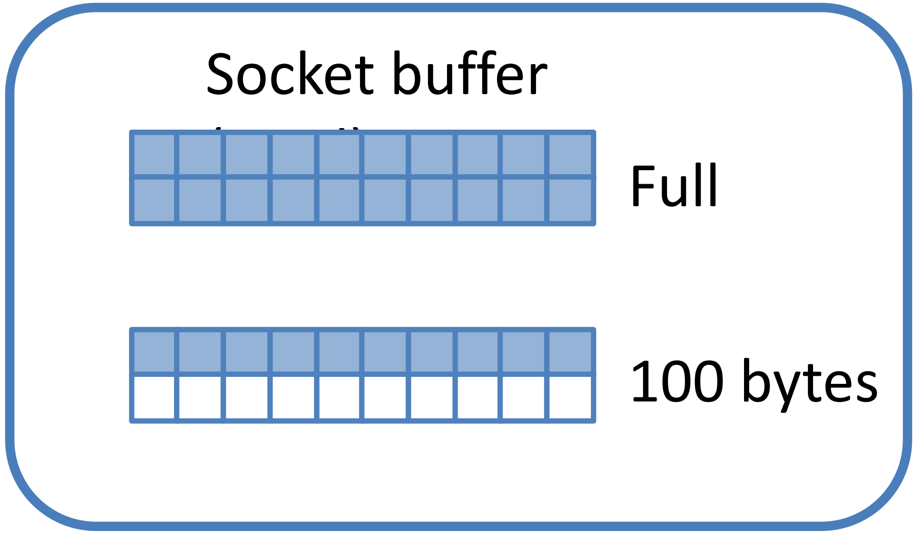
For each Process

```
int sock = socket(AF_INET, SOCK_STREAM, 0);
          (assume we connect()ed here…)
int recv_val = recv(sock, r_buf, 200, 0);
```

s_buf (size 200)



Two Scenarios:



Socket buffer

Full

100 bytes

Kernel

What should we do if the send socket buffer is full?
If it has 100 bytes?

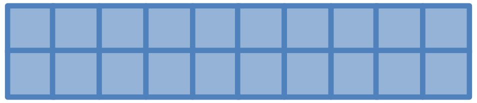
For each Process

```
int sock = socket(AF_INET, SOCK_STREAM, 0);
```

(assume we connect()ed here…)

```
int recv_val = recv(sock, r_buf, 200, 0);
```

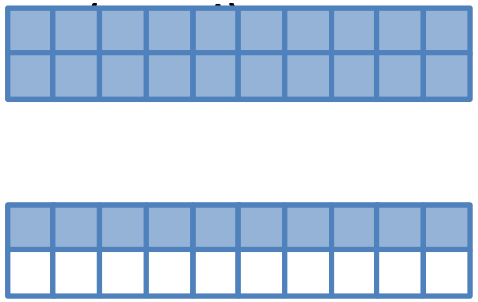
s_buf (size 200)



Two Scenarios:

	Full	100 Bytes
A	**Return 0**	**Copy 100 bytes**
B	**Block**	**Copy 100 bytes**
C	**Return 0**	**Block**
D	**Block**	**Block**
E	**Something else**	

Socket buffer



Full

100 bytes

Kernel

Blocking Implications

recv()

- Do not assume that you will recv() all of the bytes that you ask for.
- Do not assume that you are done receiving.
- Always receive in a loop!*

send()

- Do not assume that you will send() all of the data you ask the kernel to copy.
- Keep track of where you are in the data you want to send.
- Always send in a loop!*

* Unless you're dealing with a single byte, which is rare.

ALWAYS check send()/recv() return values!

When recv() returns a non-zero number of bytes always call recv() again until:

- the server closes the socket,
- or you’ve received all the bytes you expect.

ALWAYS check send()/recv() return values!

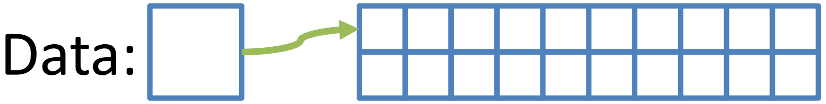
When recv() returns a non-zero number of bytes always call recv() again until:

- In the case of your web client: keep receiving until the server closes the socket.

ALWAYS check send()/recv() return values!

- E.g.: Let’s assume we have a 200 byte data buffer and we want to receive data from a server.

Data size to receive = unknown
recv(sock, data, 200, 0);



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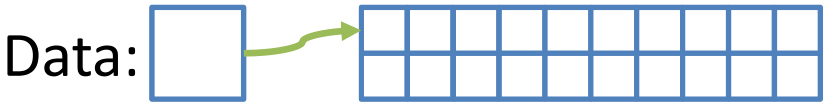
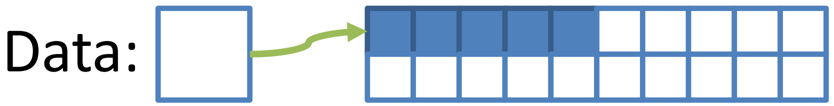


Data received = 50
Remaining buffer size = 150



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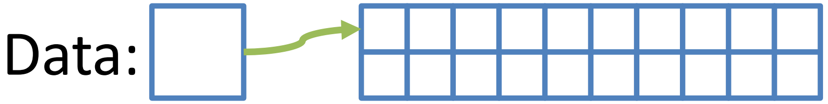

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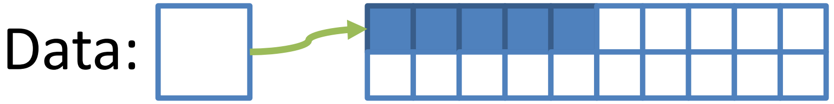


// Receive remaining bytes from offset of 50

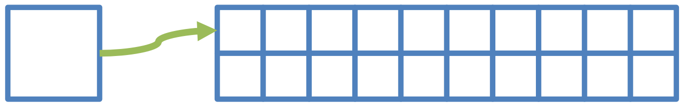
ALWAYS check send()/recv() return values!

- E.g.: Let's assume we have a 200 byte data buffer and we want to receive data from a server.

Data size to receive = unknown

recv(sock, data, 200, 0);

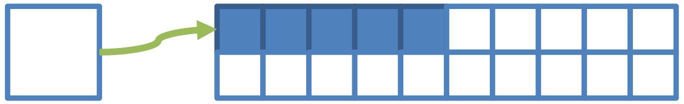
Data:



Data received = 50

Remaining buffer size = 150

Data:



// Receive remaining bytes from offset of 50

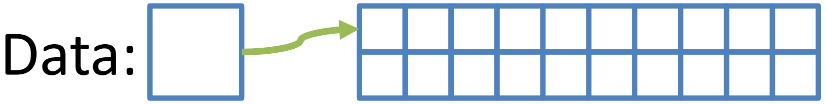
recv(sock, data + 50, 200 – 50, 0)

Data received = ?

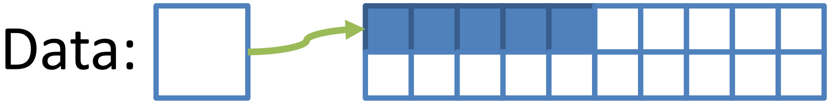
ALWAYS check send()/recv() return values!

- E.g.: Let's assume we have a 200 byte data buffer and we want to receive data from a server.

Data size to receive = unknown
recv(sock, data, 200, 0);



Data received = 50
Remaining buffer size = 150



// Receive remaining bytes from offset of 50
recv(sock, data + 50, 200 – 50, 0)
Data received = ?

Repeat until server closes the socket. (return value = 0)

Blocking Summary

send()

- Blocks when socket buffer for sending is full
- Returns less than requested size when buffer cannot hold full size

recv()

- Blocks when socket buffer for receiving is empty
- Returns less than requested size when buffer has less than full size

Always check the return value!

Create a TCP socket: socket()

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

int sock = socket(AF_INET, SOCK_STREAM, 0);

- domain: communication domain of the socket: generic interface.
- type of socket: reliable vs. best-effort
- end-to-end protocol: TCP for a stream socket -
  - 0: default E2E for specified protocol family and type.

Create a TCP socket: socket()

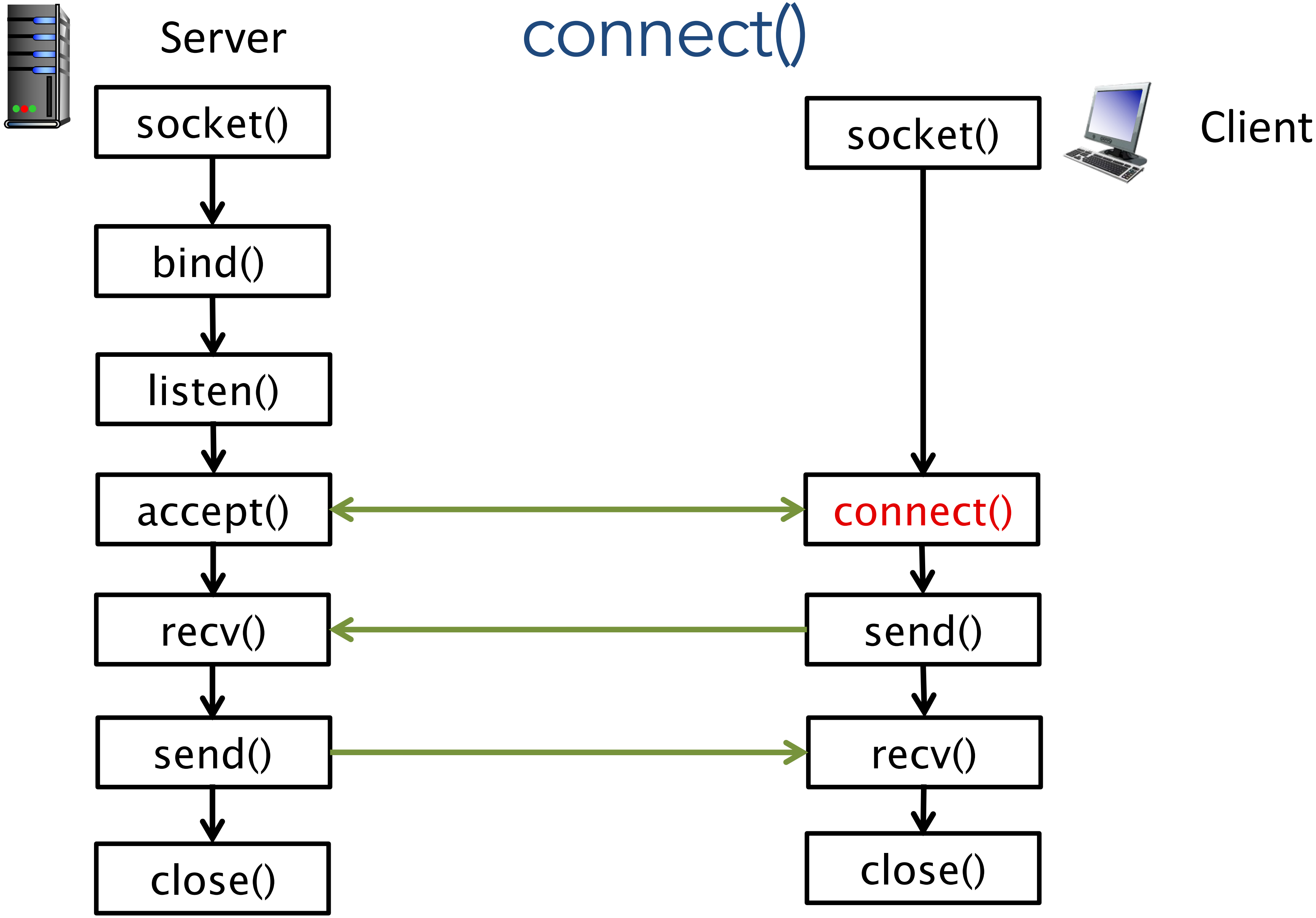
```
int socket(int domain, int type, int protocol)
int sock = socket(AF_INET, SOCK_STREAM, 0);
/* AF_INET: Communicate with IPv4 Address Family (AF),
  SOCK_STREAM: Stream-based protocol
  int sock: returns an integer-valued socket descriptor or handle
*/
   if(sock < 0) { // If socket() fails, it returns -1
      perror("socket");
      exit(1);
   }
```

Close a socket: close()

```
int close(int socket)
if (close(sock)) {
      perror("close");
      exit(1);
   }
/* int socket: int socket descriptor is passed to close()*/
```

- Close operation similar to closing a file.
- initiate actions to shut down communication
- deallocate resources associated with the socket
- cannot send(), recv() after you close the socket.

connect()


Server
socket()
bind()
listen()
accept()
recv()
send()
close()
Client
socket()
connect()
send()
recv()
close()

connect()

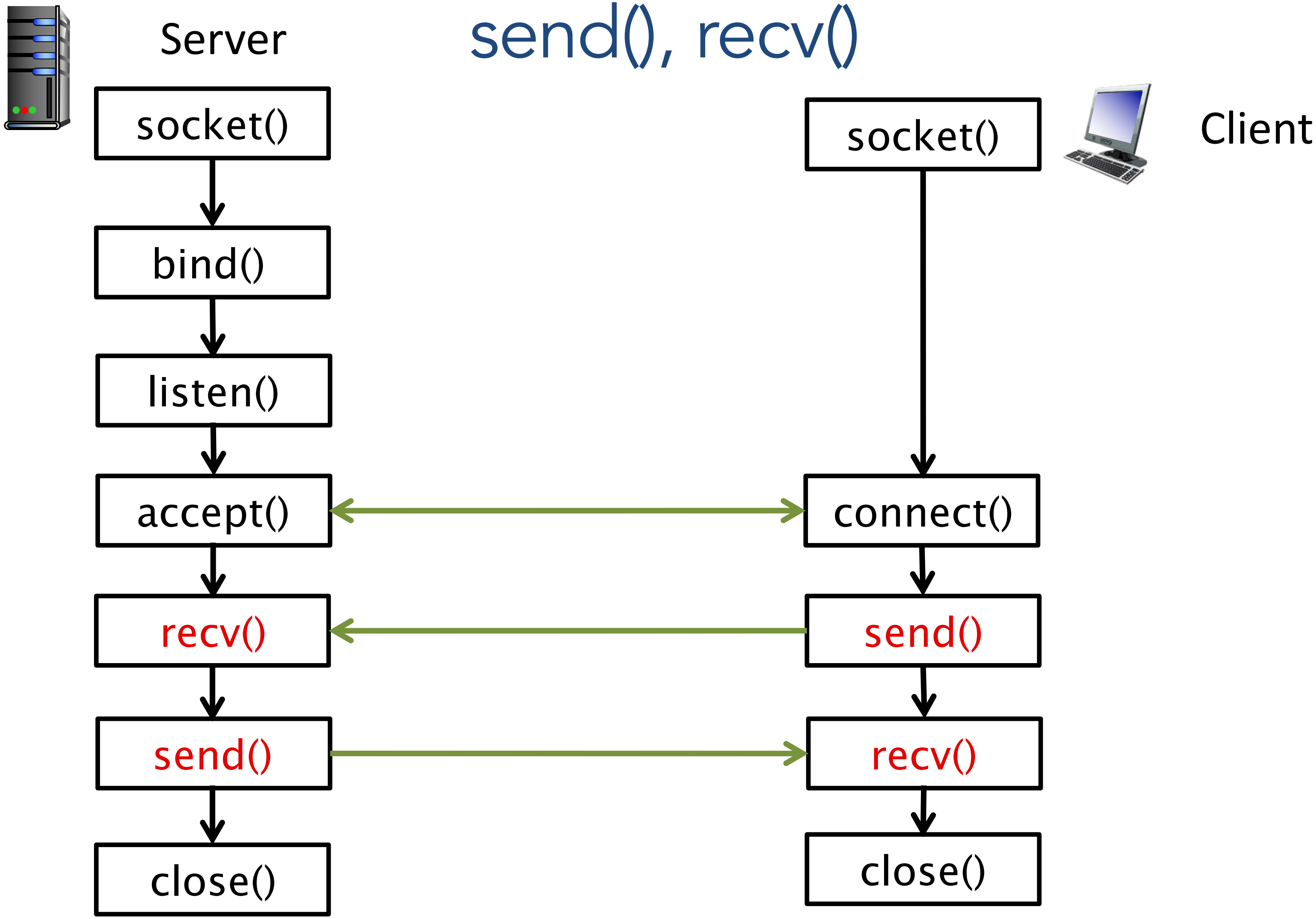
- Before you can communicate, a connection must be established.
- Client Initiates, Server waits.
- Once connect() returns, socket is connected and we can proceed with send(), recv()

```
int connect(int socket,
                const struct sockaddr *foreign Address, socklen_t addressLength)
```

connect()

```
int connect(int socket,
            const struct sockaddr *foreign Address,                    socklen_t
addressLength)
struct sockaddr_in addr;
int res = connect(sock, (struct sockaddr*)&addr, sizeof(addr));
/* int socket: socket descriptor
   foreignAddress: pointer to sockaddr_in containing Internet address, port of server.
   addressLength: length of address structure
*/
```

send(), recv()



Server

socket()

bind()

listen()

accept()

recv()

send()

close()

Client

socket()

connect()

send()

recv()

close()

send(), recv()

Socket is connected when:

- client calls connect()
- connected socket is returned by accept() on server

```
ssize_t send(int socket, const void *msg, msgLength, int flags)
ssize_t recv (int socket, void *rcvBuffer, size_t bufferLength, int flags)
```

```
/* int socket: socket descriptor
   return: # bytes sent/received or -1 for failure.
```

send()

send():

- by default send: blocks until data is sent

ssize_t send(int socket, const void *msg, msgLength, int flags)

/* int socket: socket descriptor

send(): msg: sequence of bytes to be sent

send(): mesgLength: # bytes to send

send(), recv()

recv():

```
ssize_t recv (int socket, void *rcvBuffer, size_t bufferLength, int flags)
int recv_count = recv(sock, buf, 255, 0);

/* int socket: socket descriptor
   void *rcvBuffer: generally a char array
   size_t bufferLength: length of buffer: max # bytes that can be received at once.
   flags: setting flag to zero specifies default behavior.
```

⚠ Place all send() and recv() calls in a loop, until you are left with no more bytes to send or receive. One call to send()/recv(), irrespective of the buffer does not necessarily mean all your data will be received at once.