CS 43: Computer Networks

03: HTTP & Sockets

September 15, 2020

SWARTHMORE COLLEGE

Five-Layer Internet Model

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

Transport: end-to-end connections, reliability

Network: routing

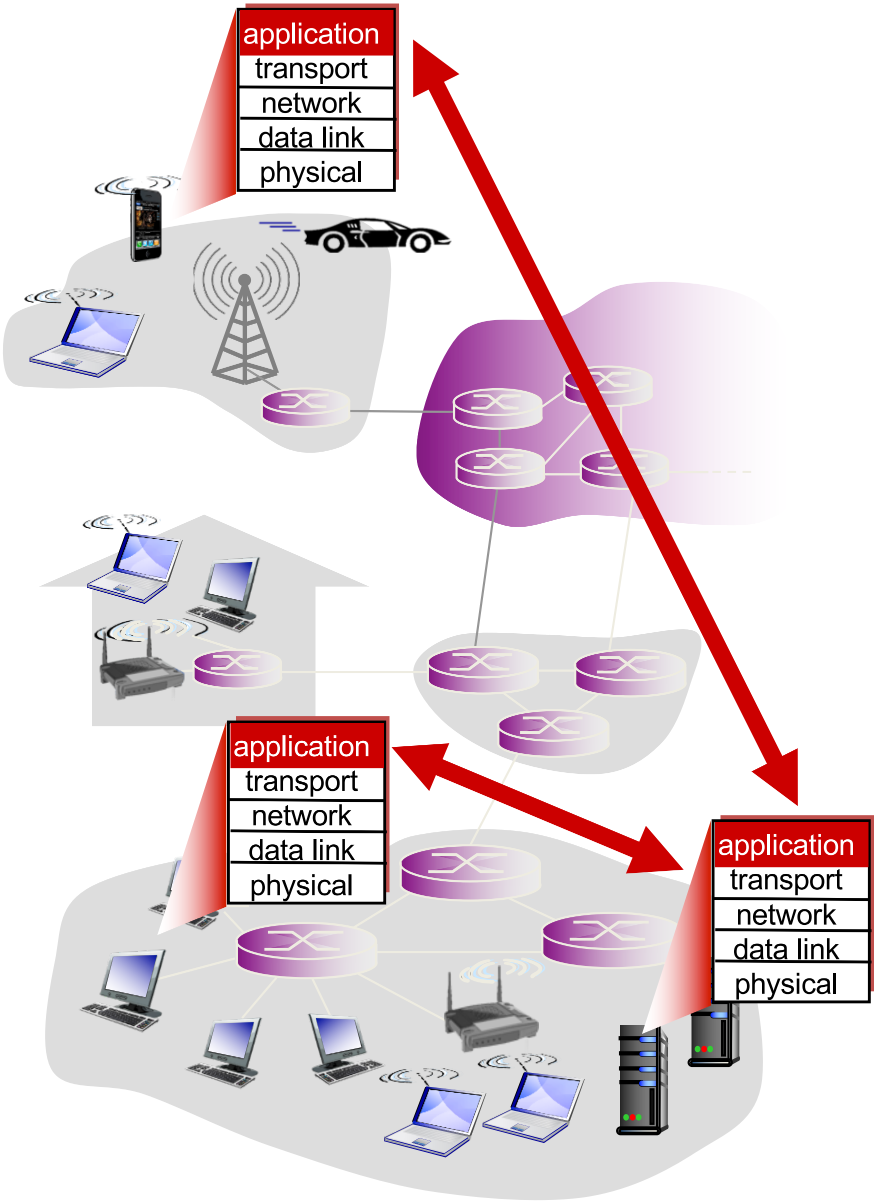
Link (data-link): framing, error detection

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

Creating a network app

write programs that:

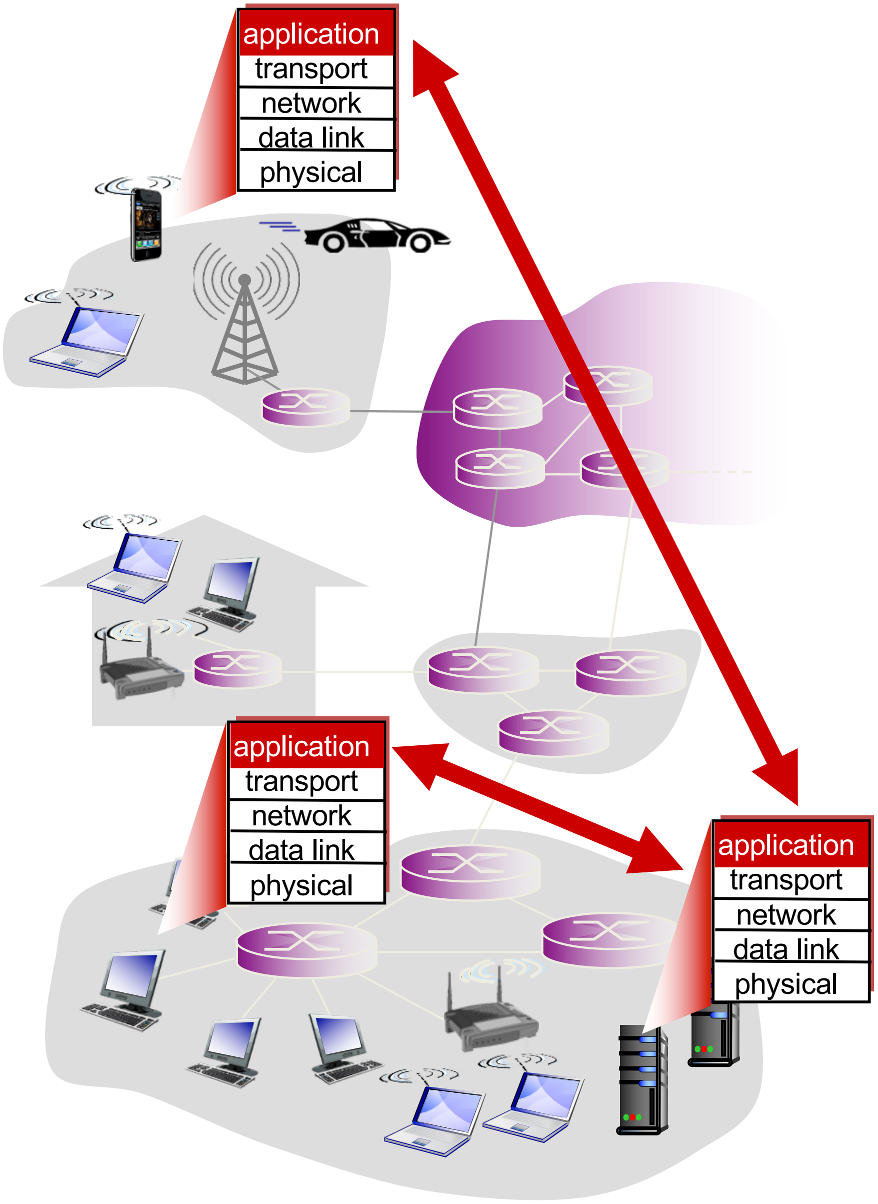
- run on (different) *end systems*
- communicate over network
- e.g., web server s/w communicates with browser software



Creating a network app

no need to write software for network-core devices!

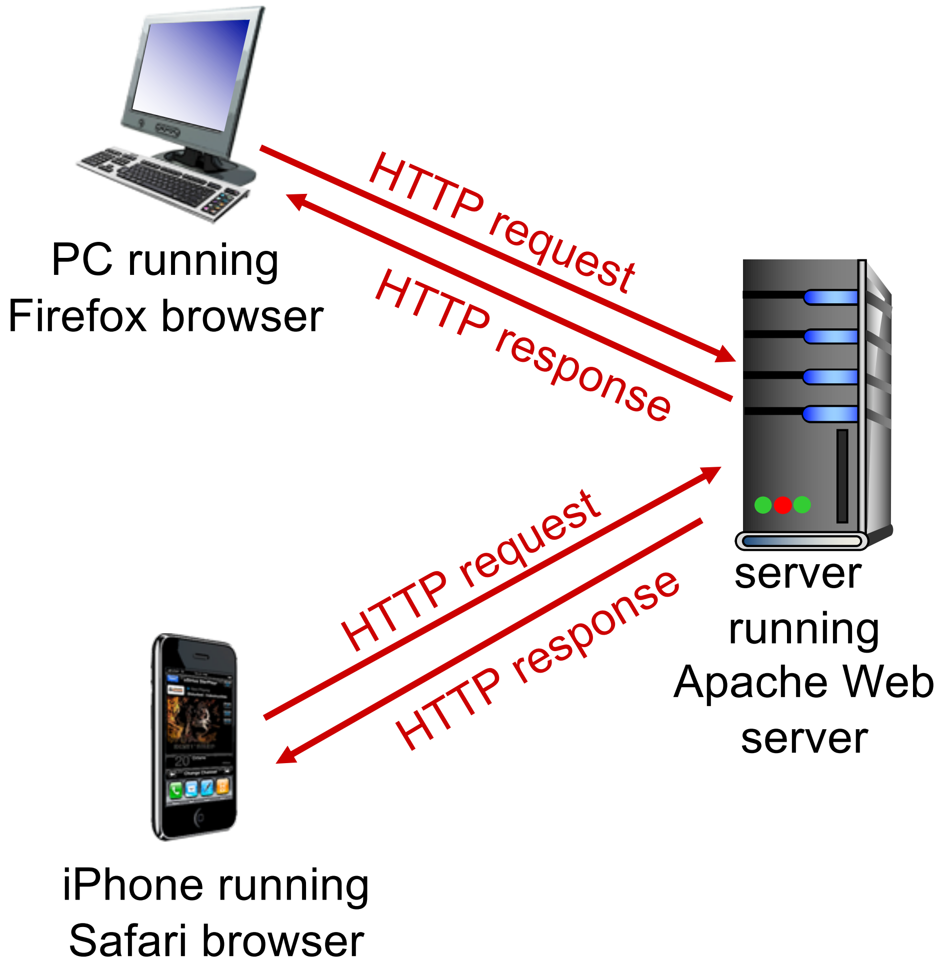
- network-core devices <u>do not run user applications</u>
- applications on end systems
  - rapid app development, propagation



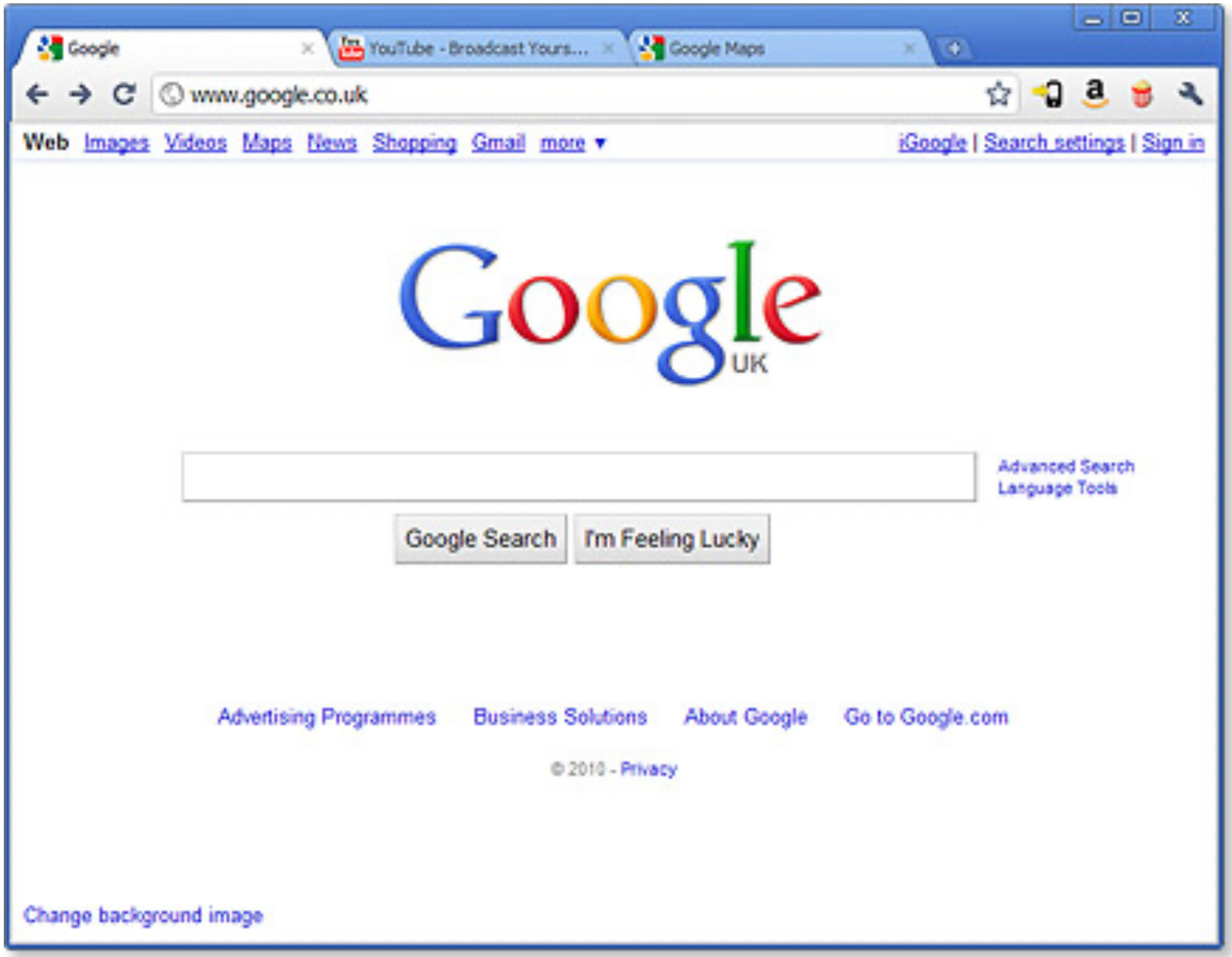
HTTP: HyperText Transfer Protocol

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.



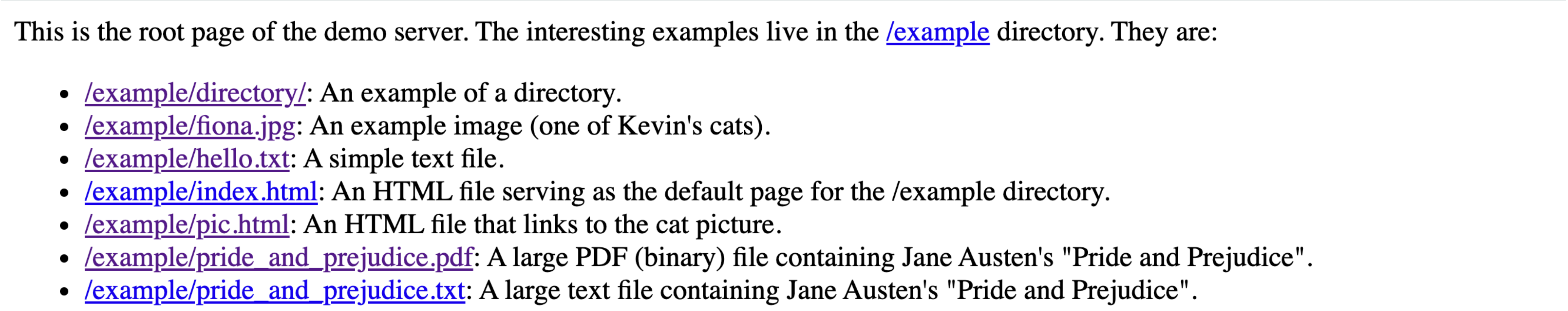
What IS A Web Browser?



HTTP and the Web

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

demo.cs.swarthmore.edu/index.html

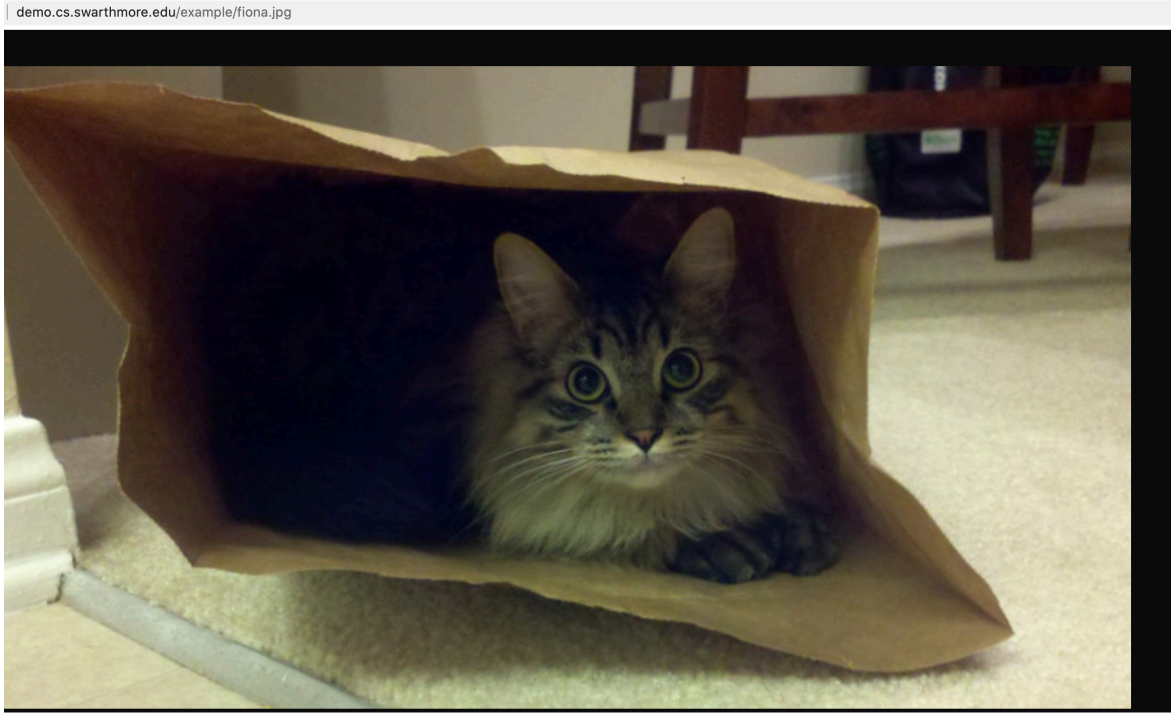


This is the root page of the demo server. The interesting examples live in the /example directory. They are:

- /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".

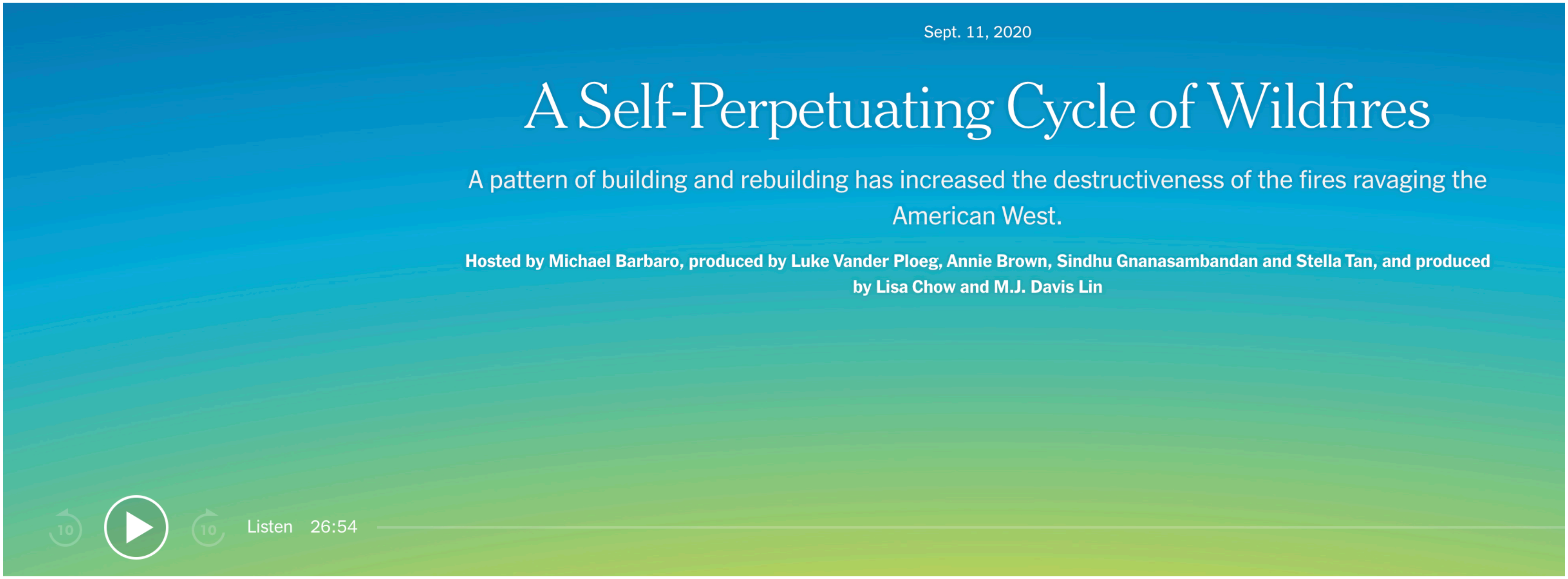
Web objects

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



Web objects

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



Sept. 11, 2020

A Self-Perpetuating Cycle of Wildfires

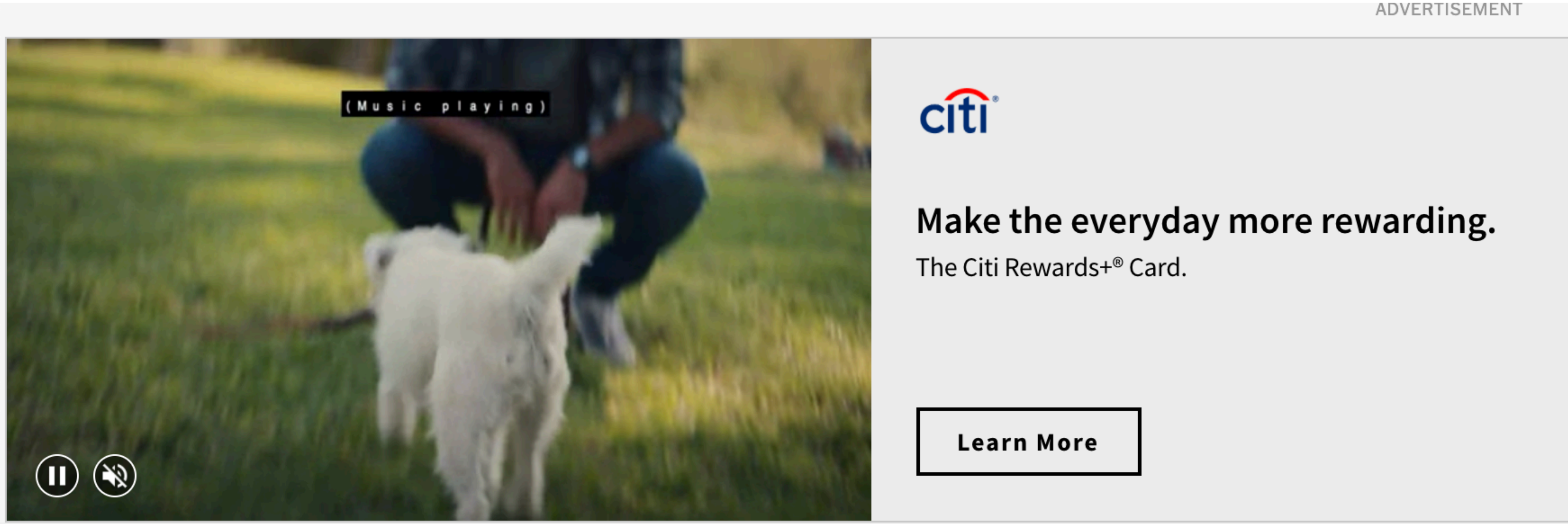
A pattern of building and rebuilding has increased the destructiveness of the fires ravaging the American West.

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

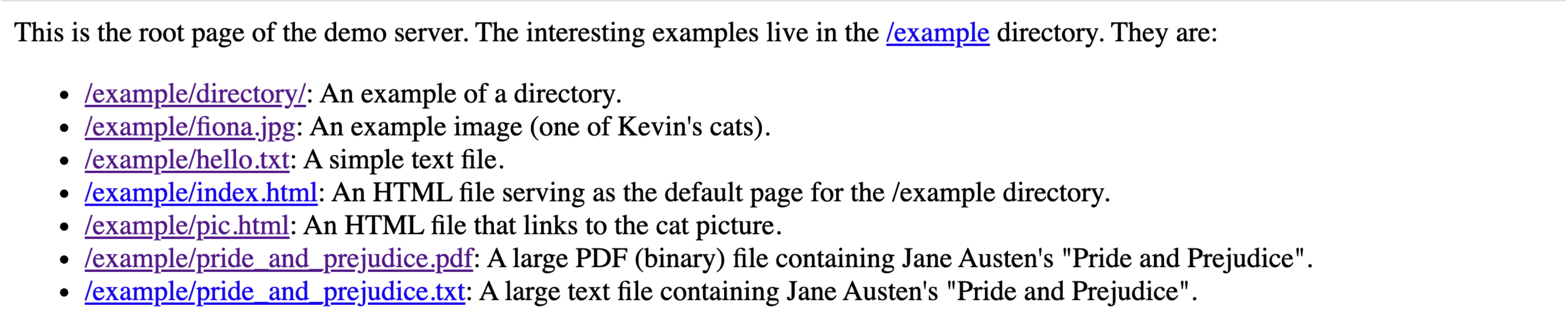
Web objects

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

HTTP Overview

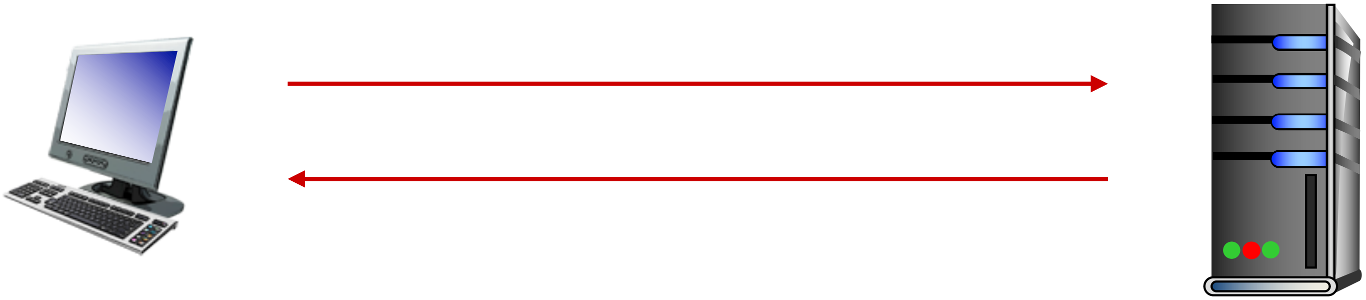
1. User types in a URL.

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.

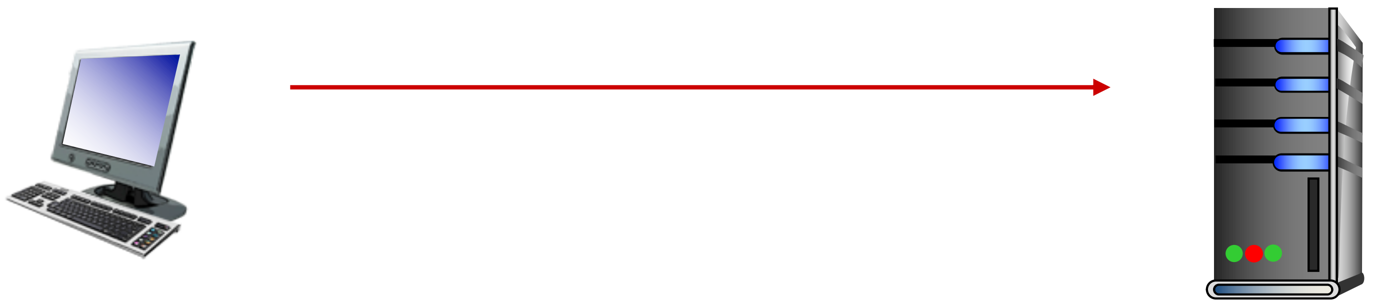
Calls socket()   // create a socket

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)

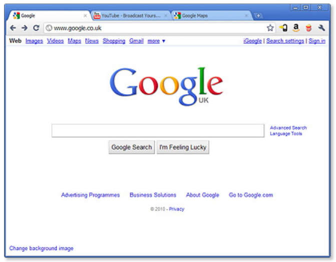
Accept-language: en

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
```

Why do we have these \r\n (CRLF) things all over the place?

```
GET /index.html HTTP/1.1\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
```

A. They're generated when the user hits 'enter'.
B. They signal the end of a field or section.
C. They're important for some other reason.
D. They're an unnecessary protocol artifact.

Why do we have these \r\n (CRLF) things all over the place?

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Accept-Charset: ISO-8859-1,utf-8;q=0.7\r\n
Keep-Alive: 115\r\n
Connection: keep-alive\r\n
\r\n
```

A. They're generated when the user hits 'enter'.

B. They signal the end of a field or section.

C. They're important for some other reason.

D. They're an unnecessary protocol artifact.

How else might we delineate messages?

A. There’s not much else we can do.

B. Force all messages to be the same size.

C. Send the message size prior to the message.

D. Some other way (discuss).

HTTP is all text…

- Makes the protocol simple
  - Easy to delineate message (\r\n)
  - (Relatively) human-readable
  - No worries about encoding or formatting data
  - Variable length data
- Not the most efficient
  - Many protocols use binary fields
    - Sending “12345678” as a string is 8 bytes
    - As an integer, 12345678 needs only 4 bytes
  - The headers may come in any order
  - Requires string parsing / processing

HTTP response message

status line
(protocol
status code
status phrase)

```
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 ...
```

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

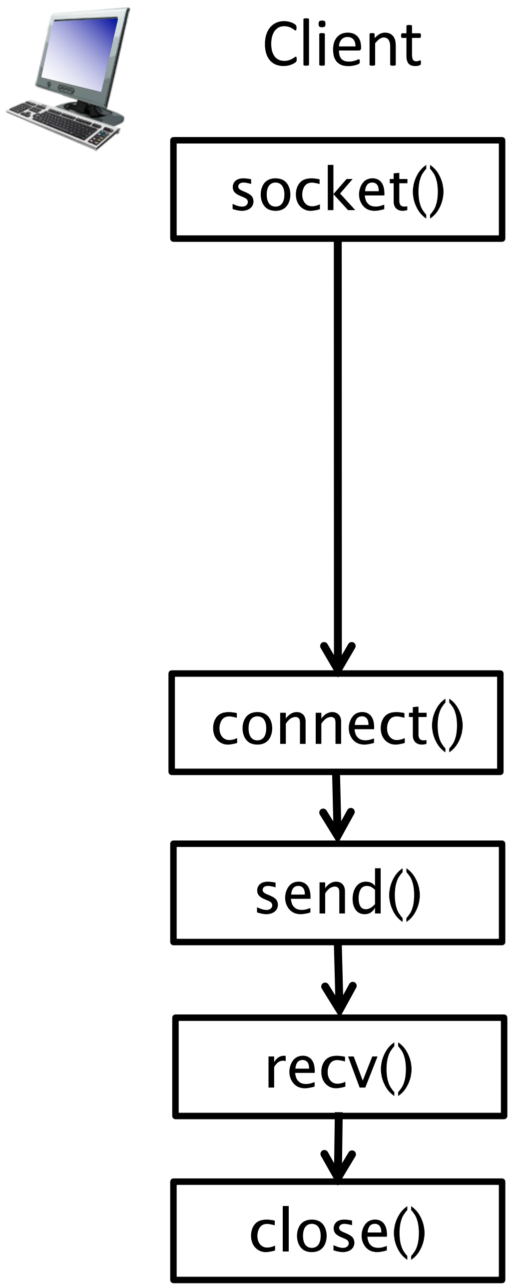
- Client:
  - initiates communication
  - must know the address and port of the server
  - active socket
- Server:
  - passively waits for and responds to clients
  - passive socket

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.

TCP Socket Procedures: Client



create a new communication endpoint

actively attempt to establish a connection

receive some data over a connection

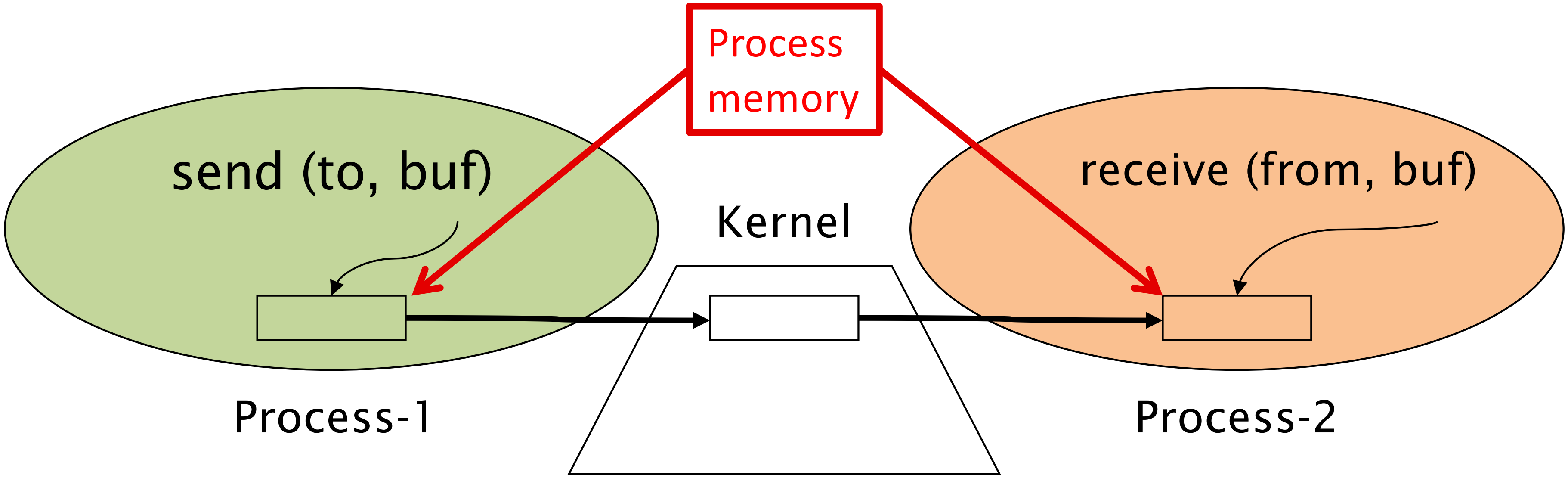
send some data over a connection

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

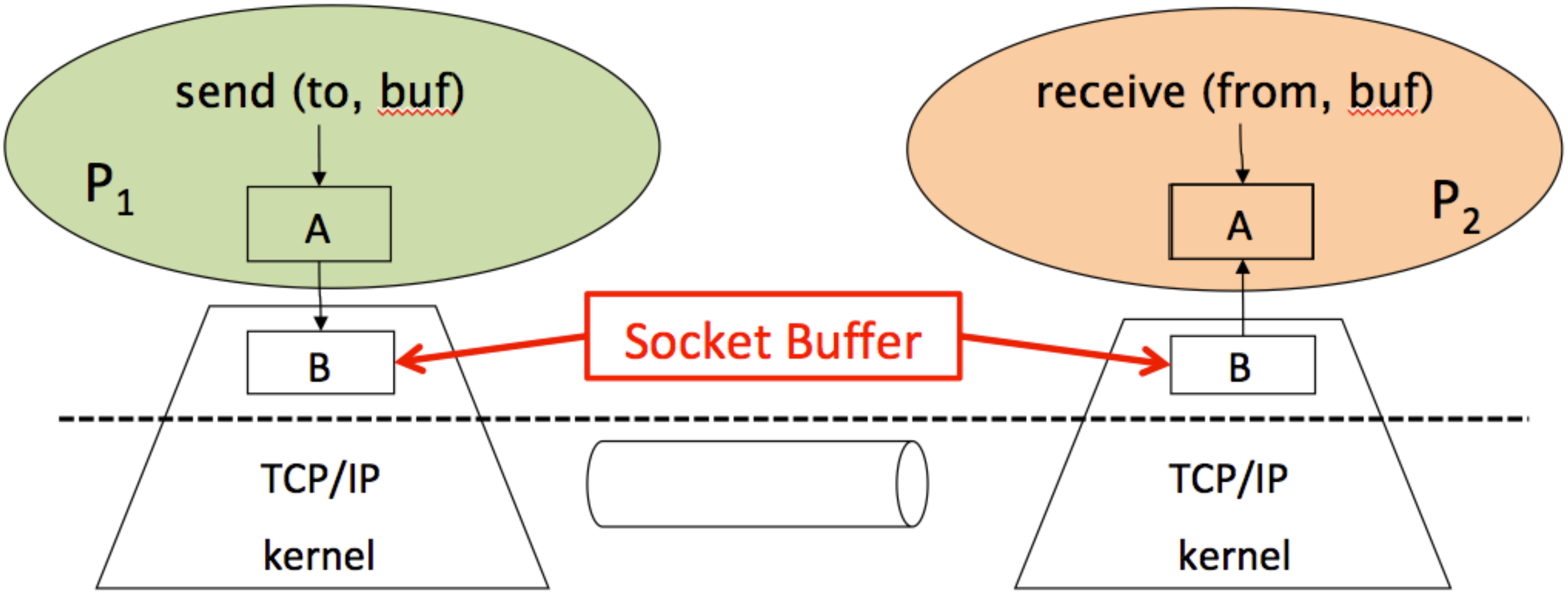
Interprocess Communication (non-local)

- Processes must communicate to cooperate

- Must have two mechanisms:
  - Data transfer
  - Synchronization

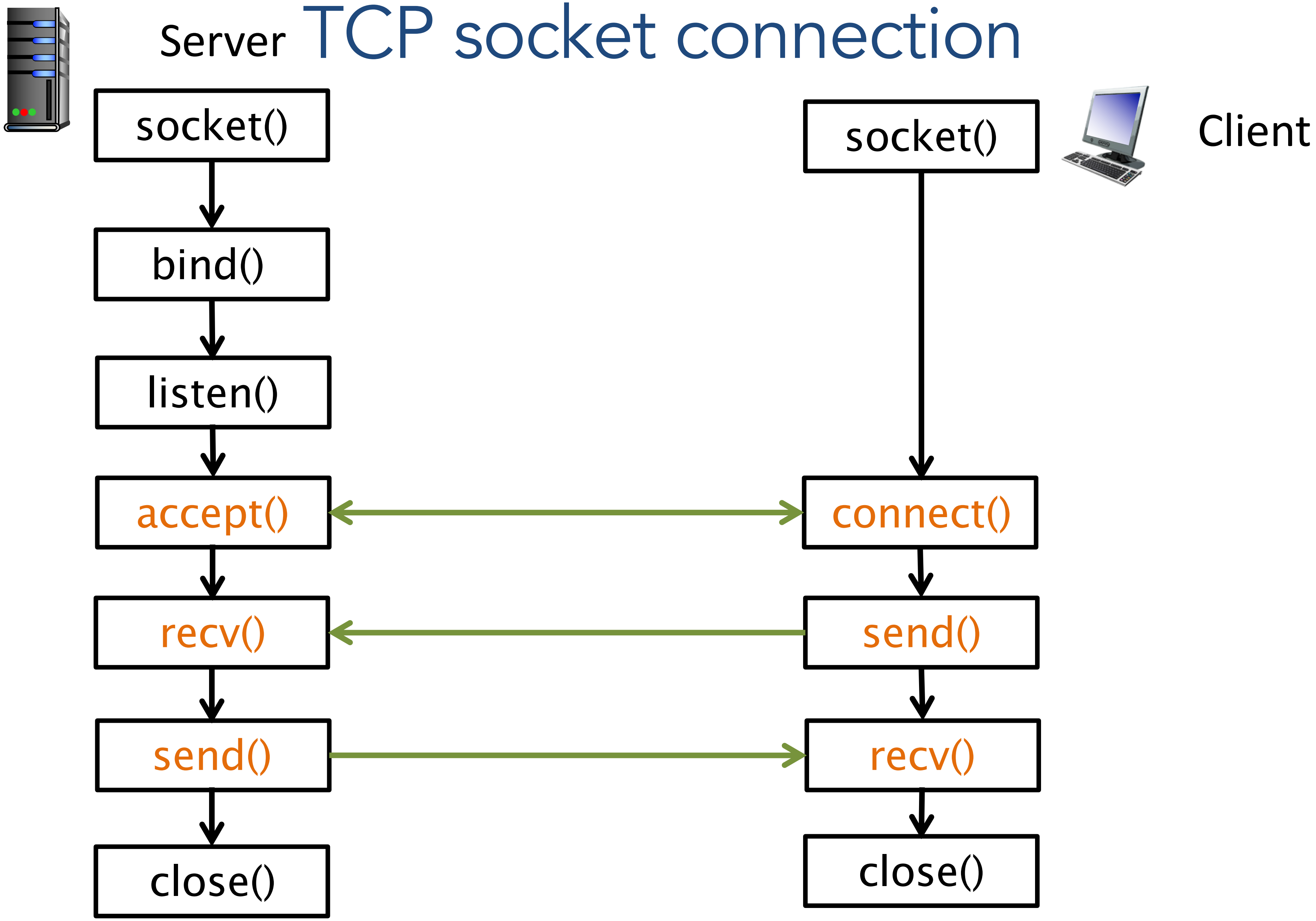
- Across a network:
  - Threads (shared memory) <u>NOT AN OPTION</u>!
  - Message passing

Message Passing (network)



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

TCP socket connection



Server

socket()

bind()

listen()

accept()

recv()

send()

close()

Client

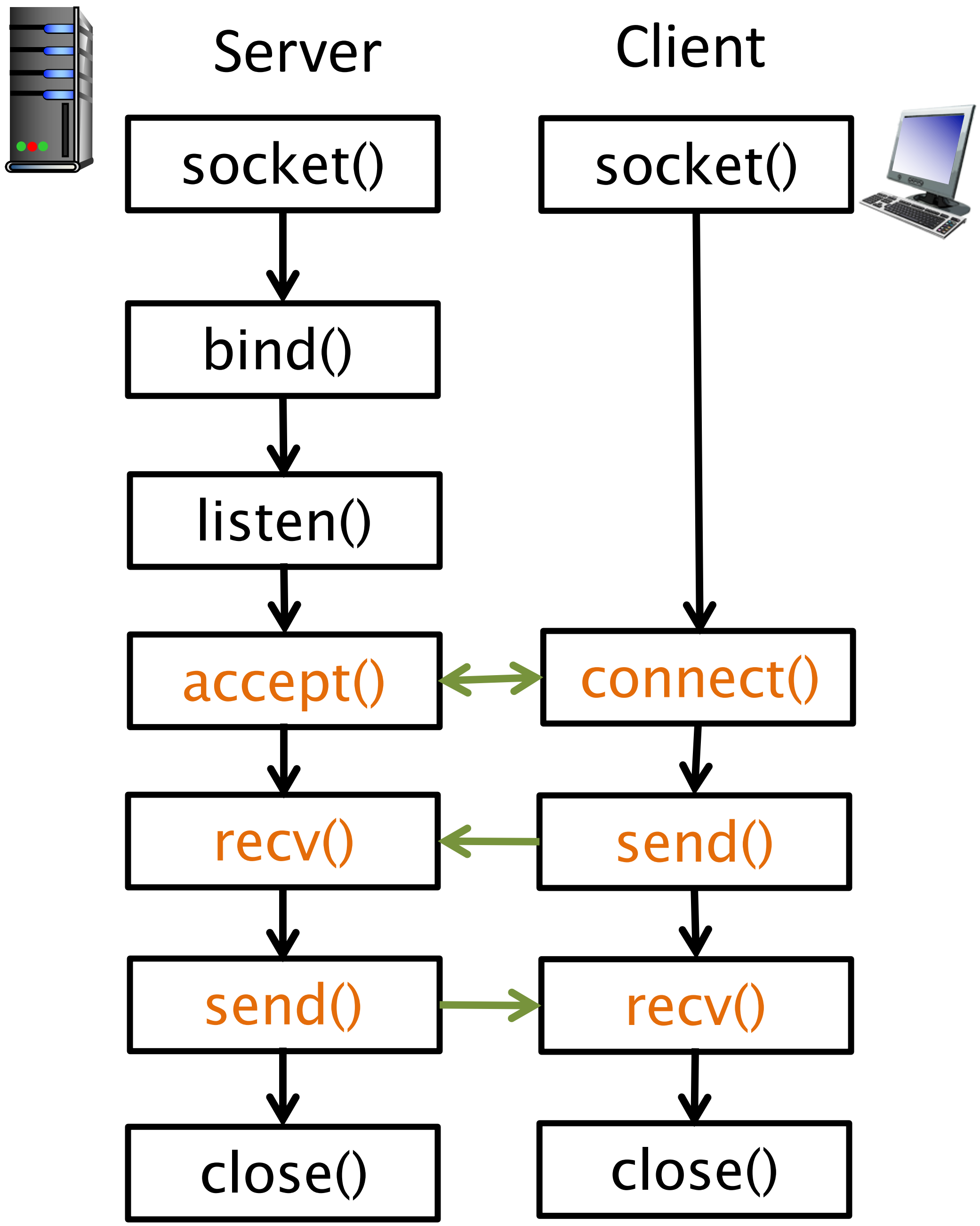
socket()

connect()

send()

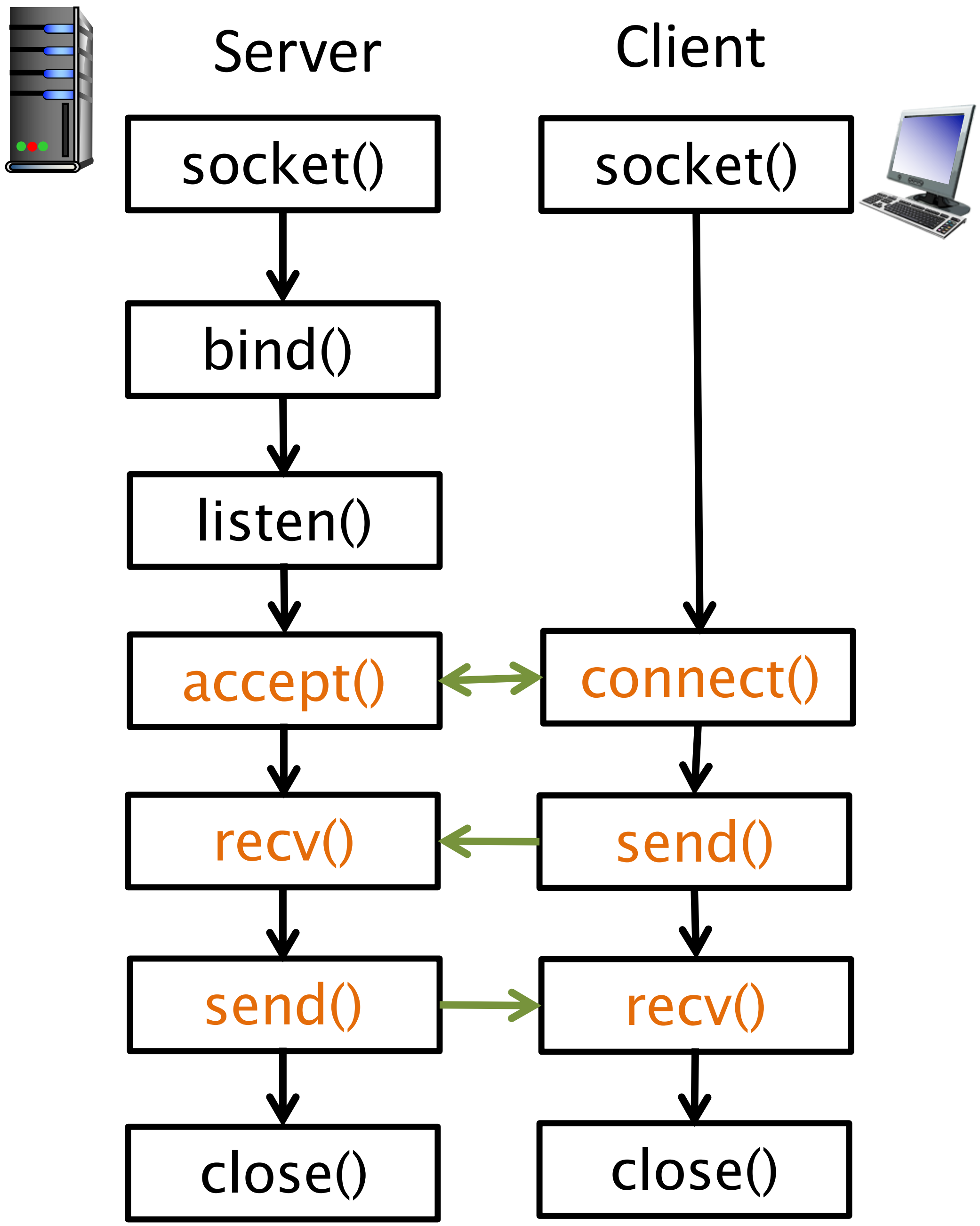
recv()

close()



If the client sends a GET request to the server using send() but forgets to send the last /r/n which of the following can happen?

A. Server, Client both recv()
B. Server send()s,
   Client recv()s
C. Server recv()s,
   Client send()s
D. Some other combination



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recv()

send()

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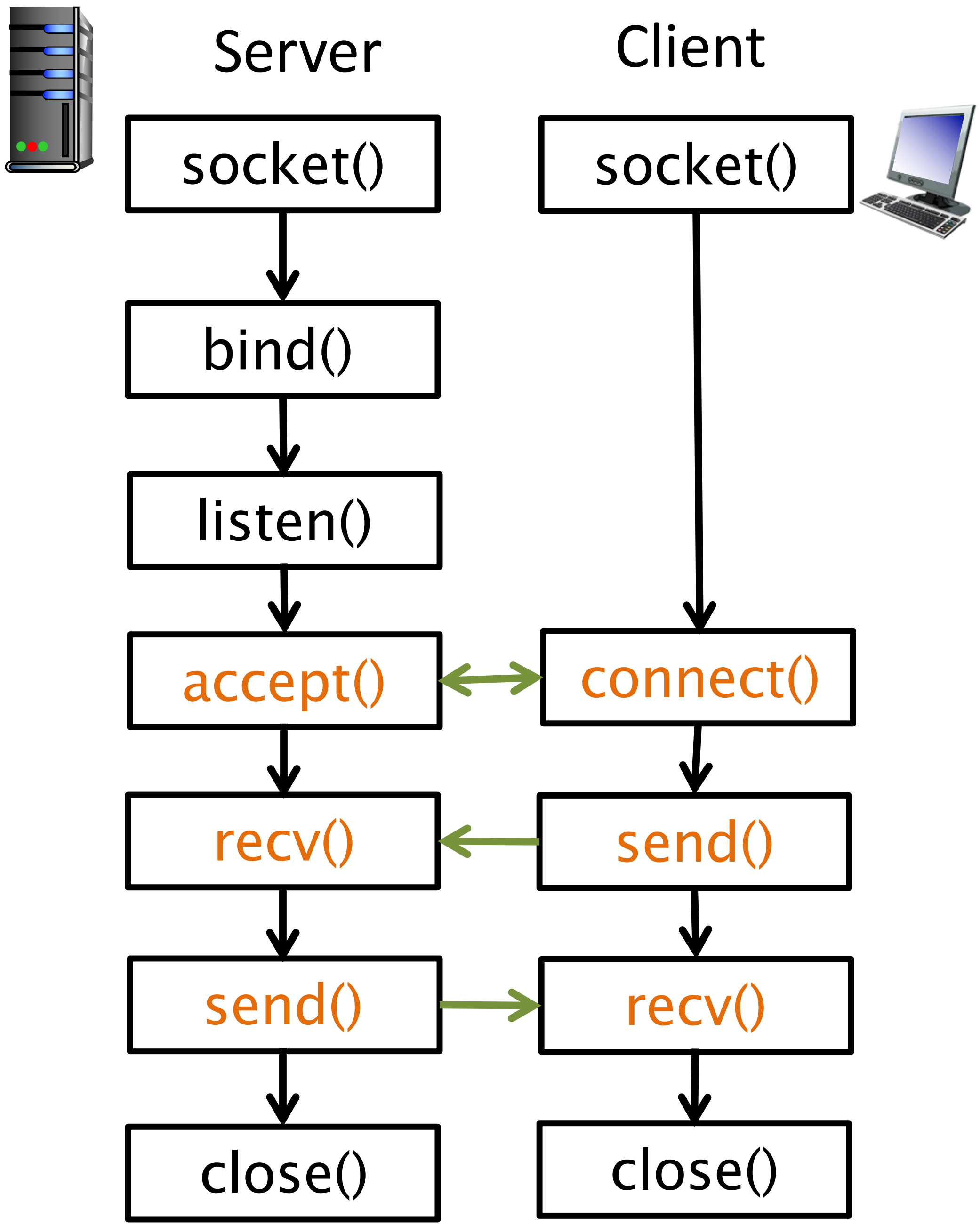


If the client sends a GET request to the server using send() but forgets to send the last /r/n which of the following can happen?

Synchronization

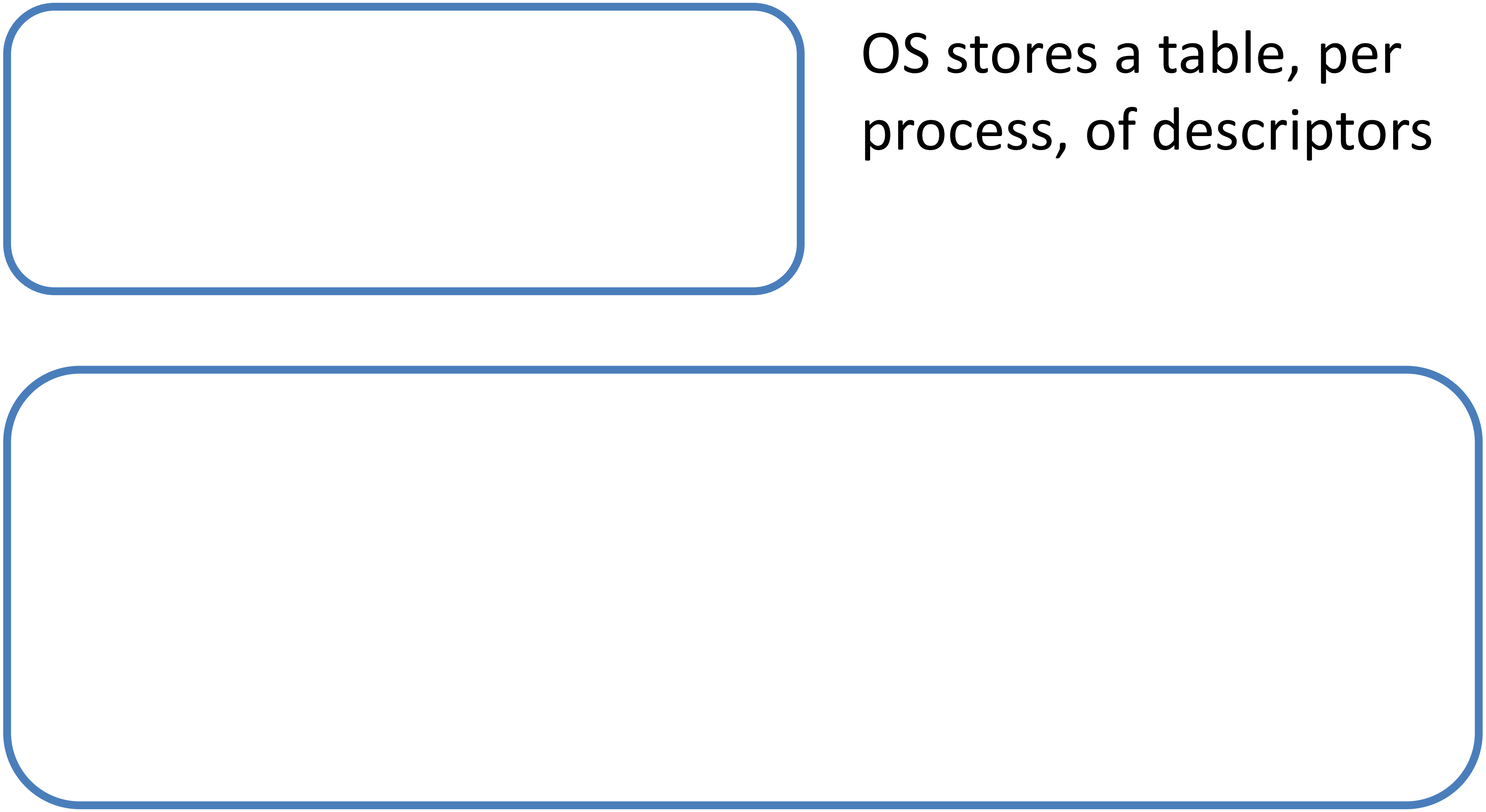
locally on one machine:

- relies on synchronization primitives.

over the network:

- depends on the order of sends and receives!

Descriptor Table

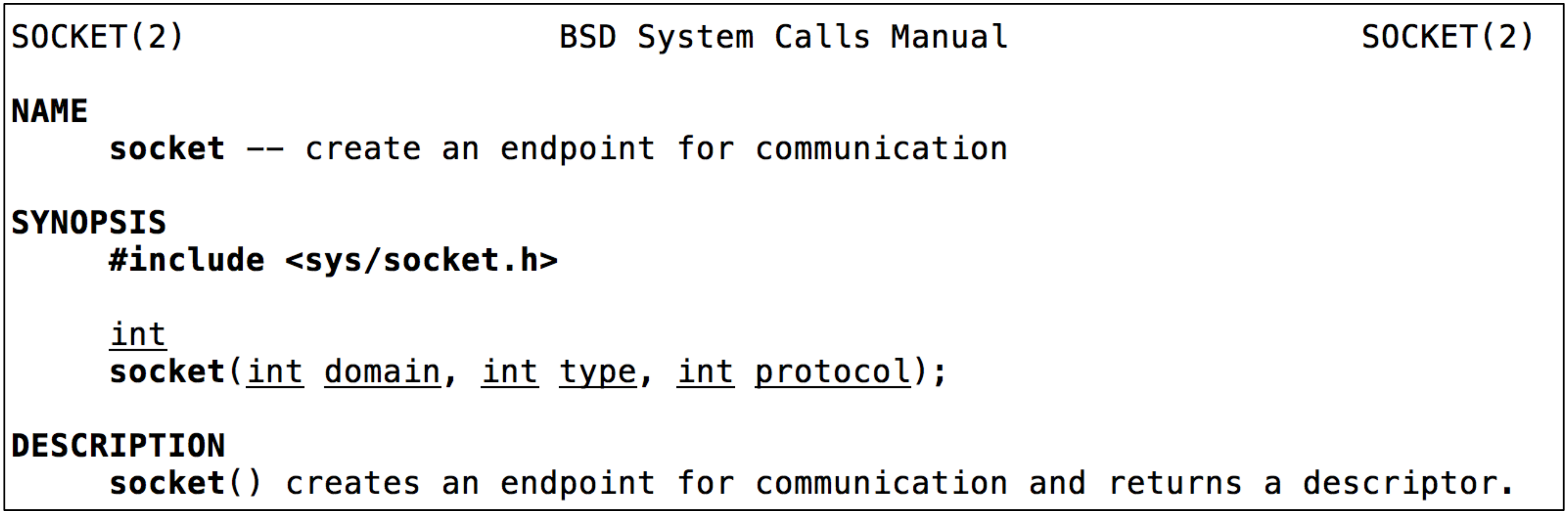


For each Process

OS stores a table, per process, of descriptors

Kernel

Descriptors



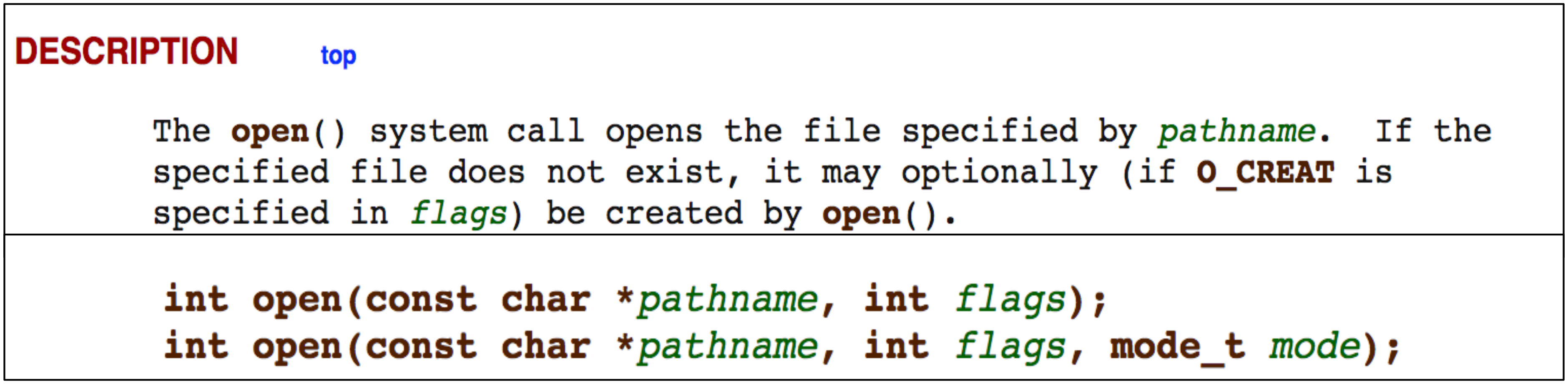
```
SOCKET(2)                 BSD System Calls Manual                SOCKET(2)

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.
```

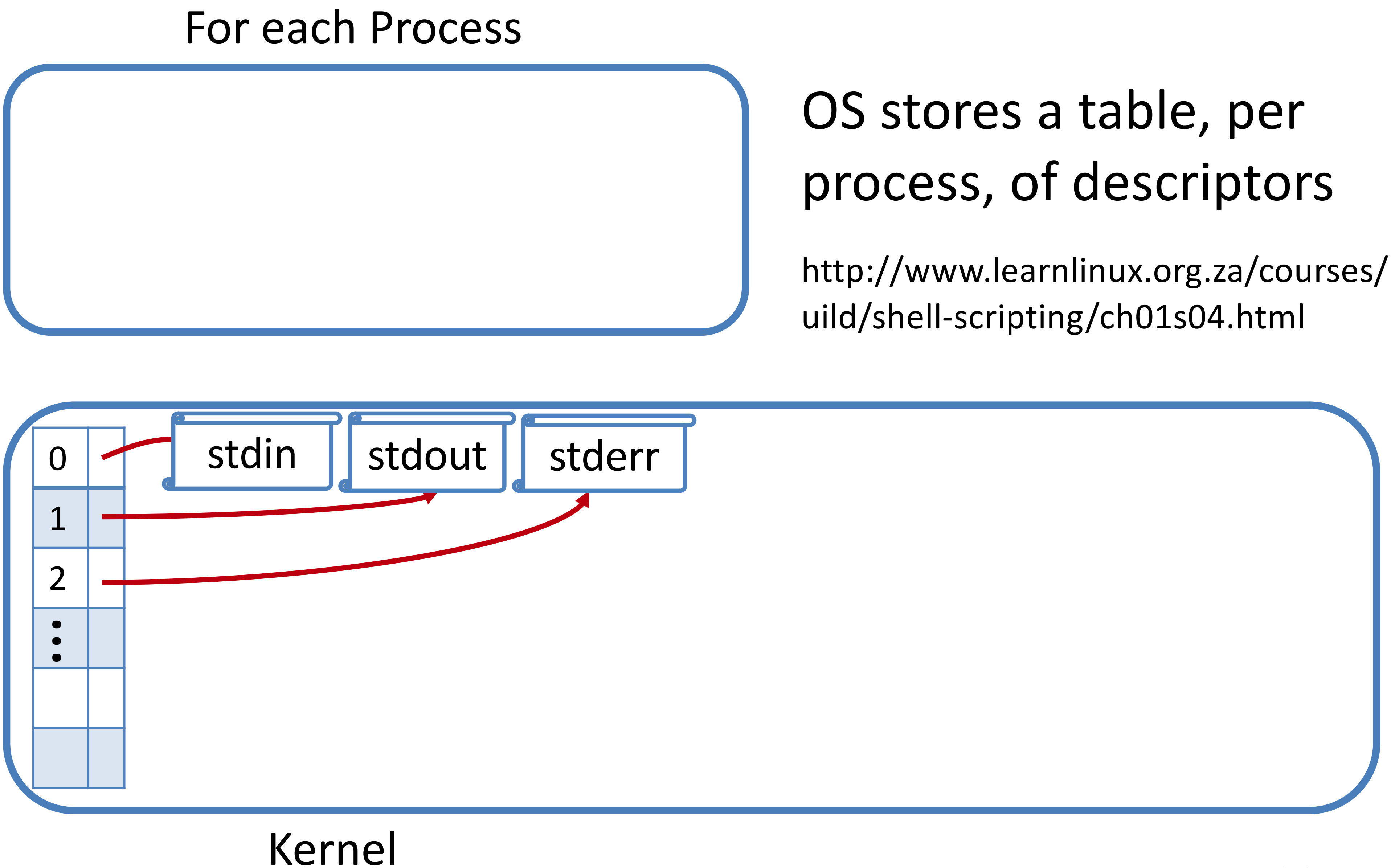


DESCRIPTION top

```
       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



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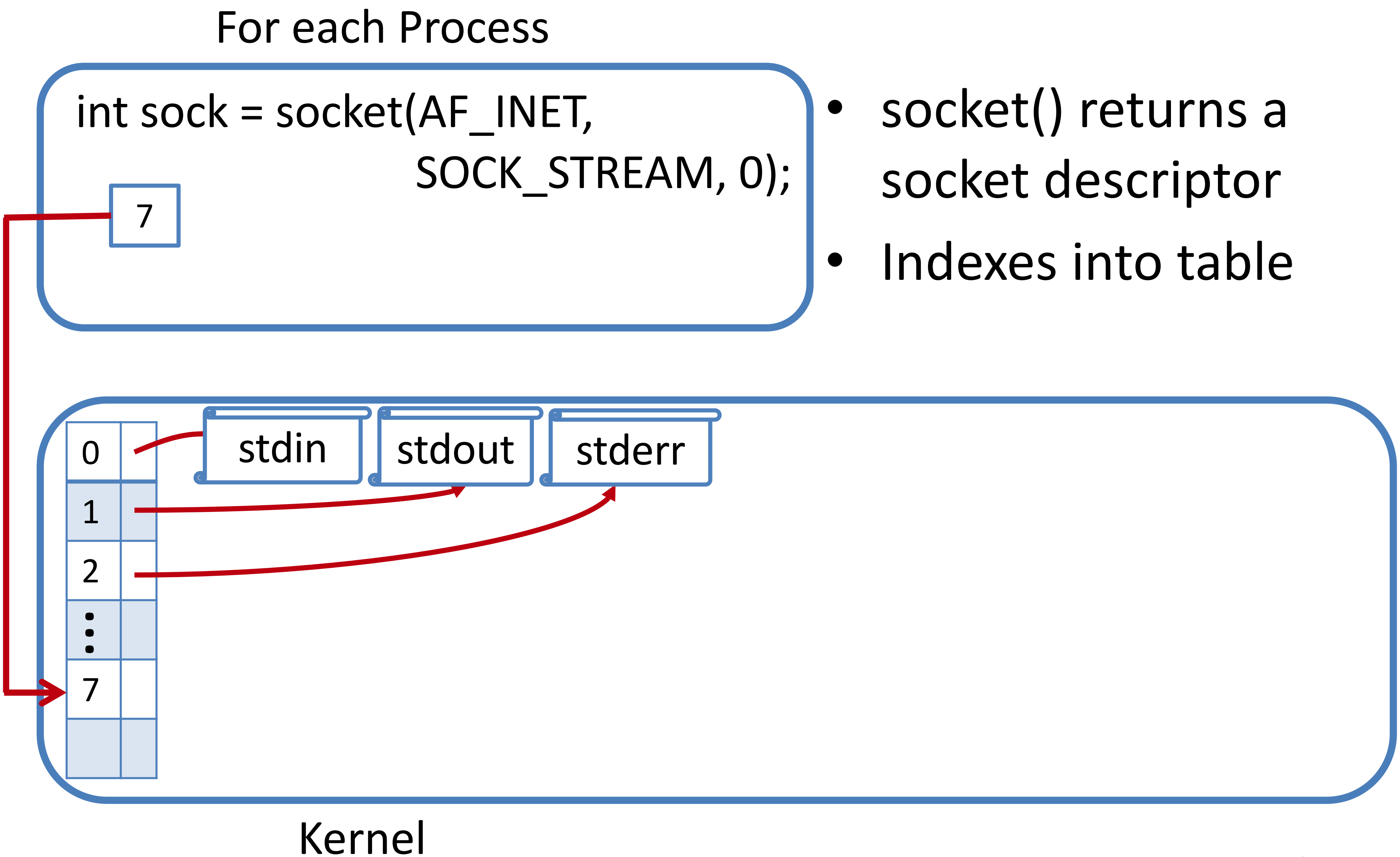
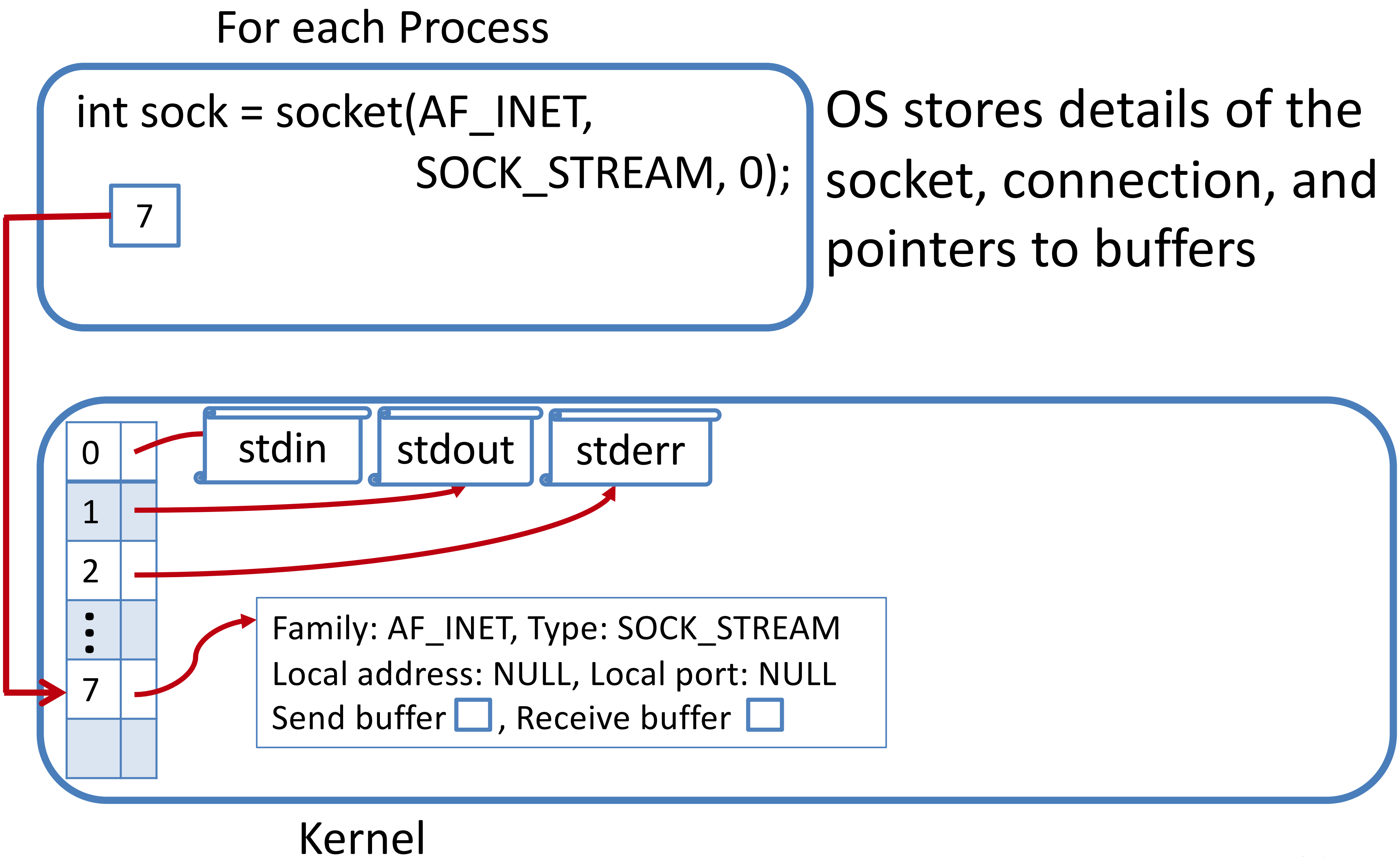
http://www.learnlinux.org.za/courses/build/shell-scripting/ch01s04.html

socket()



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

socket()

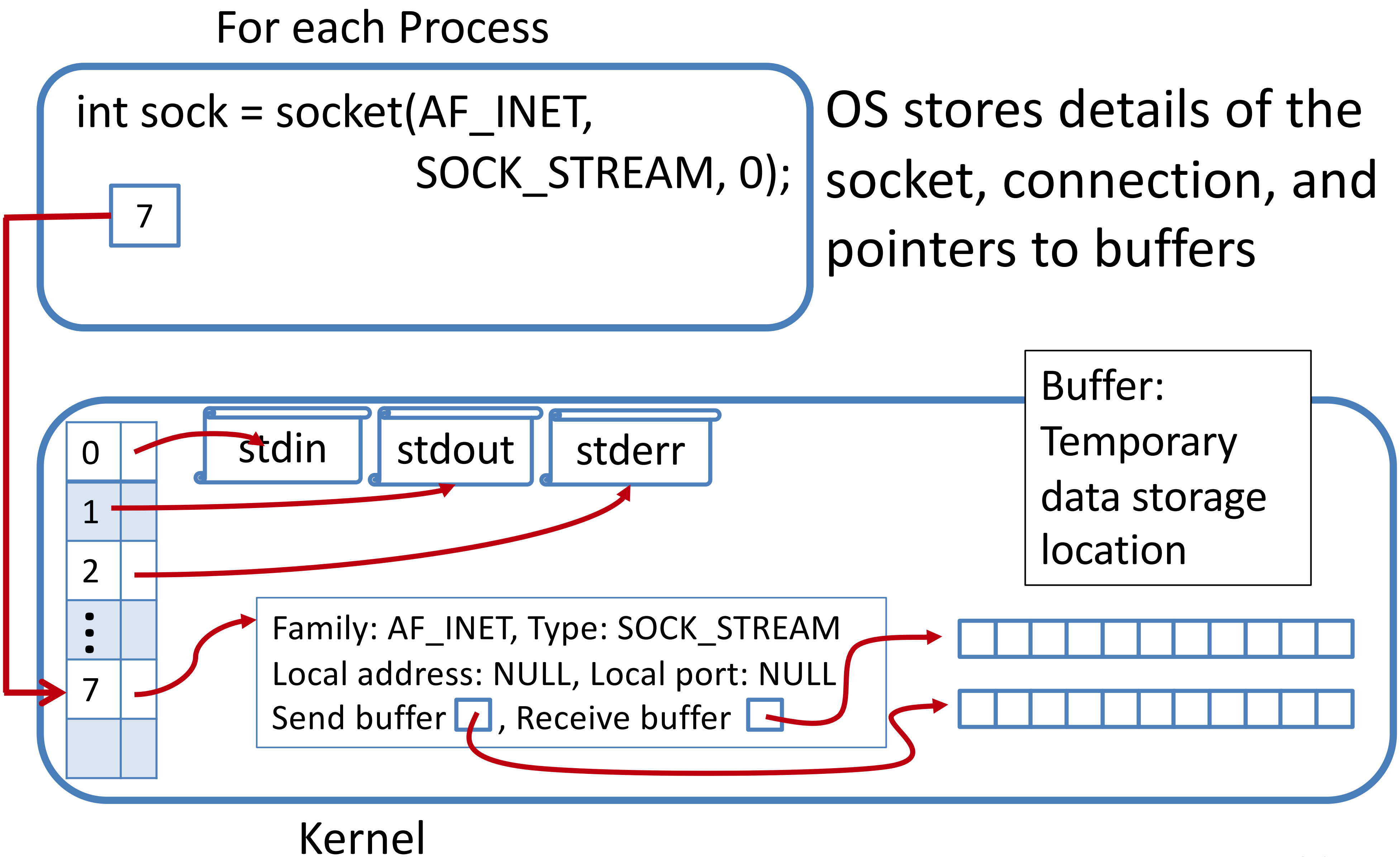


```
int sock = socket(AF_INET,
                  SOCK_STREAM, 0);
```

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

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

socket()



For each Process

```
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```

7

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

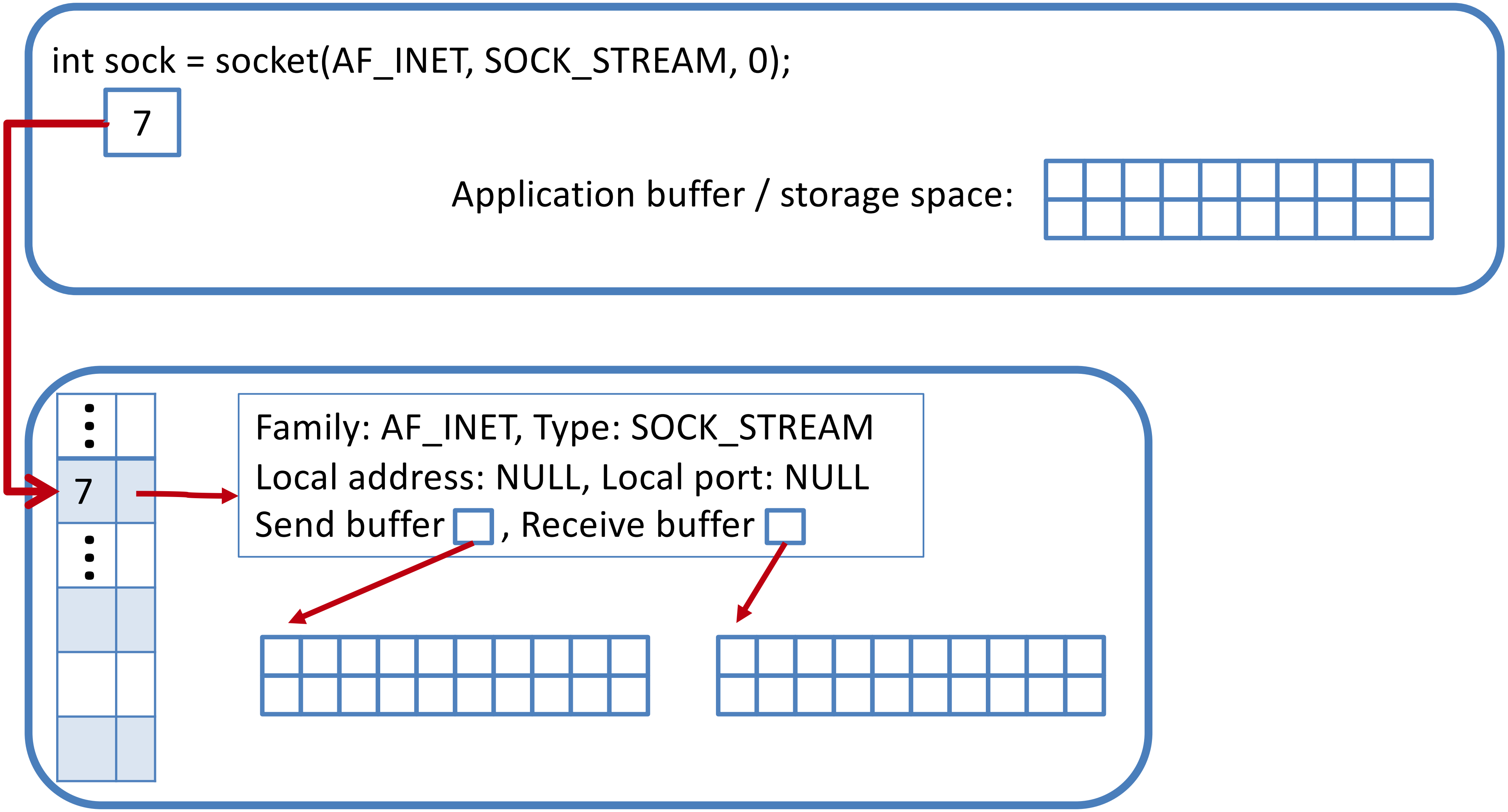
Family: AF_INET, Type: SOCK_STREAM
Local address: NULL, Local port: NULL
Send buffer ☐, Receive buffer ☐

Buffer: Temporary data storage location

Kernel

Socket Buffers

For each Process



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

Application buffer / storage space:

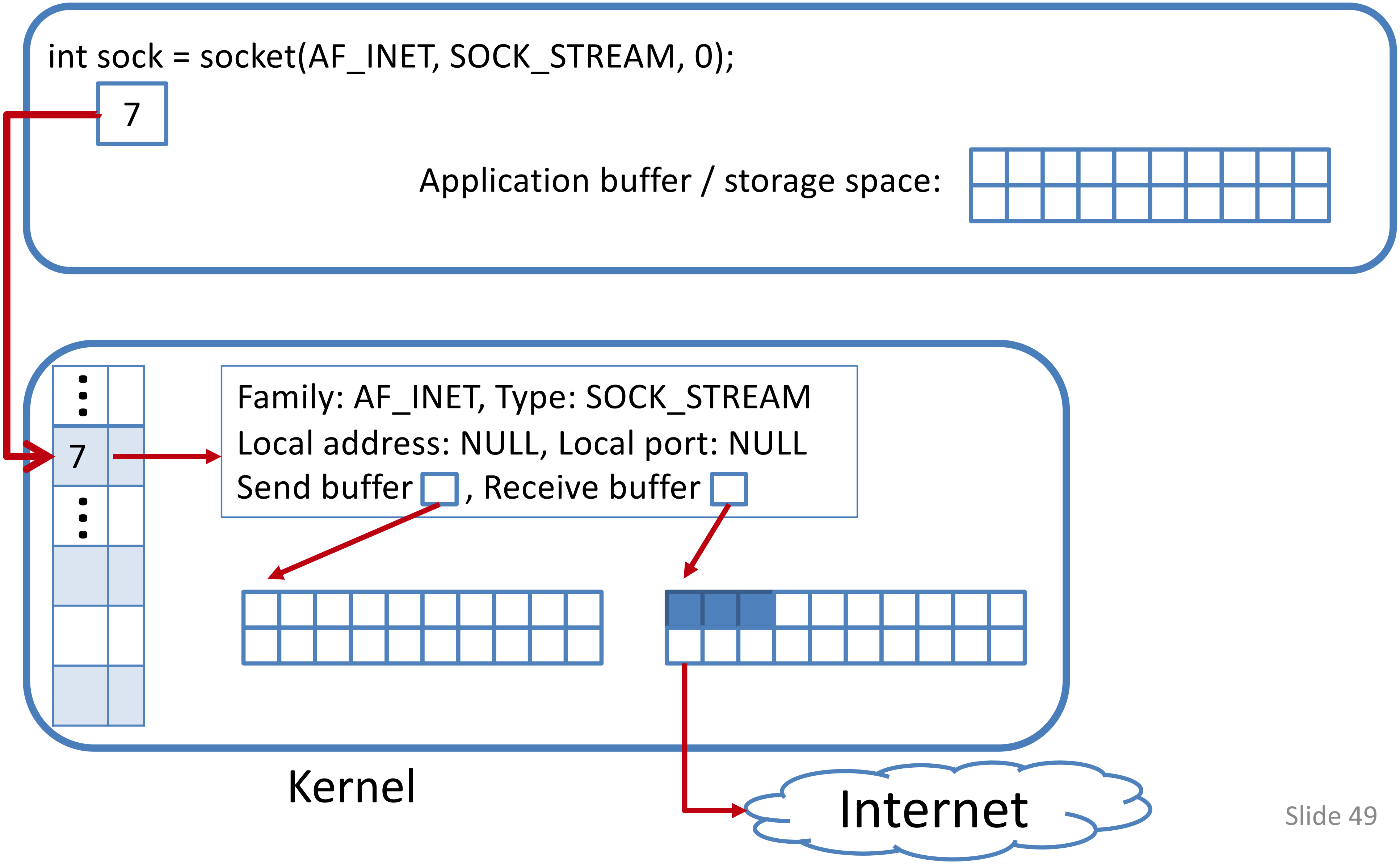
Family: AF_INET, Type: SOCK_STREAM

Local address: NULL, Local port: NULL

Send buffer ☐, Receive buffer ☐

Kernel

Socket Buffers



For each Process

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Family: AF_INET, Type: SOCK_STREAM

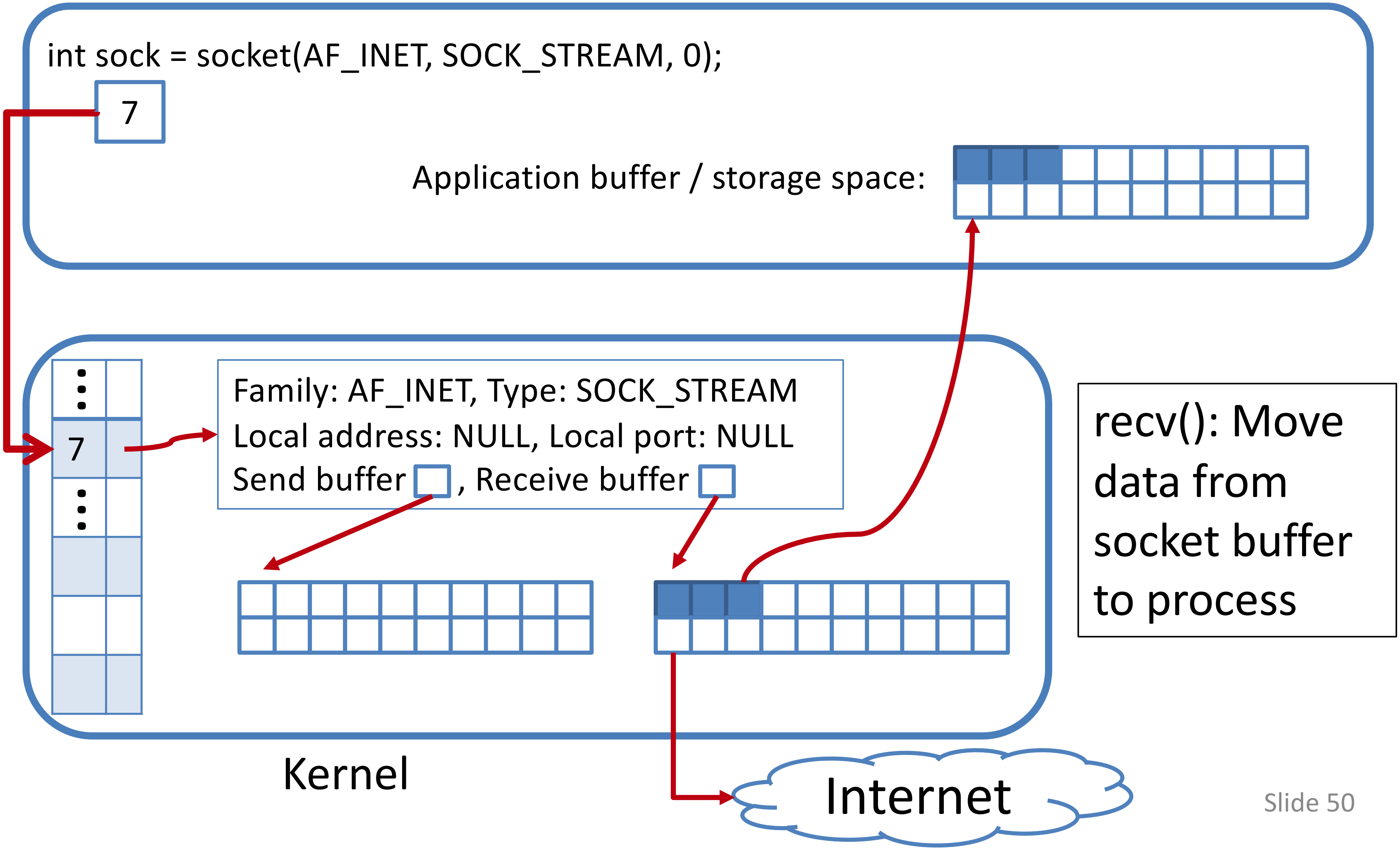
Local address: NULL, Local port: NULL

Send buffer ☐, Receive buffer ☐

Kernel

Internet

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

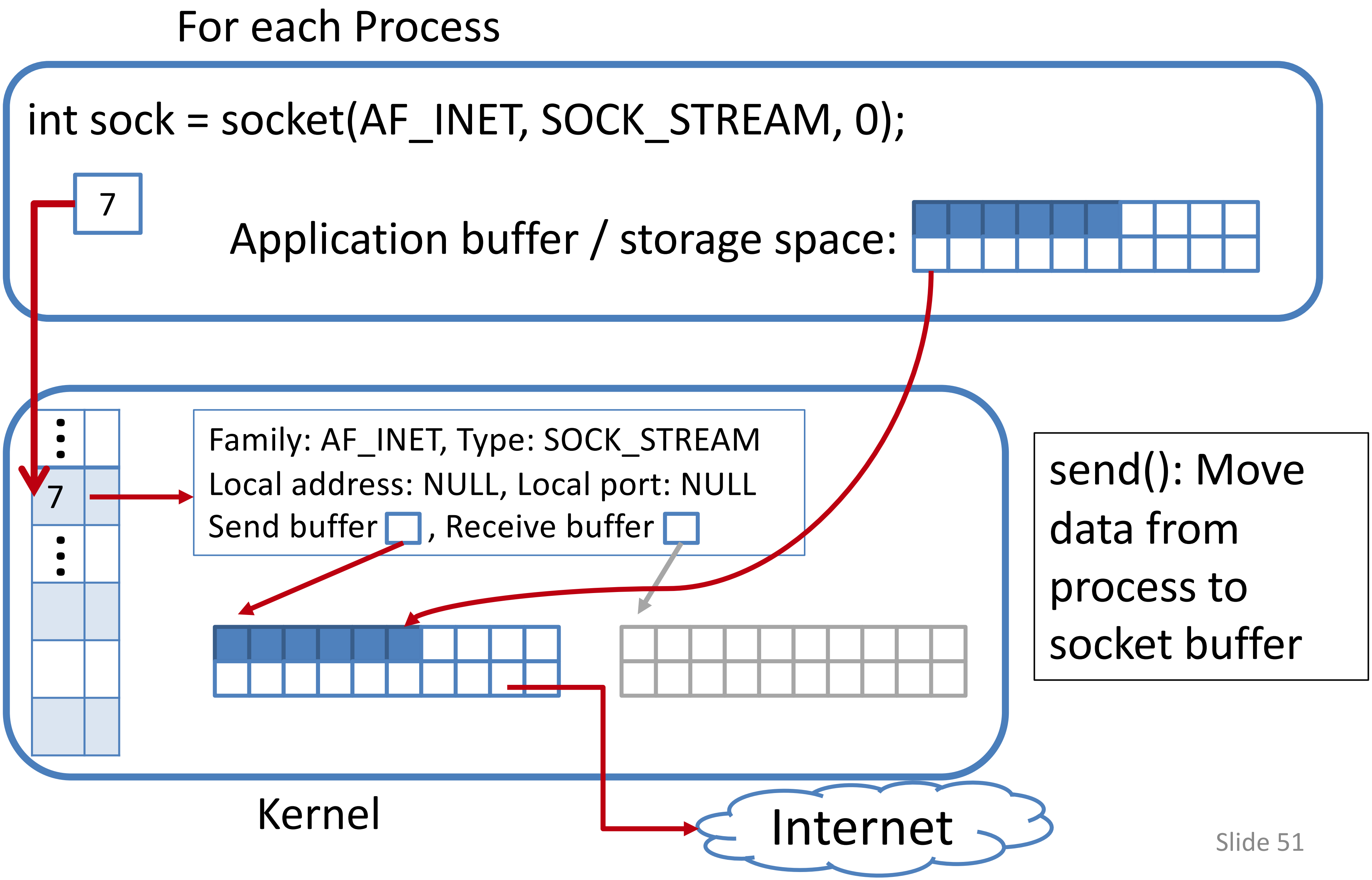
Send buffer ☐, Receive buffer ☐

Kernel

Internet

recv(): Move data from socket buffer to process

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

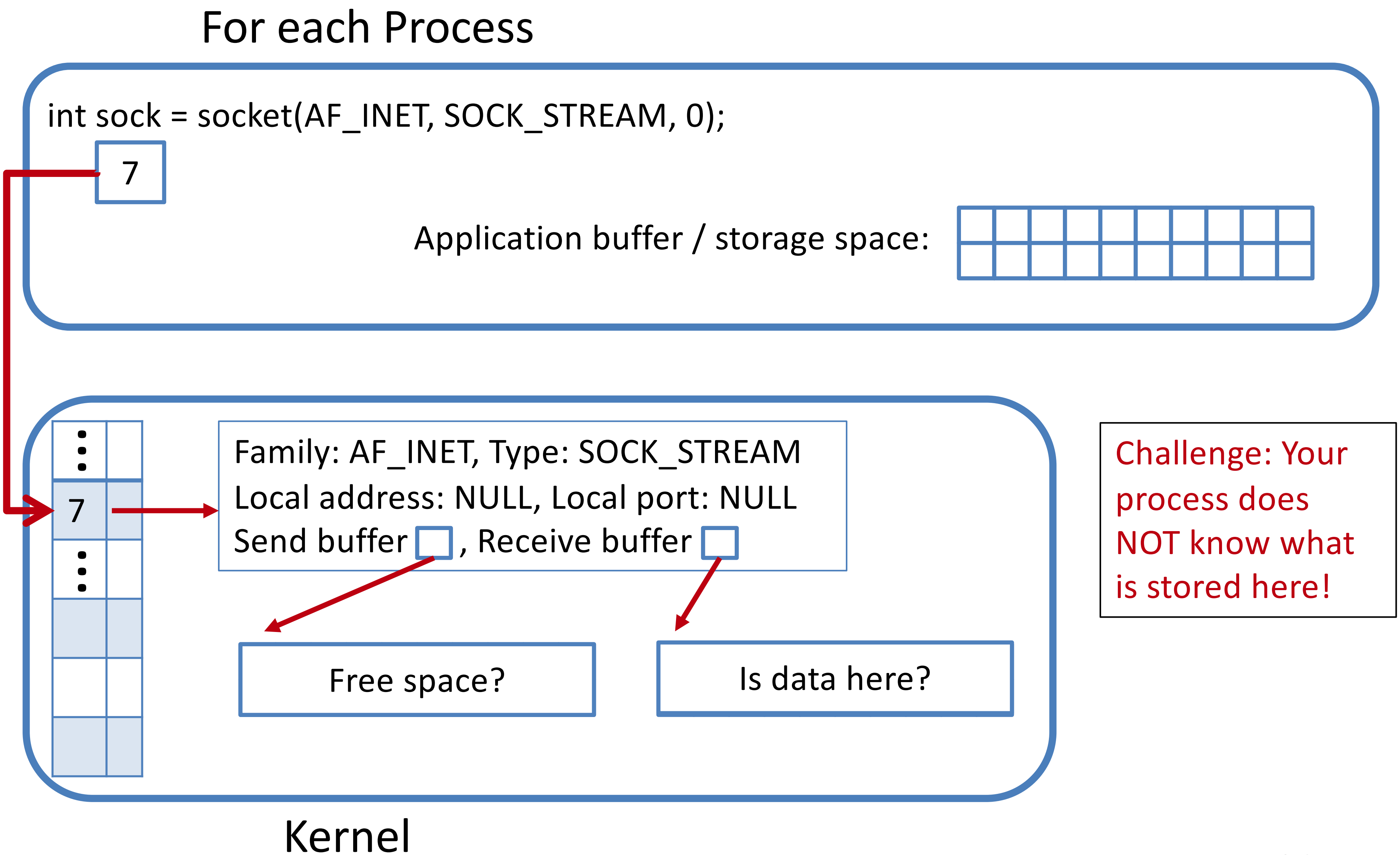
Send buffer ☐, Receive buffer ☐

send(): Move data from process to socket buffer

Kernel

Internet

Socket Buffers



For each Process

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

7

Application buffer / storage space:

7

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!

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

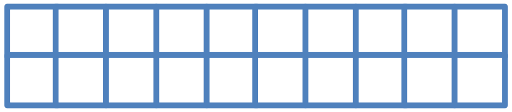
For each Process

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

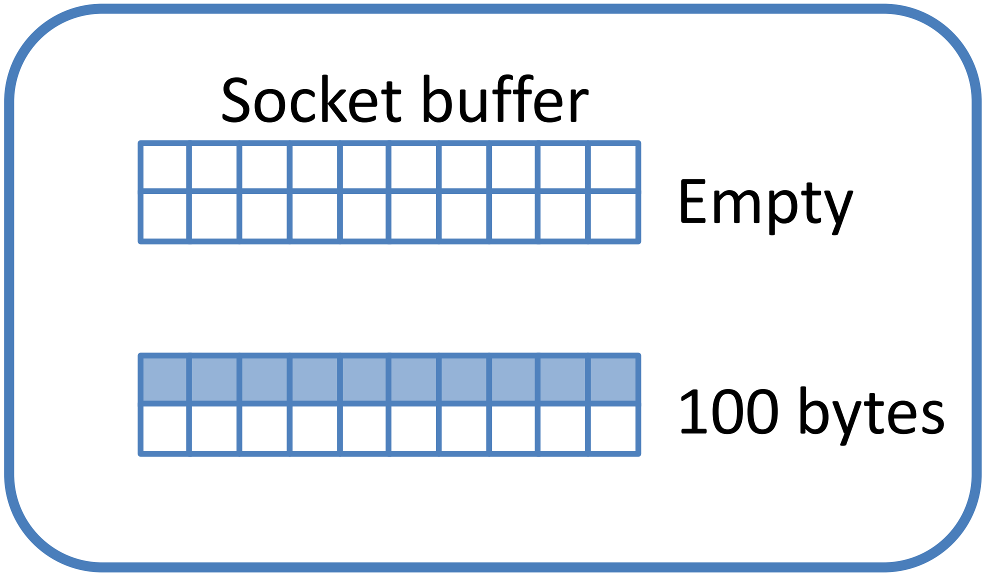
(assume we connect()ed here…)

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

r_buf (size 200)



Two Scenarios:



Socket buffer

Empty

100 bytes

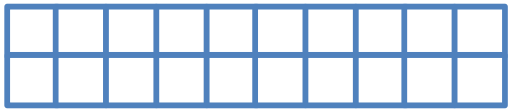
Kernel

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

For each Process

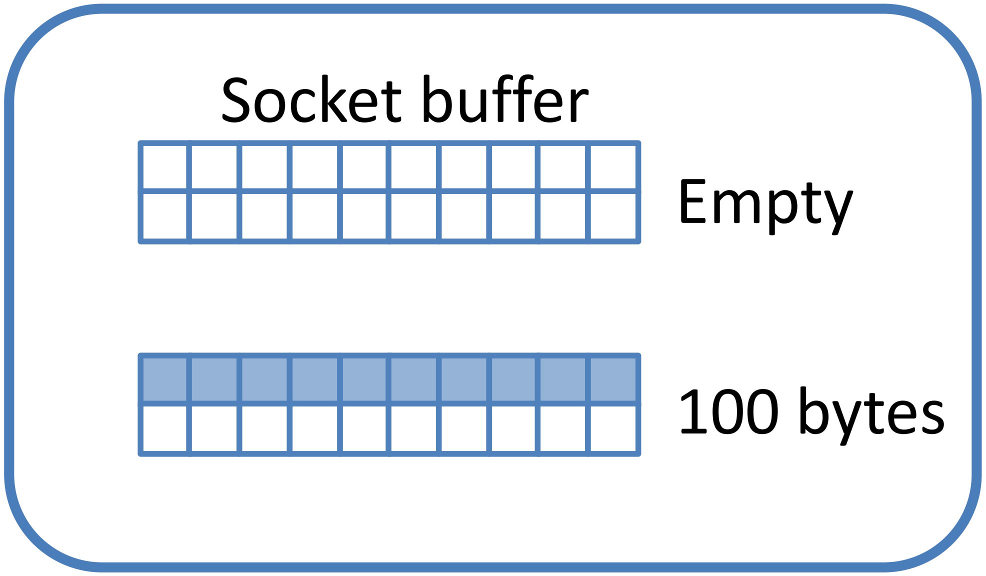
```
int sock = socket(AF_INET, SOCK_STREAM, 0);
        (assume we connect()ed here…)
int recv_val = recv(sock, r_buf, 200, 0);
```

r_buf (size 200)



Two Scenarios:

	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**	



Socket buffer

Empty

100 bytes

Kernel

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

For each Process

```
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          (assume we connect()ed here…)
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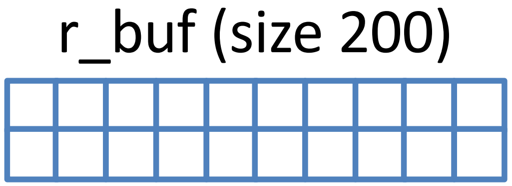
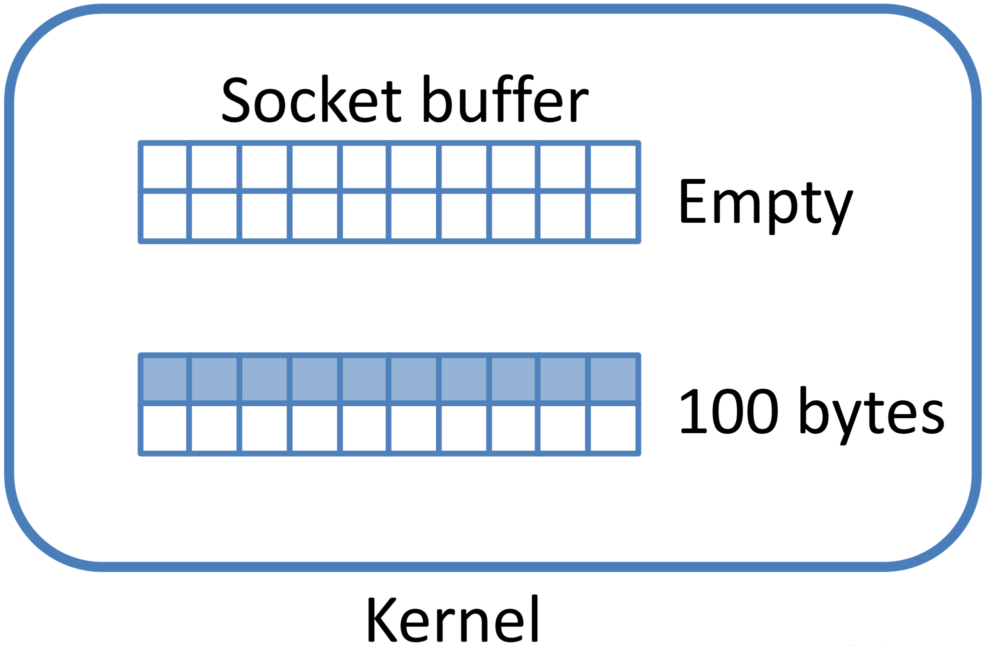


Two Scenarios:

	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**	

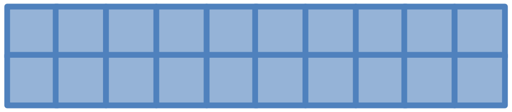


What should we do if the send socket buffer is full? If it has 100 bytes?

For each Process

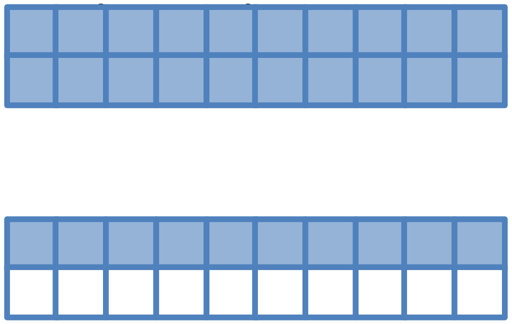
```
int sock = socket(AF_INET, SOCK_STREAM, 0);
        (assume we connect()ed here…)
int send_val = send(sock, r_buf, 200, 0);
```

s_buf (size 200)



Two Scenarios:

Socket buffer



Full

100 bytes

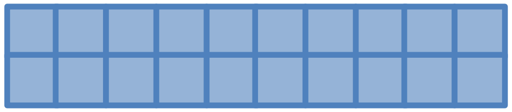
Kernel

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

For each Process

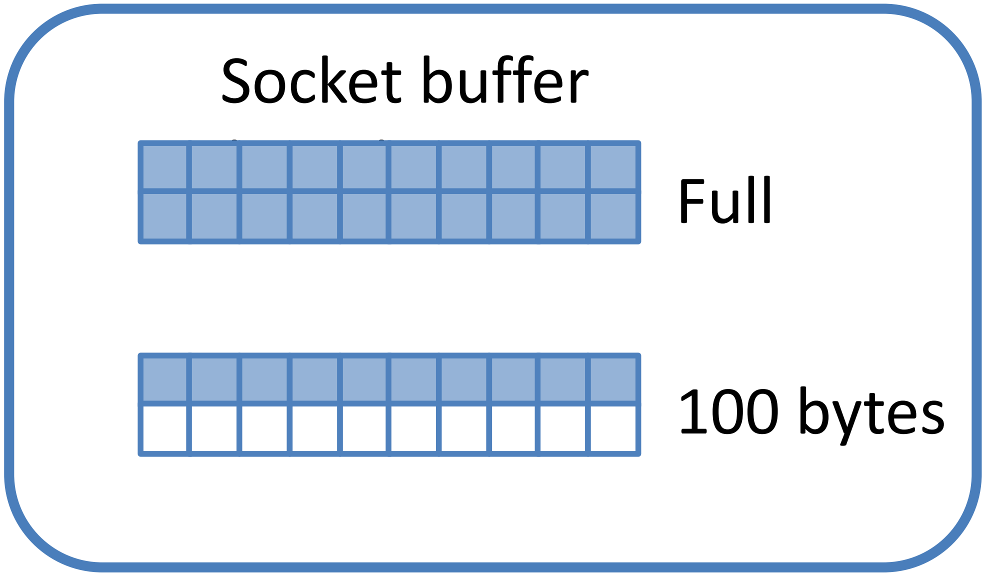
```
int sock = socket(AF_INET, SOCK_STREAM, 0);
        (assume we connect()ed here…)
int send_val = send(sock, r_buf, 200, 0);
```

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!

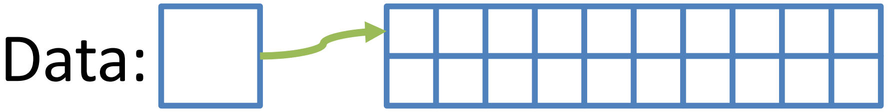
When recv() returns a non-zero number of bytes always call recv() again until:

  - 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);



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

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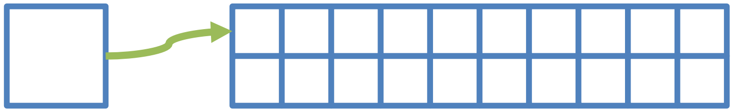
`recv(sock, data, 200, 0);`

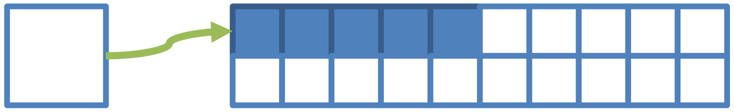
Data:



Data received = 50

Remaining buffer size = 150

Data:



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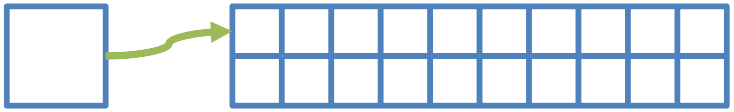

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Remaining buffer size = 150

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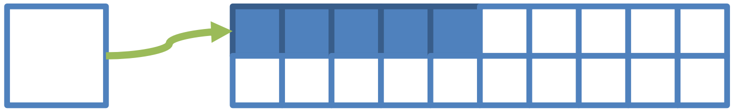


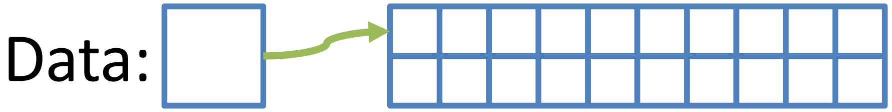
// Receive remaining bytes from offset of 50

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.

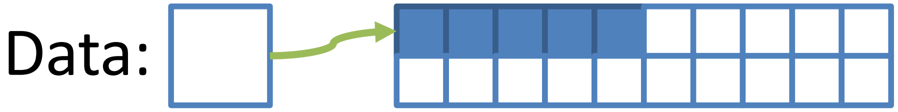
Data size to receive = unknown

recv(sock, data, 200, 0);



Data received = 50

Remaining buffer size = 150



// Receive remaining bytes from offset of 50

recv(sock, data + 50, 200 – 50, 0)

Data received = ?

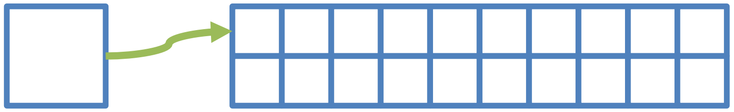
ALWAYS check send()/recv() return values!

- 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);

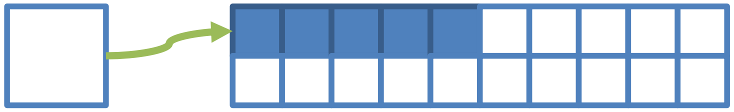
Data:



Data received = 50

Remaining buffer size = 150

Data:



// 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)

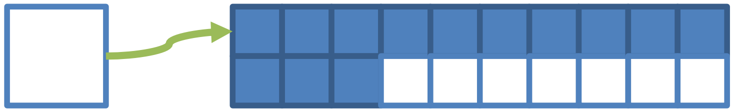
ALWAYS check send() and recv()'s return value!

- When send() /recv() return value is less than the data size, **you are responsible for sending/receiving the rest**.

Data sent: 0

Data to send: 130

Data:



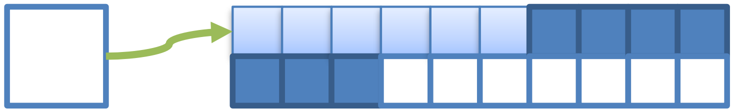
60

send(sock, data, 130, 0);

Data sent: 60

Data to send: 130

Data:



// what should your next send call look like?

send(...)

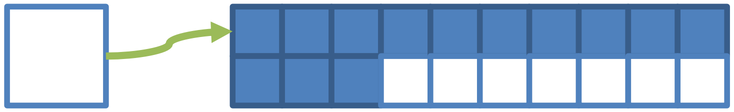
ALWAYS check send() return value!

- When send() return value is less than the data size, **you are responsible for sending the rest.**

Data sent: 0

Data to send: 130

Data:



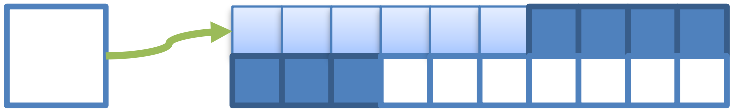
60

send(sock, data, 130, 0);

Data sent: 60

Data to send: 130

Data:



// Copy the 70 bytes starting from offset 60.

send(sock, data + 60, 130 - 60, 0);

ALWAYS check send() return value!

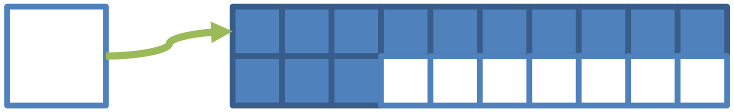
- When send() return value is less than the data size, **you are responsible for sending the rest.**

Data sent: 0

Data to send: 130

60 send(sock, data, 130, 0);

Data:



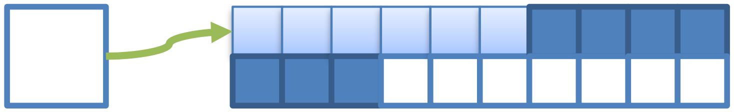
Data sent: 60

Data to send: 130

? // Copy the 70 bytes starting from offset 60.

send(sock, data + 60, 130 - 60, 0);

Data:



Repeat until all bytes are sent. (data_sent == data_to_send)…

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!