CSE 43: Computer Networks
Structure, Threading, and Blocking

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Agenda

- Under-the-hood look at system calls
  - Data buffering and blocking
- Processes, threads, and concurrency models
- Event-based, non-blocking I/O

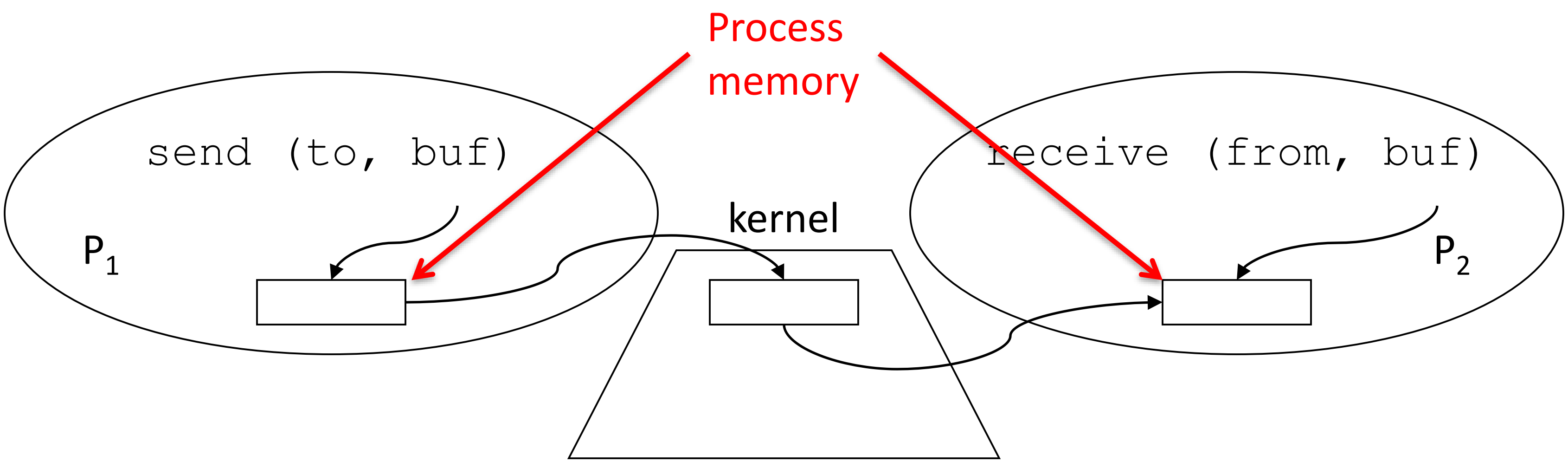
Recall Interprocess Communication

- 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: ?

Where is the synchronization in message passing IPC?

A. The OS adds synchronization.

B. Synchronization is determined by the order of sends and receives.

C. The communicating processes exchange synchronization messages (lock/unlock).

D. There is no synchronization mechanism.

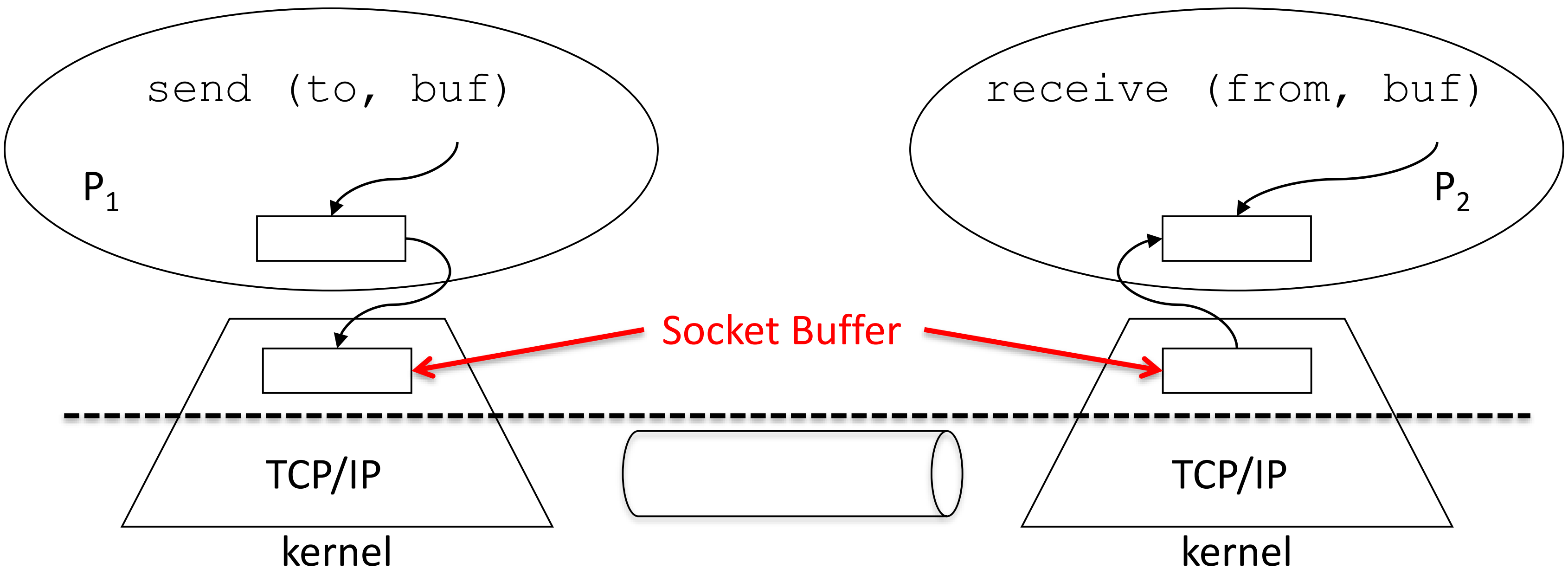
Interprocess Communication (non-local)

- 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

Process

- OS stores a table, per process, of descriptors

Kernel

Descriptors

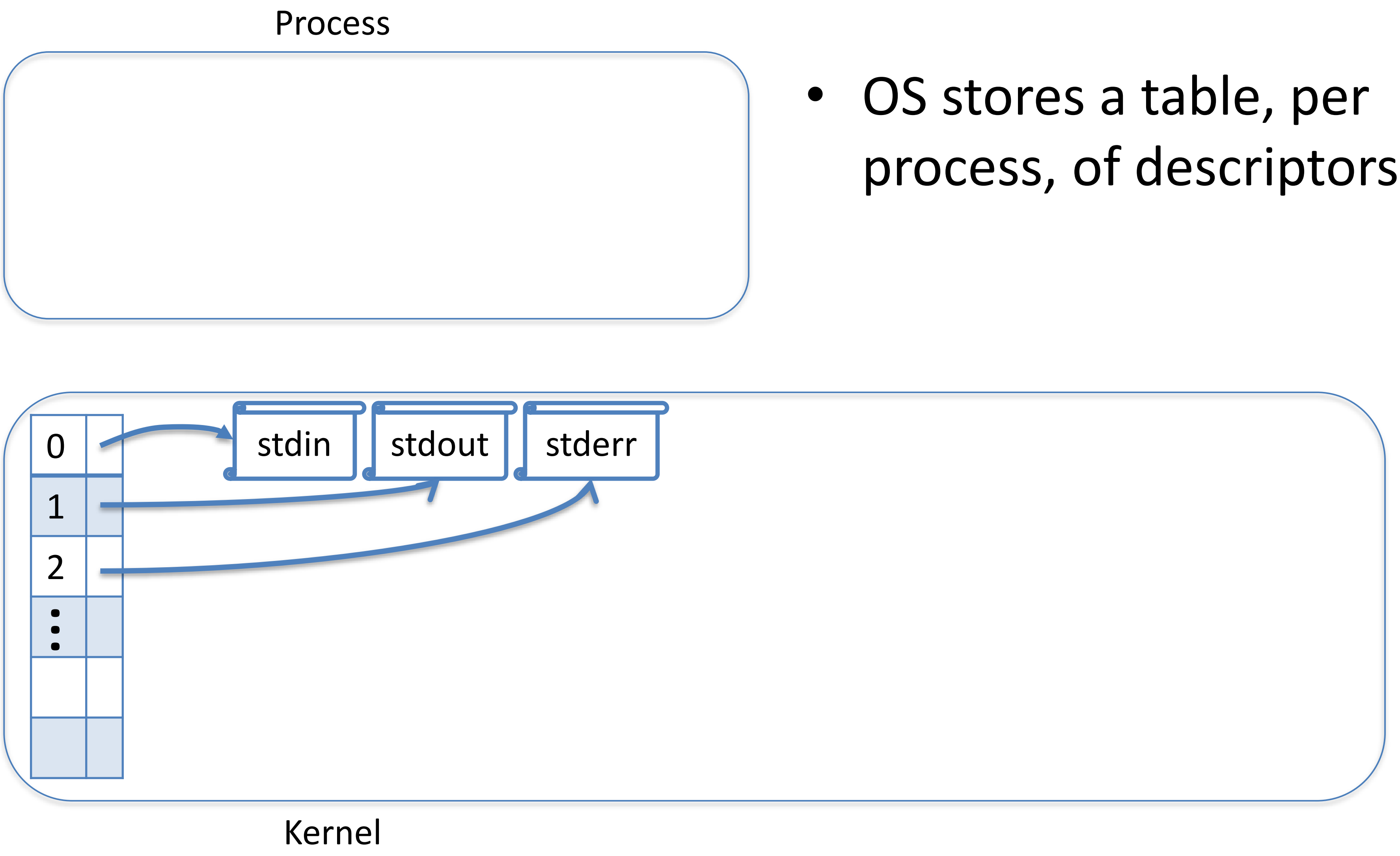
Where do descriptors come from?

What are they?

```
OPEN(2)                    Linux Programmer's Manual
          OPEN(2)

NAME
       open, openat, creat - open and possibly create a file

SYNOPSIS
       #include <sys/types.h>
       #include <sys/stat.h>
       #include <fcntl.h>

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

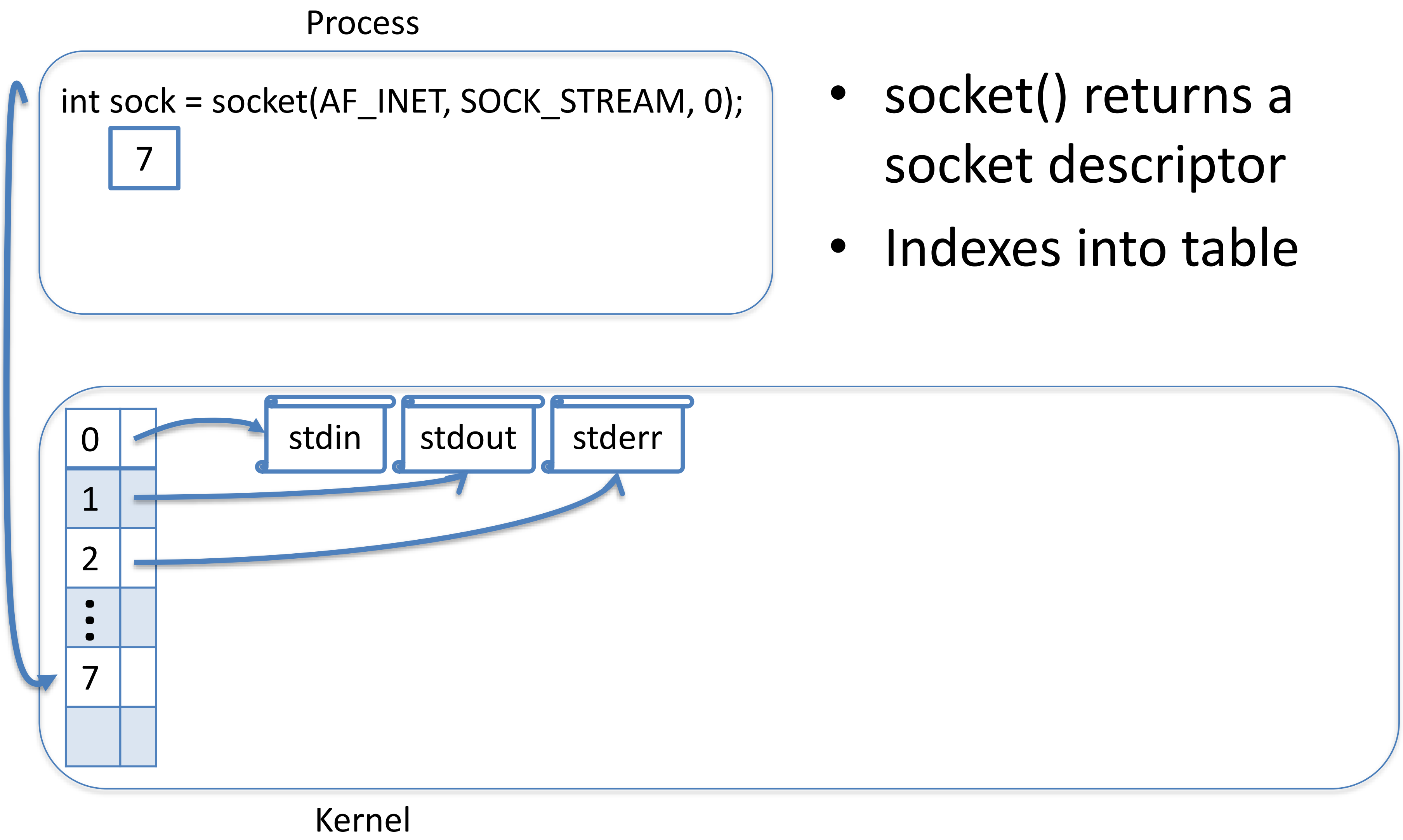
```
SOCKET(2)          Linux Programmer's Manual          SOCKET(2)

NAME
       socket - create an endpoint for communication

SYNOPSIS
       #include <sys/types.h>          /* See NOTES */
       #include <sys/socket.h>

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

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

Descriptor Table



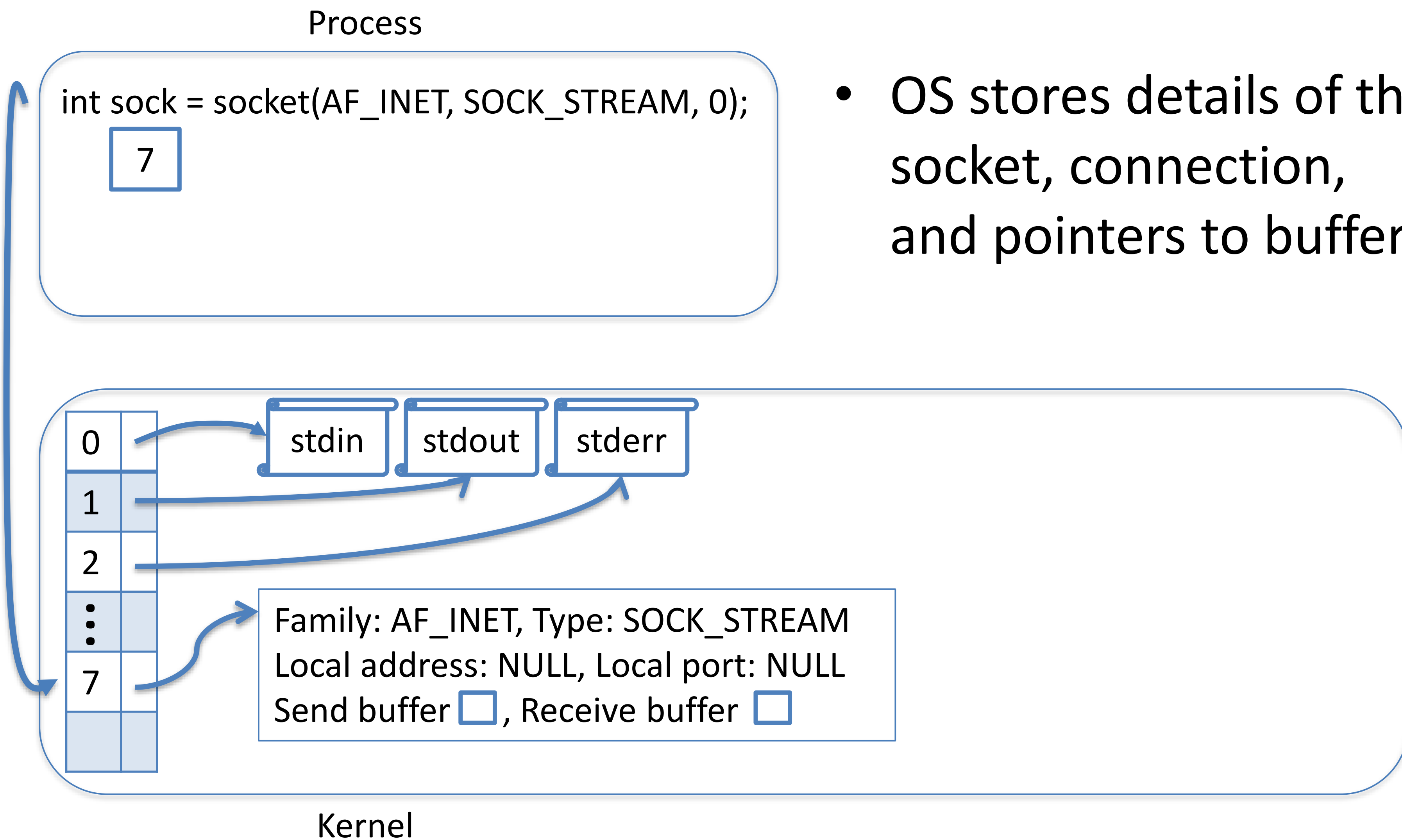
- OS stores a table, per process, of descriptors

socket()



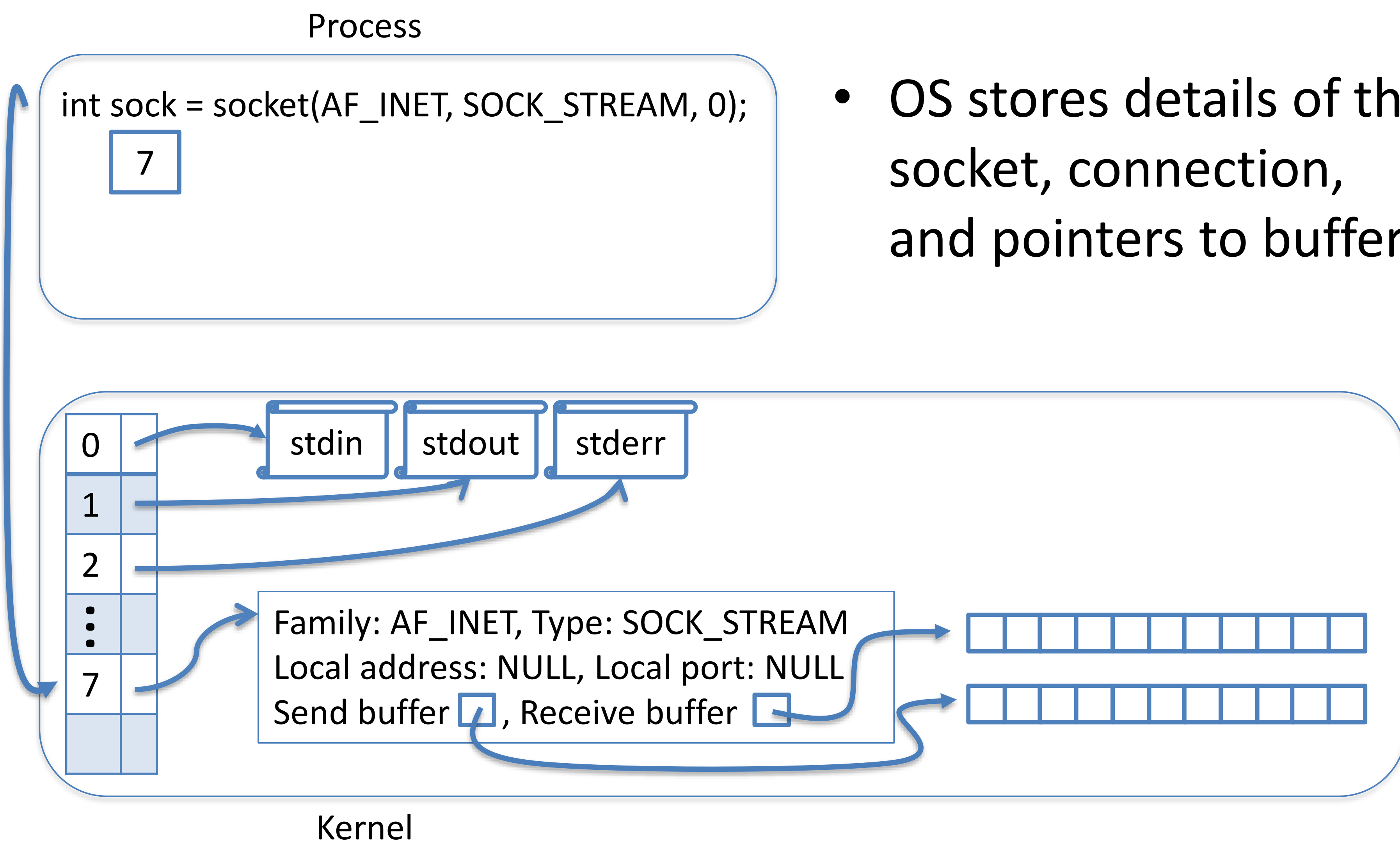
- socket() returns a socket descriptor
- Indexes into table

socket()



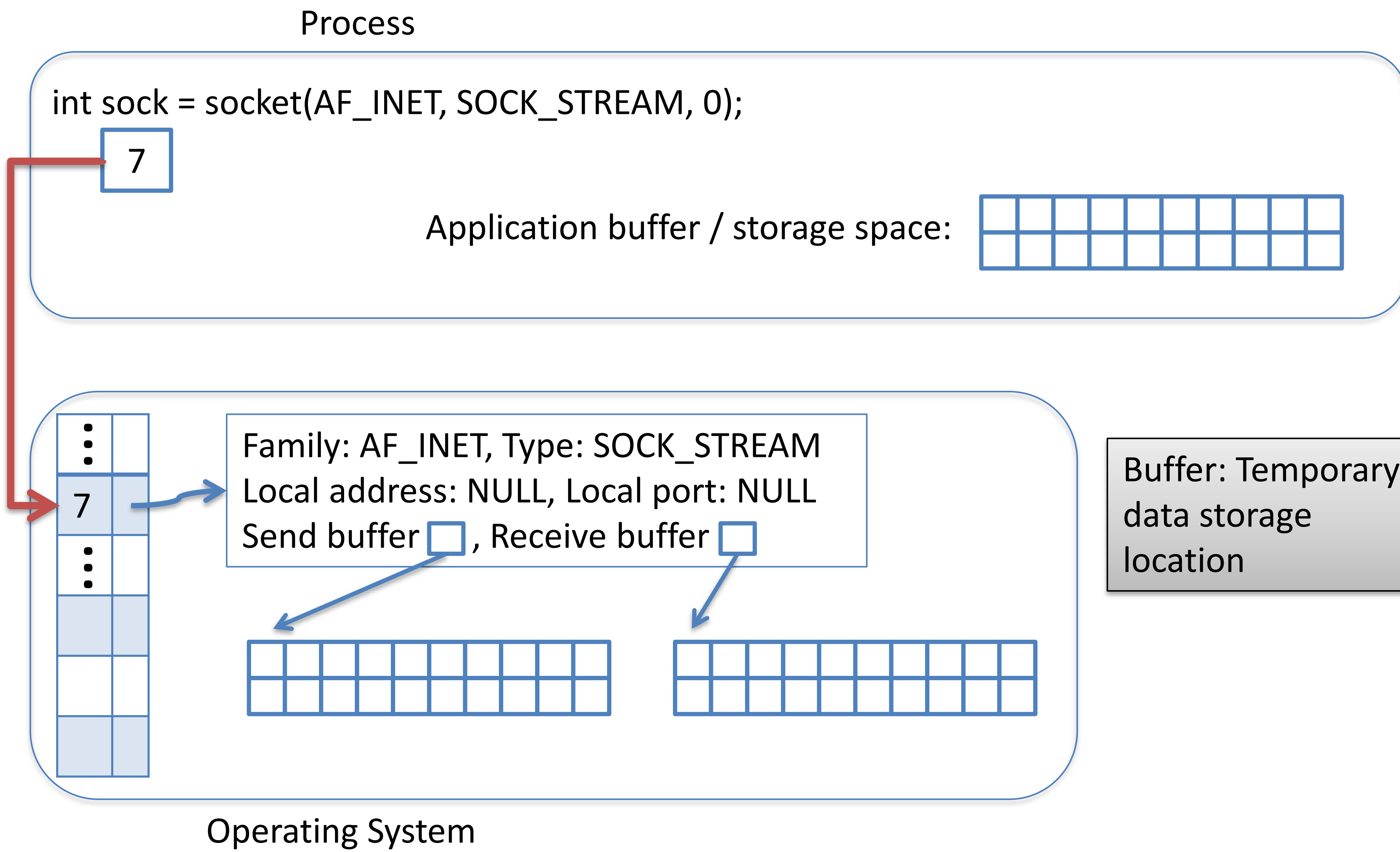
- OS stores details of the socket, connection, and pointers to buffers

socket()



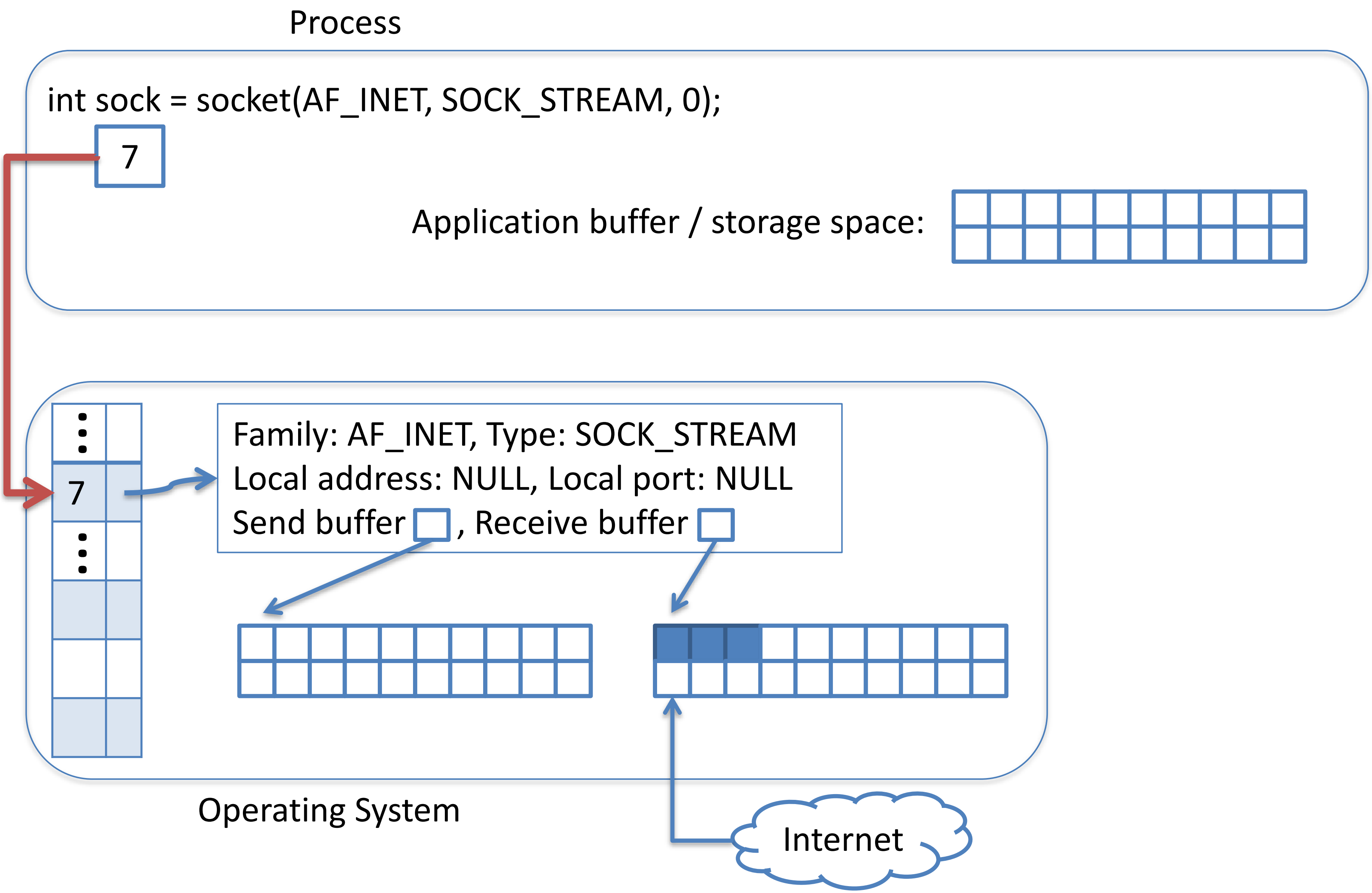
- OS stores details of the socket, connection, and pointers to buffers

Socket Buffers

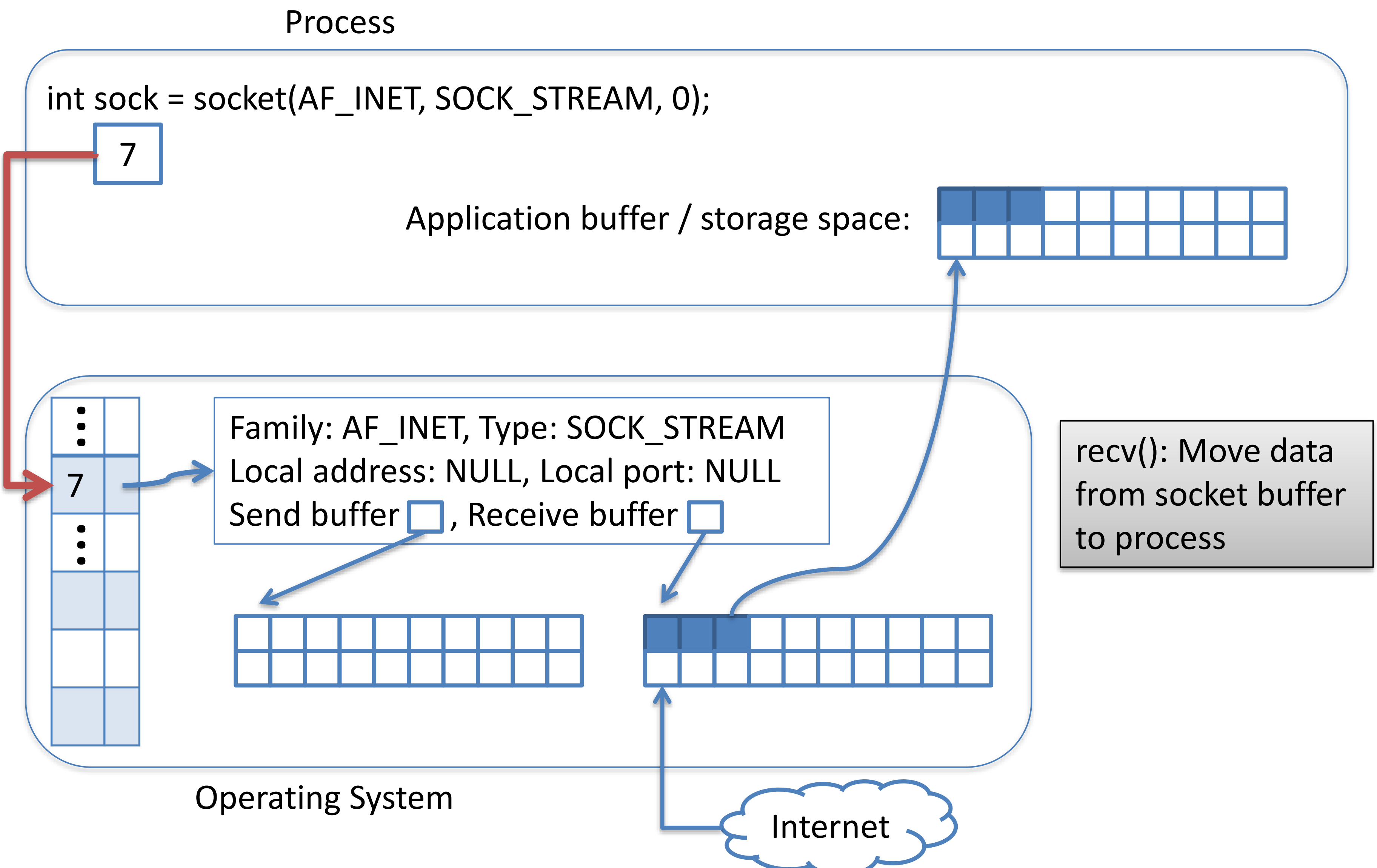


Buffer: Temporary data storage location

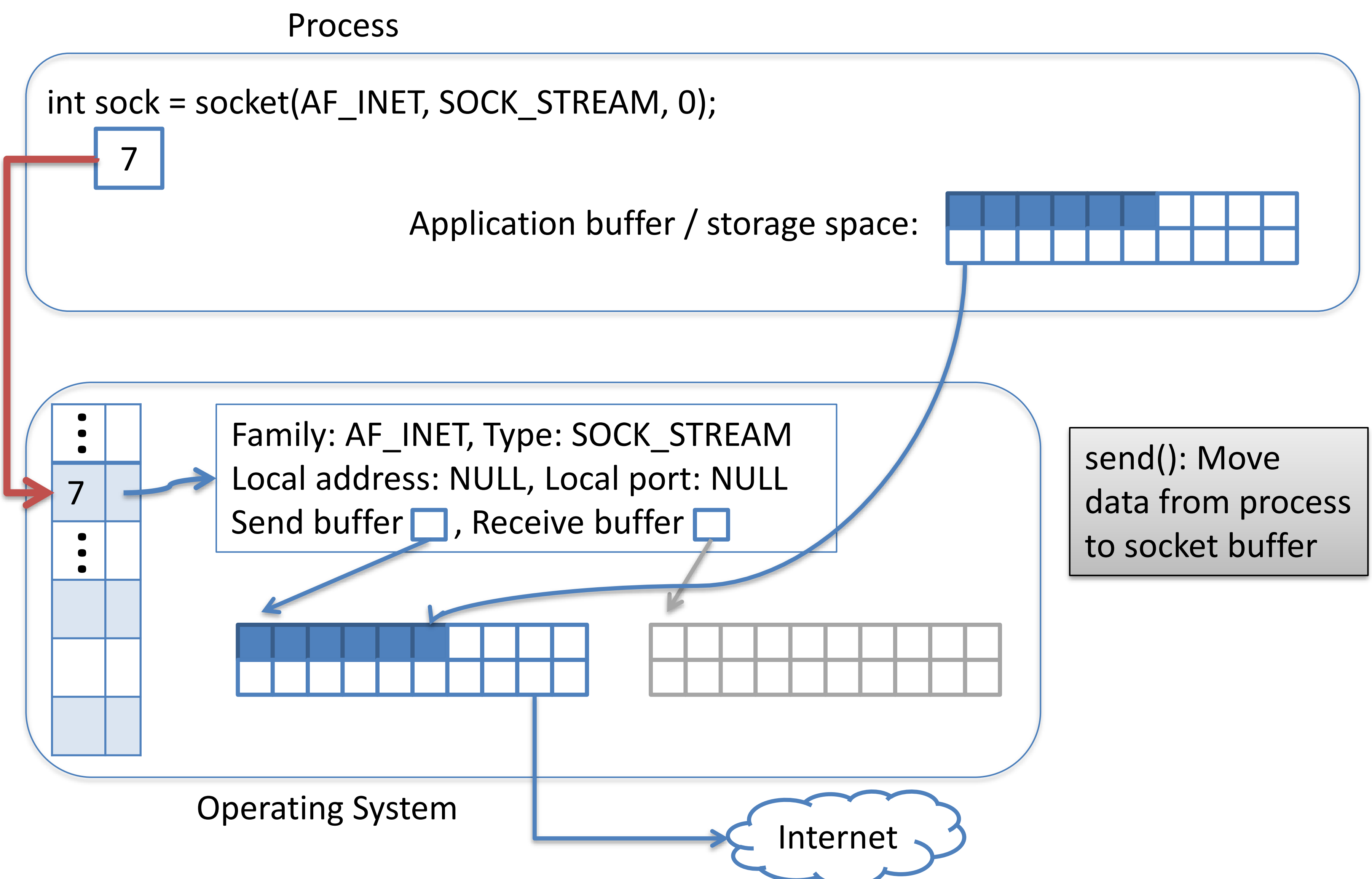
Socket Buffers



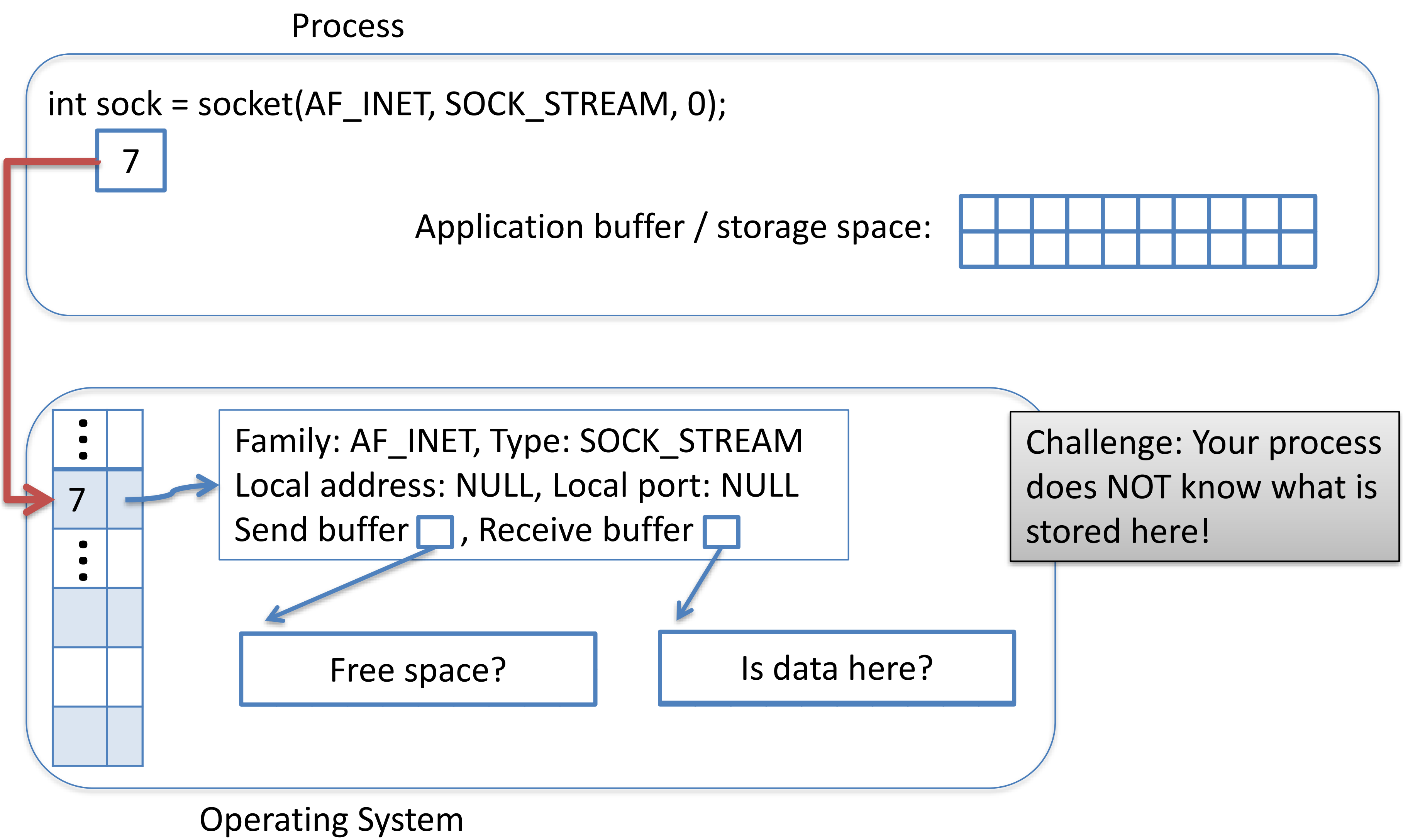
Socket Buffers



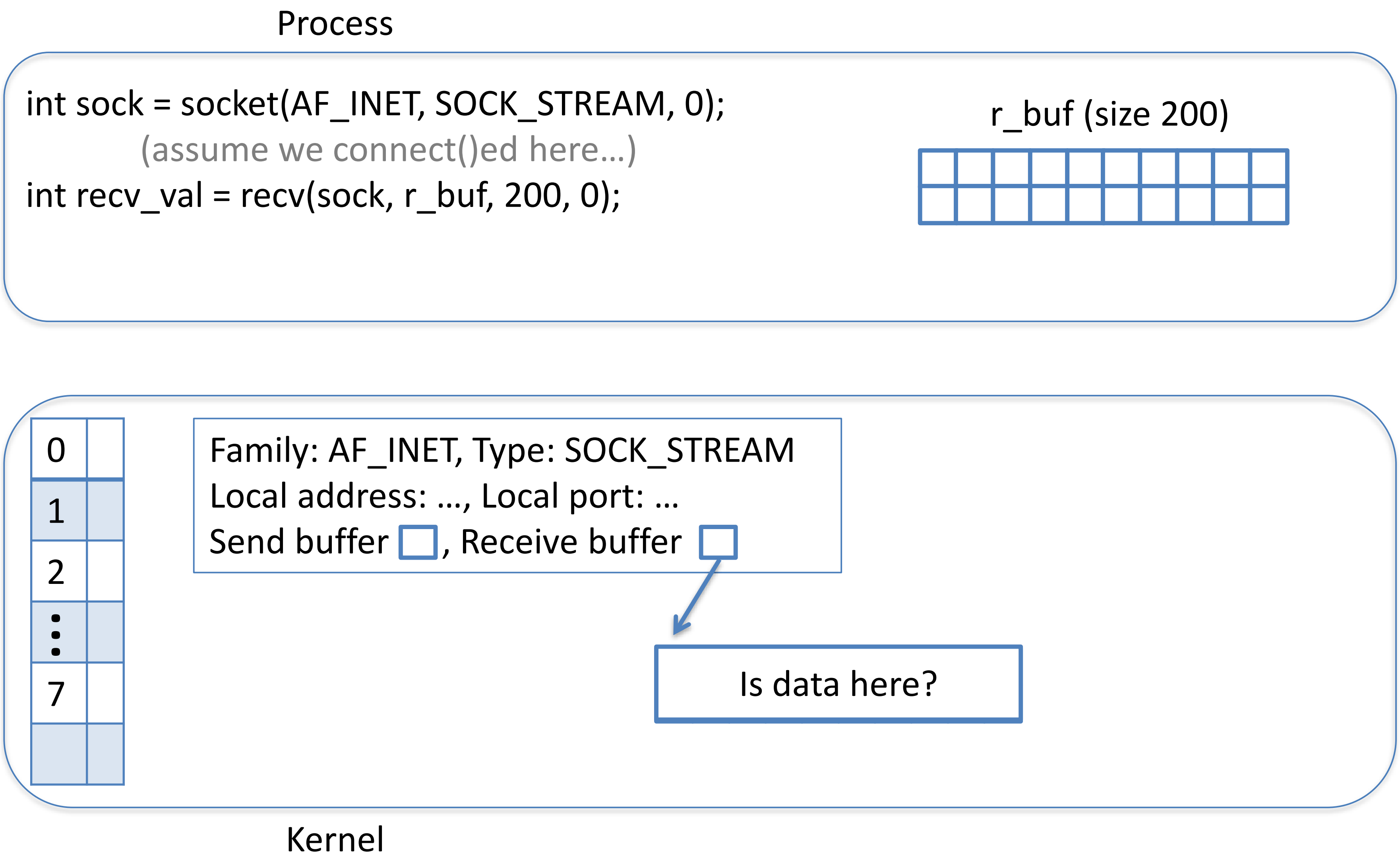
Socket Buffers



Socket Buffers



recv()

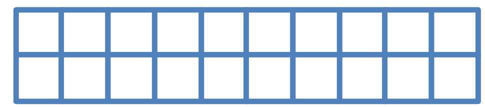

Process
int sock = socket(AF_INET, SOCK_STREAM, 0);
(assume we connect()ed here…)
int recv_val = recv(sock, r_buf, 200, 0);
r_buf (size 200)
0
1
2
7
Family: AF_INET, Type: SOCK_STREAM
Local address: …, Local port: …
Send buffer, Receive buffer
Is data here?
Kernel

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

Process

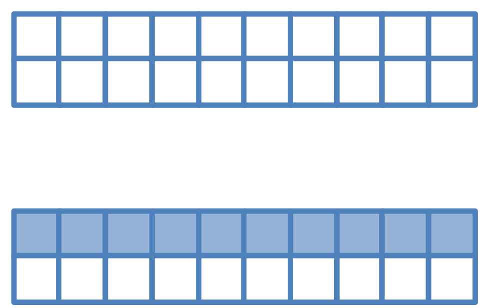
```
int sock = socket(AF_INET, SOCK_STREAM, 0);
        (assume we connect()ed here…)
int recv_val = recv(sock, r_buf, 200, 0);
```

r_buf (size 200)



Two Scenarios:

Socket buffer (receive)



Empty

100 bytes

Kernel

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

Process

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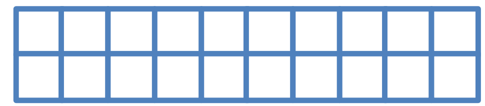
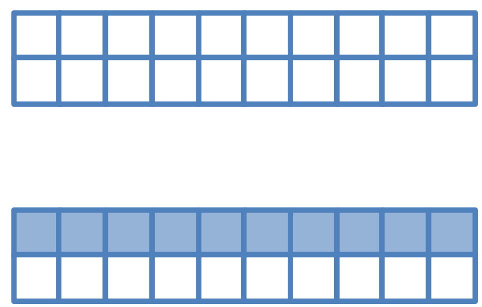

r_buf (size 200)



	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**	

Two Scenarios:

Socket buffer (receive)



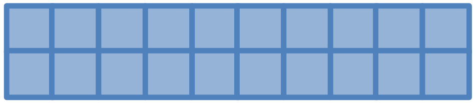
Kernel

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

Process

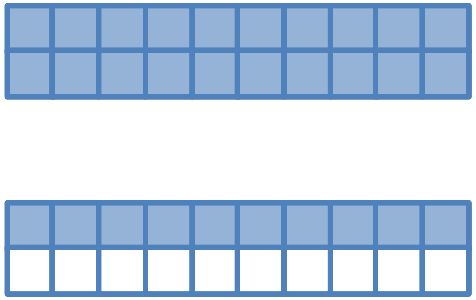
```
int sock = socket(AF_INET, SOCK_STREAM, 0);
        (assume we connect()ed here…)
int send_val = send(sock, s_buf, 200, 0);
```

s_buf (size 200)



Two Scenarios:

Socket buffer (send)



Full

100 bytes

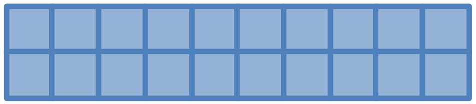
Kernel

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

Process

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

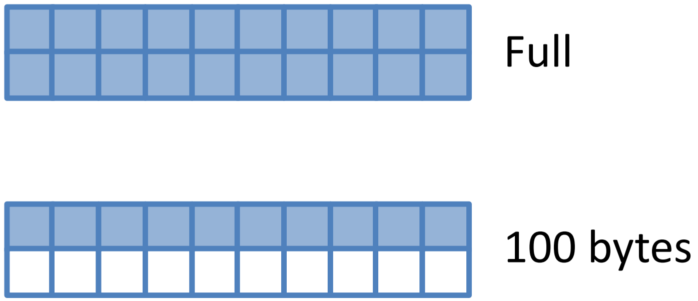
s_buf (size 200)



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

Two Scenarios:

Socket buffer (send)



Kernel

Blocking Implications

- 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!*

- 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!*

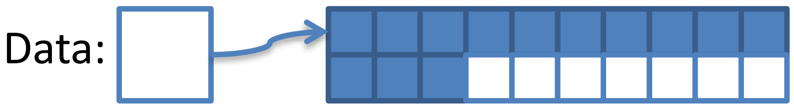
* Unless you're dealing with a single byte, which is rare.

ALWAYS check send() 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

send(sock, data, 130, 0);



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Data sent: 0
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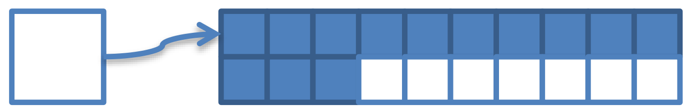
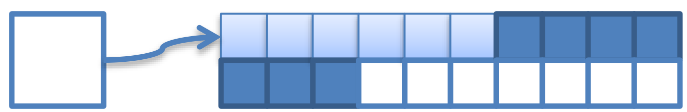
Data: 

60

send(sock, data, 130, 0);

Data sent: 60
Data to send: 130

Data: 

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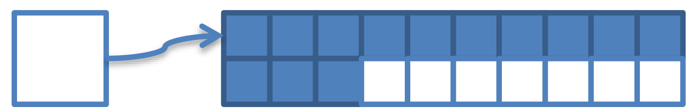
Data:



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Data sent: 60
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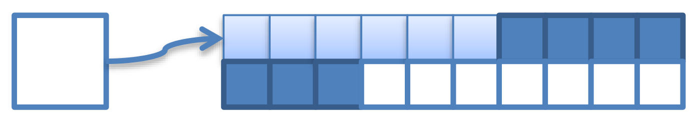
Data:

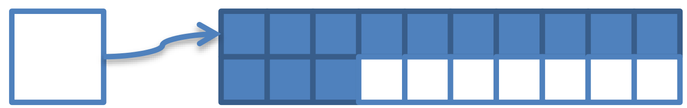


```
// Copy the 70 bytes starting from offset 60.
send(sock, data + 60, 130 - 60, 0);
```

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

Data: 

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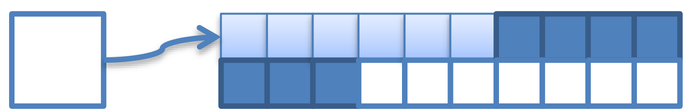
Data to send: 130

Data: 

// Copy the 70 bytes starting from offset 60.
? send(sock, data + 60, 130 - 60, 0);

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

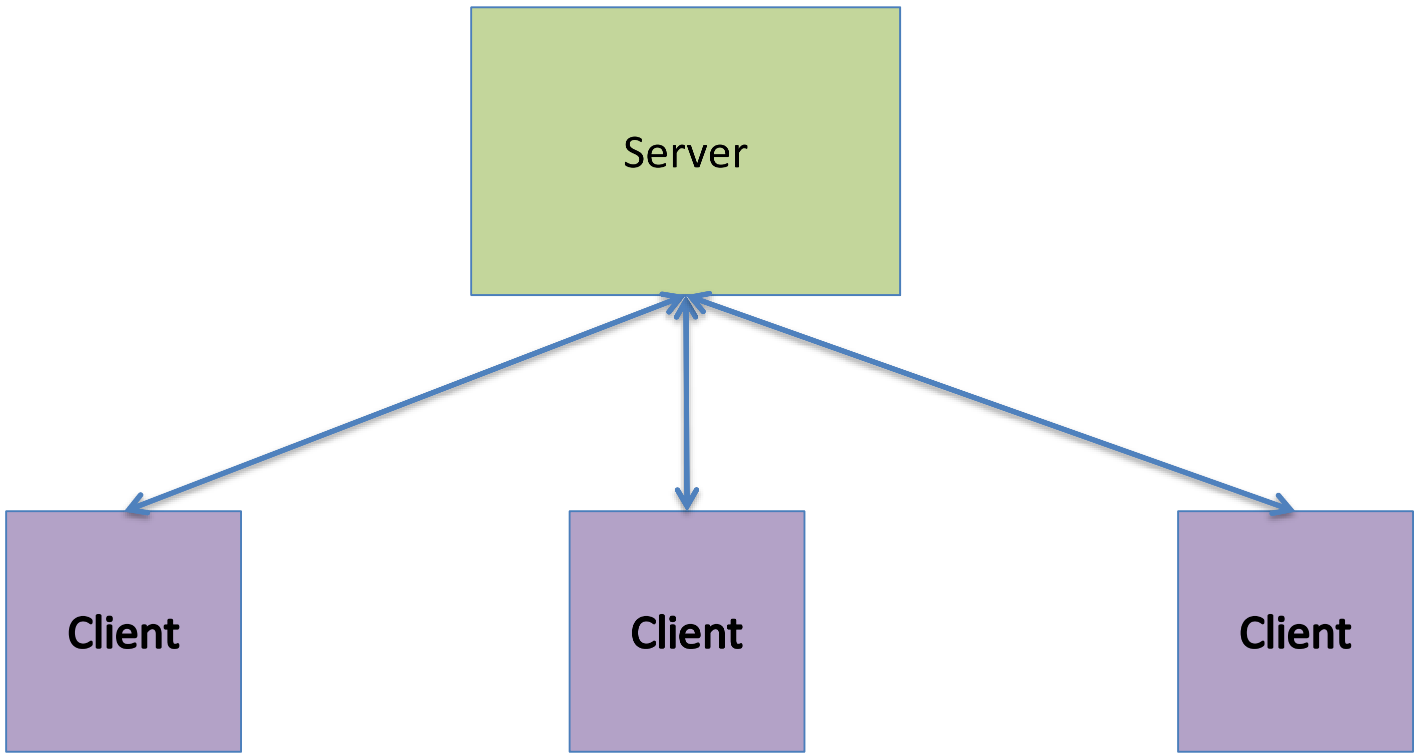
recv()

- 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!

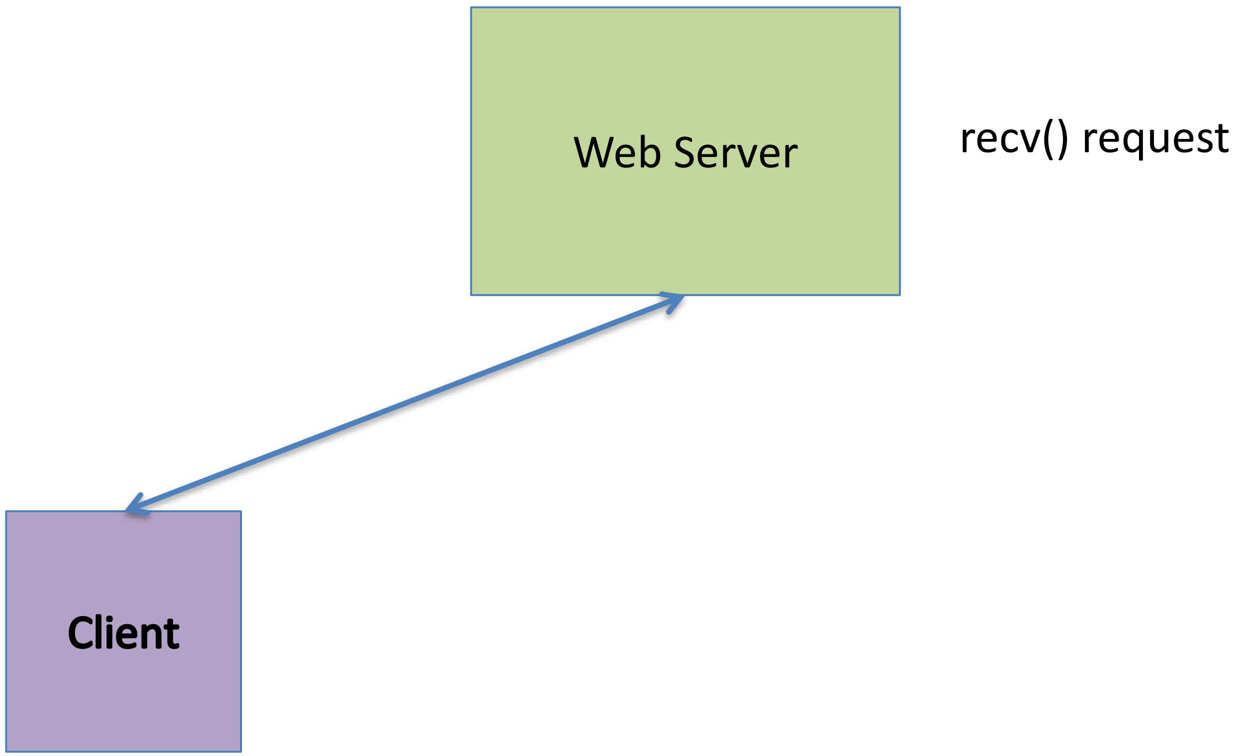
Concurrency

- Think you're the only one talking to that server?



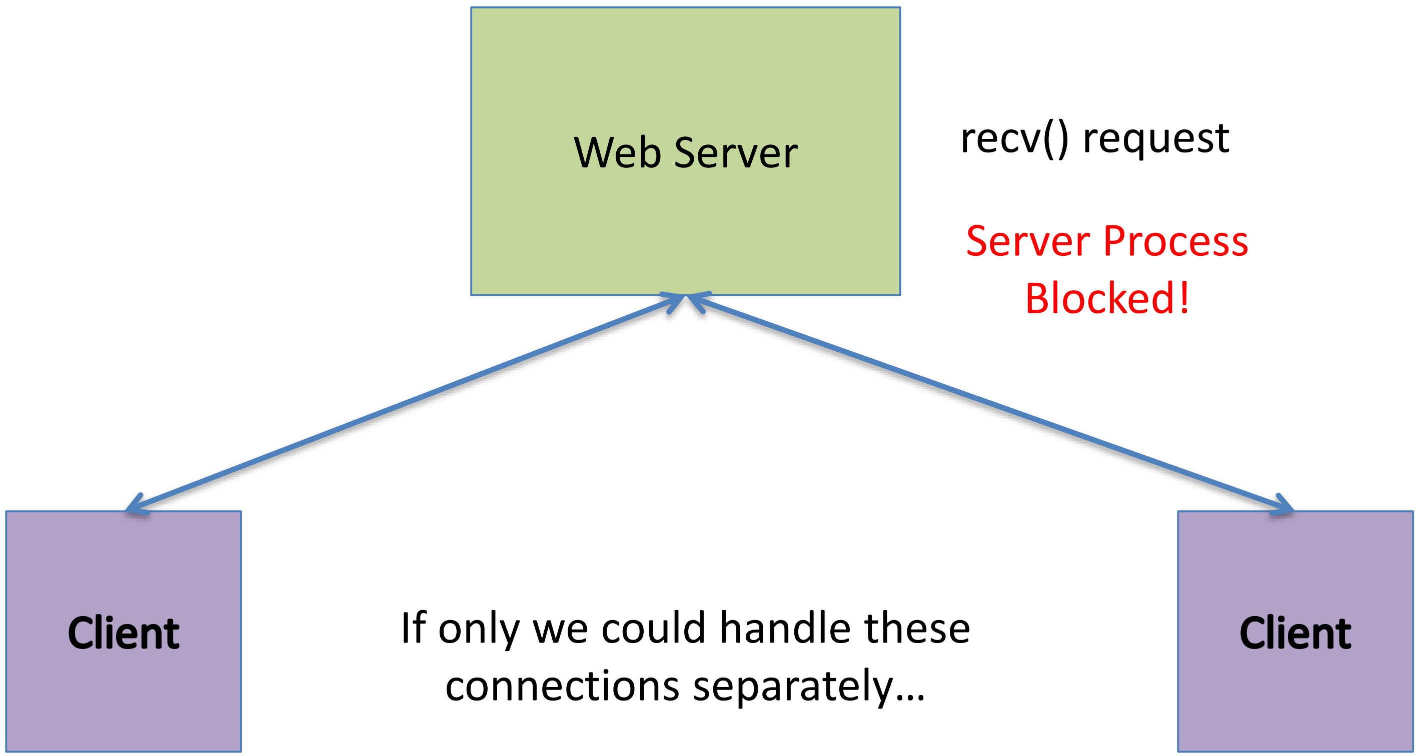
Without Concurrency

- Think you're the only one talking to that server?

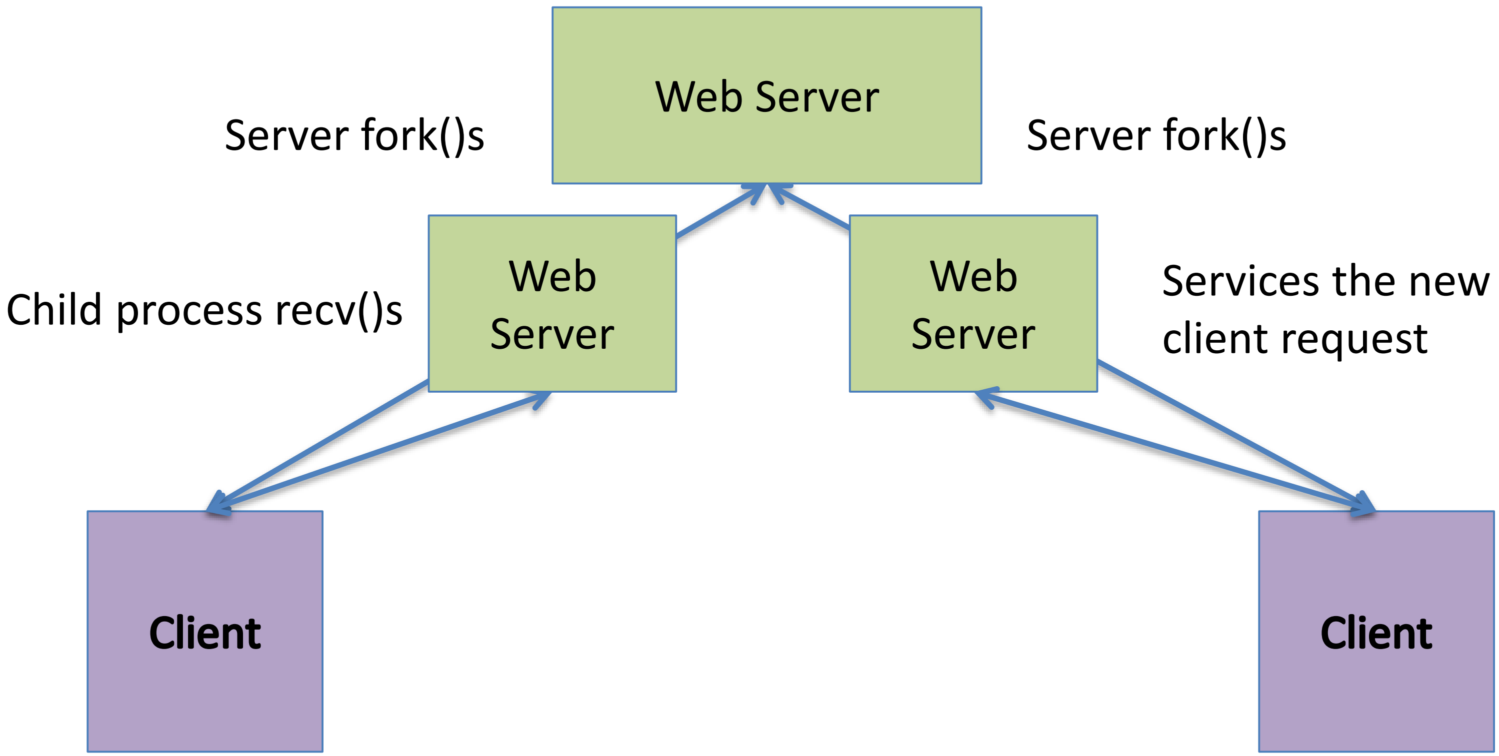


Without Concurrency

- Think you’re the only one talking to that server?



Multiple Processes



Processes/Threads vs. Parent

(More details in an OS class…)

Spawned Process

- Inherits descriptor table
- Does not share memory
  - New memory address space
- Scheduled independently
  - Separate execution context
  - Can block independently

Spawned Thread

- Shares descriptor table
- Shares memory
  - Uses parent's address space
- Scheduled independently
  - Separate execution context
  - Can block independently

Processes/Threads vs. Parent

(More details in an OS class…)

Spawned Process

- Inherits descriptor table
- Does not share memory
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Spawned Thread

- Shares descriptor table
- Shares memory
  - Uses parent's address space
- Scheduled independently
  - Separate execution context
  - Can block independently

Often, we don't need the extra isolation of a separate address space. Faster to skip creating it and share with parent – threading.

Threads & Sharing

- Global variables and static objects are shared
  - Stored in the static data segment, accessible by any thread
- Dynamic objects and other heap objects are shared
  - Allocated from heap with malloc/free or new/delete
- Local variables are not shared
  - Refer to data on the stack
  - Each thread has its own stack
  - Never pass/share/store a pointer to a local variable on another thread's stack

Whether processes or threads…

- Several benefits
  - Modularizes code:
    - one piece accepts connections, another services them
  - Each can be scheduled on a separate CPU
  - Blocking I/O can be overlapped

Which benefit is the most critical?

A. Modular code/separation of concerns.

B. Multiple CPU/core parallelism.

C. I/O overlapping.

D. Some other benefit.

Whether processes or threads…

- Several benefits
  - Modularizes code:
    - one piece accepts connections, another services them
  - Each can be scheduled on a separate CPU
  - Blocking I/O can be overlapped

- Still not maximum efficiency…
  - Creating/destroying threads still takes time
  - Requires memory to store thread execution state
  - Lots of context switching overhead

Non-blocking I/O

- One operation: add a flag to send/recv
- Permanently, for socket: fcntl() – “file control”
  - Allows setting options on file/socket descriptors

```
int sock, result, flags = 0;
sock = socket(AF_INET, SOCK_STREAM, 0);
result = fcntl(sock, F_SETFL, flags|O_NONBLOCK)
```

check result – 0 on success

Non-blocking I/O

- With O_NONBLOCK set on a socket
  - No operations will block!

- On recv(), if socket buffer is empty:
  - returns -1, *errno* is EAGAIN or EWOULDBLOCK

- On send(), if socket buffer is full:
  - returns -1, errno is EAGAIN or EWOULDBLOCK

How about…

```
server_socket = socket(), bind(), listen()
connections = []

while (1)
  new_connection = accept(server_socket)
  if new_connection != -1, add it to connections
  for connection in connections:
     recv(connection, …)  // Try to receive
     send(connection, …) // Try to send, if needed
}
```

Will this work?

```
server_socket = socket(), bind(), listen()
connections = []

while (1)
  new_connection = accept(server_socket)
  if new_connection != -1, add it to connections
  for connection in connections:
     recv(connection, …)  // Try to receive
     send(connection, …) // Try to send, if needed
}
```

A. Yes, this will work.
B. No, this will execute too slowly.
C. No, this will use too many resources.
D. No, this will still block.

Event-based Concurrency

- Rather than checking over and over, let the OS tell us when data can be read/written
- Create set of FDs we want to read and write
- Tell system to block until at least one of those is ready for us to use. The OS worry about selecting which one.

select()

select()

```
int main(void) {
    fd_set rfds;
    struct timeval tv;
    int retval;

   /* Watch stdin (fd 0) to see when it has input. */
    FD_ZERO(&rfds);
    FD_SET(0, &rfds);

   /* Wait up to five seconds. */
    tv.tv_sec = 5;
    tv.tv_usec = 0;

   retval = select(1, &rfds, NULL, NULL, &tv);
    /* Don't rely on the value of tv now! */

   if (retval == -1)
        perror("select()");
    else if (retval)
        printf("Data is available now.\n");
        /* FD_ISSET(0, &rfds) will be true. */
    else
        printf("No data within five seconds.\n");
}
```

- More interesting example in the select_tut man page.
- Beej’s guide also has a good example.
- You’ll use it in a future lab!

Event-based Concurrency

- Rather than checking over and over, let the OS tell us when data can be read/written

- Tell system to block until at least one of those is ready for us to use. The OS worry about selecting which one.

- Only one process/thread (or one per core)
  - No time wasted on context switching
  - No memory overhead for many processes/threads