CSE 124 AND CSE 224:

ESTABLISHING TCP CONNECTIONS AND SIMPLE CLIENT-SERVER EXAMPLES

George Porter
April 10, 2025

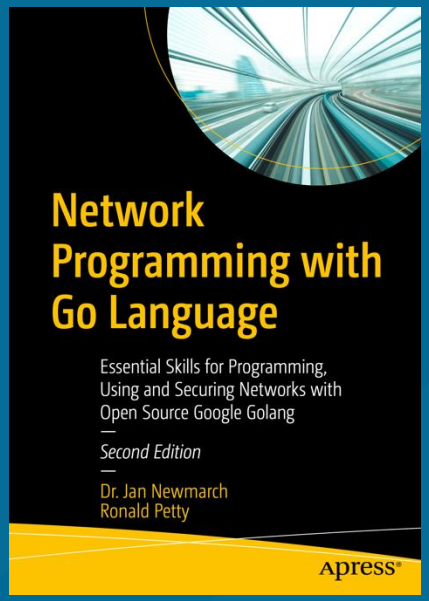
UC San Diego

ATTRIBUTION

- These slides incorporate material from:
  - Alex C. Snoeren, UC San Diego
  - Michael Freedman and Kyle Jamieson, Princeton University
  - Internet Society
  - Computer Networking: A Top Down Approach
  - DK Moon, Berkeley's EE122
  - Network Programming With Go (Woodbeck)

UC San Diego

REFERENCE MATERIAL



Chapter 3

UC San Diego

Today's agenda

- Let's write a couple Go programs that send/receive data over the network using the TCP protocol
- Then we'll go back and take a deep dive on why they work and what is going on "under the engine hood"
- TCP and "blocking" in the OS
- Wrap-up/Q&A

UNIX “TIME” PROTOCOL

TCP Transport Protocol

TCP Port 13

Format of the response

Network Working Group
Request for Comments: 867

J. Postel
ISI
May 1983

Daytime Protocol

This RFC specifies a standard for the ARPA Internet community. Hosts on the ARPA Internet that choose to implement a Daytime Protocol are expected to adopt and implement this standard.

A useful debugging and measurement tool is a daytime service. A daytime service simply sends a the current date and time as a character string without regard to the input.

TCP Based Daytime Service

One daytime service is defined as a connection based application on TCP. A server listens for TCP connections on TCP port 13. Once a connection is established the current date and time is sent out the connection as a character string (and any data received is thrown away). The service closes the connection after sending the quote.

UDP Based Daytime Service

Another daytime service service is defined as a datagram based application on UDP. A server listens for UDP datagrams on UDP port 13. When a datagram is received, an answering datagram is sent containing the current date and time as a ASCII character string (the data in the received datagram is ignored).

Daytime Syntax

There is no specific syntax for the daytime. It is recommended that it be limited to the ASCII printing characters, space, carriage return, and line feed. The daytime should be just one line.

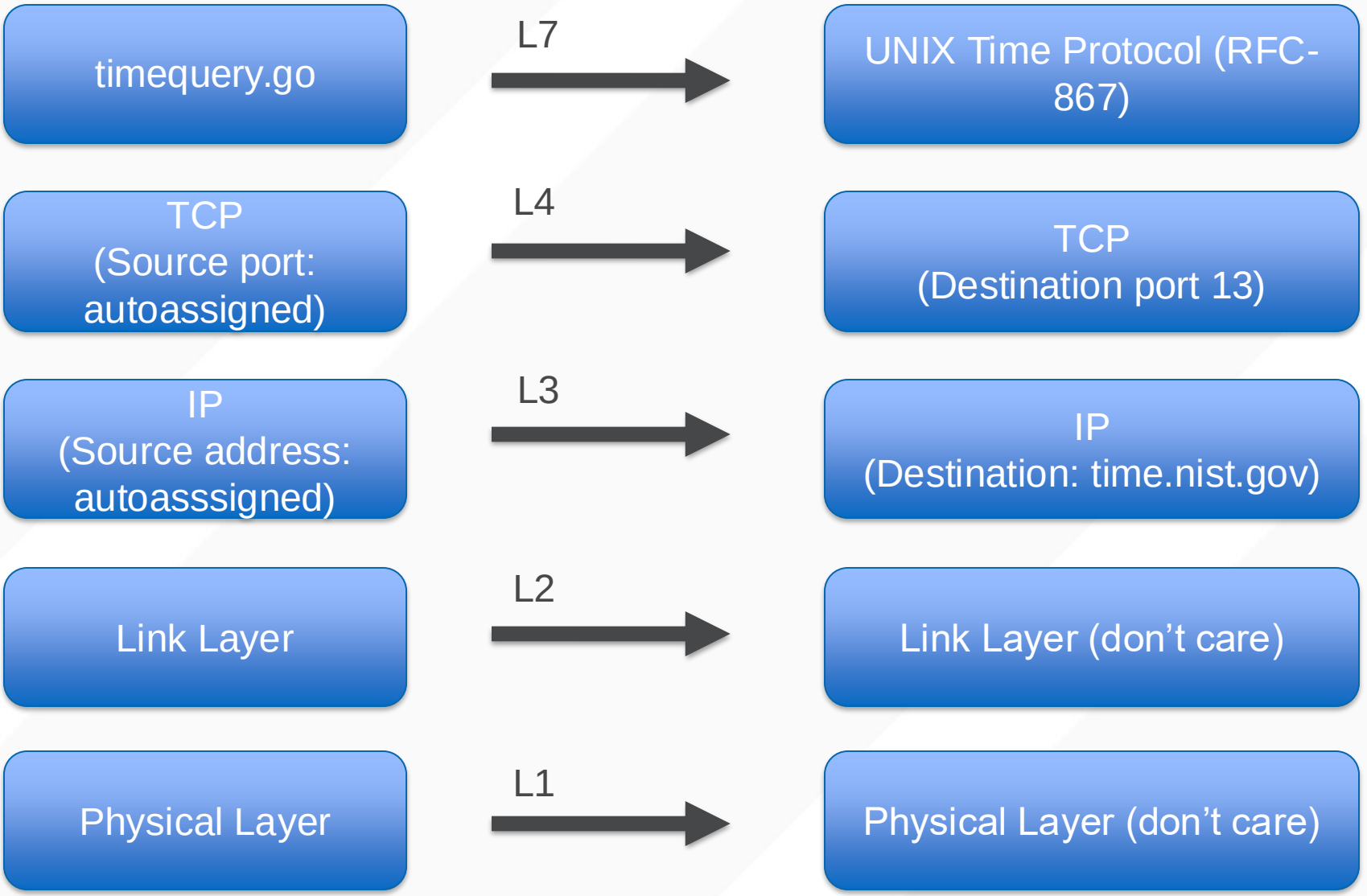
One popular syntax is:

Weekday, Month Day, Year Time-Zone

Example:

Tuesday, February 22, 1982 17:37:43-PST

UNIX TIME PROTOCOL AND LAYERING



MINI DEMO: TIMEQUERY.GO

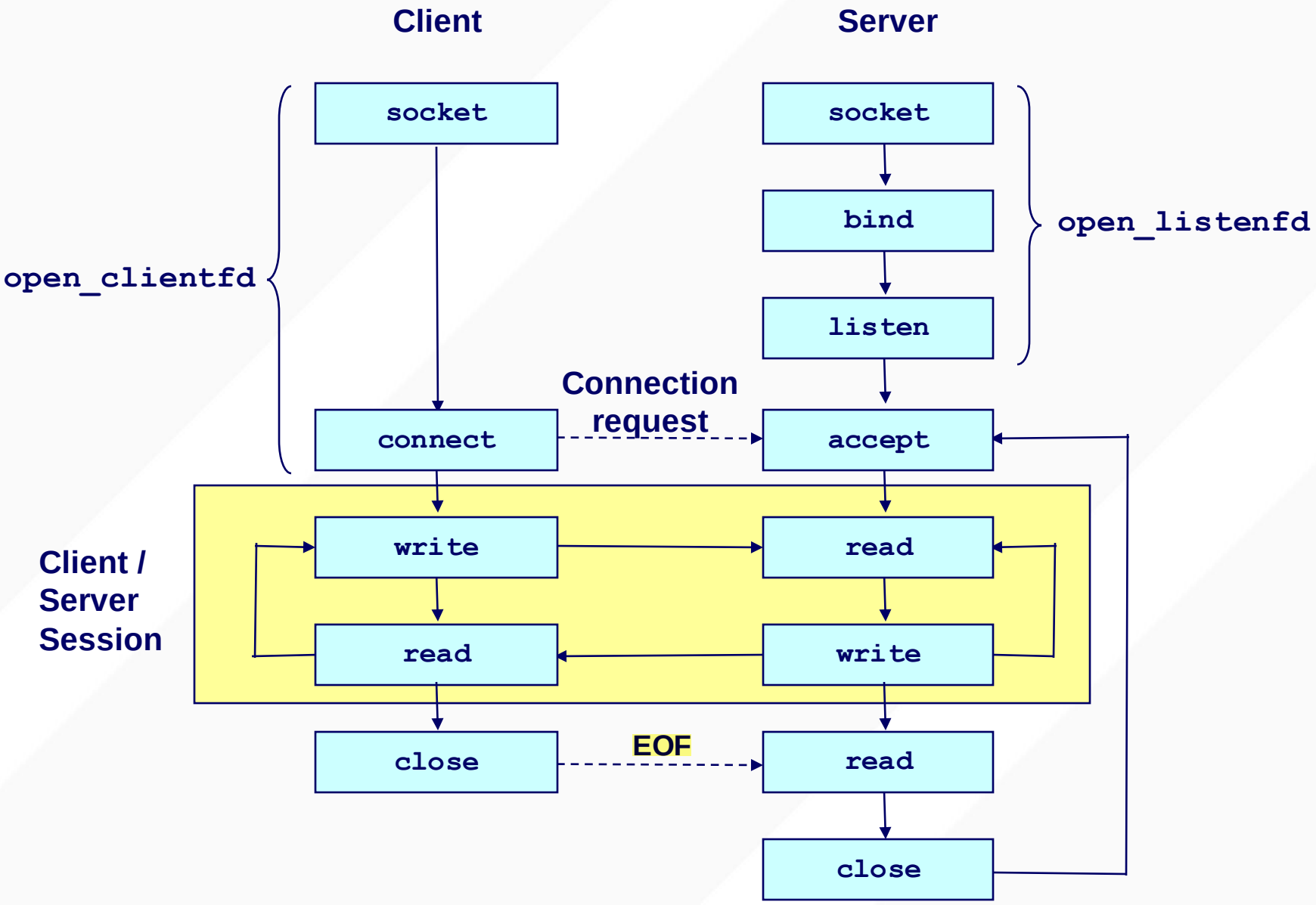
```
gmporter@spookybytes w2-timedate % go run timequery/timequery.go localhost:13000
Wednesday, April 9, 2025 15:36:48-PDT
gmporter@spookybytes w2-timedate %
```

Full list of servers at: https://tf.nist.gov/tf-cgi/servers.cgi

Note that running on port 13 requires administrator access, so my local timedate server runs on port 13000 instead.

LET'S LOOK AT HOW GO'S TCP SOCKETS ARE IMPLEMENTED WITHIN THE OS

CLIENT AND SERVER SOCKETS (SYSTEM CALLS)



INITIALIZATION (CLIENT AND SERVER)

```
int sock = socket(AF_INET, SOCK_STREAM, 0);
if (sock < 0) {
   perror("socket() failed");
   abort();
}
```

- **socket() : returns a socket descriptor**
- **AF_INET : IPv4 address family.** (also OK with PF_INET)
  - C.f. IPv6 => AF_INET6
- **SOCK_STREAM: streaming socket type**
  - C.f. SOCK_DGRAM
- **perror()** : prints out an error message

INITIALIZATION ON THE SERVER VIA BIND()

- Server needs to bind a particular port number.

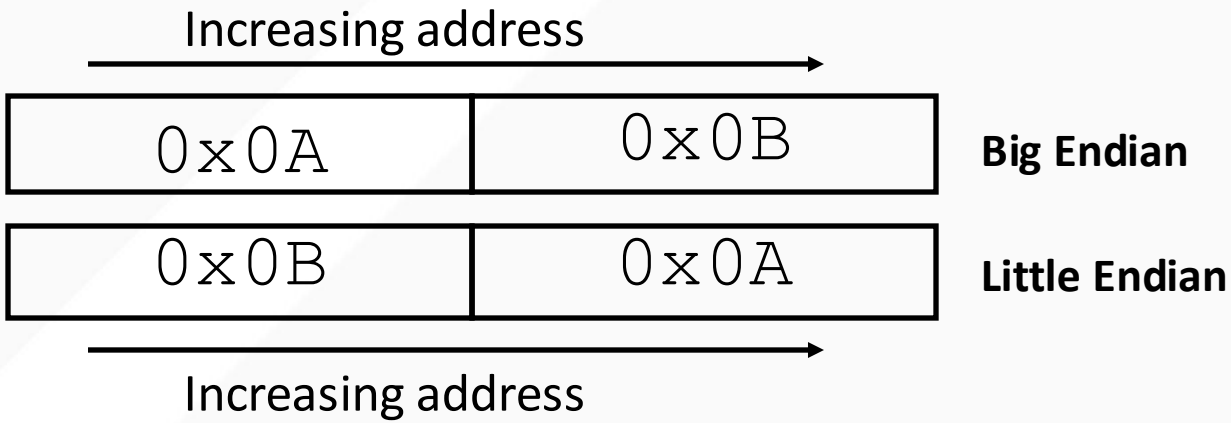
```
struct sockaddr_in sin;
memset(&sin, 0, sizeof(sin));
sin.sin_family = AF_INET;
sin.sin_addr.s_addr = INADDR_ANY;
sin.sin_port = htons(server_port);

if (bind(sock, (struct sockaddr *) &sin, sizeof(sin)) < 0) {
   perror("bind failed");
   abort();
}
```

- **bind()** : binds a socket with a particular port number.
  - Kernel remembers which process has bound which port(s).
  - Only one process can bind a particular port number at a time.
- **struct sockaddr_in**: Ipv4 socket address structure. (c.f., struct sockaddr_in6)
- **INADDR_ANY**: If server has multiple IP addresses, binds any address.
- **htons()**: converts host byte order into network byte order.

ENDIANESS

- Q) You have a 16-bit number: 0x0A0B. How is it stored in memory?



- Host byte order is not uniform
  - Some machines are Big endian, others are Little endian

- Communicating between machines with different host byte orders is problematic
  - Transferred $256 (0x0100), but received $1 (0x0001)

- For Internet, we standardize on big-endianness
  - htons() and ns

ENDIANESS (CON'T)

- Network byte order: Big endian
  - To avoid the endian problem
- We must use network byte order when sending 16bit, 32bit , 64bit numbers.
- Utility functions for easy conversion

```
uint16_t htons(uint16_t host16bitvalue);
uint32_t htonl(uint32_t host32bitvalue);
uint16_t ntohs(uint16_t net16bitvalue);
uint32_t ntohl(uint32_t net32bitvalue);
```

- Hint: **h**, **n**, **s**, and **l** stand for host byte order, network byte order, short(16bit), and long(32bit), respectively

INITIALIZATION, SERVER VIA LISTEN()

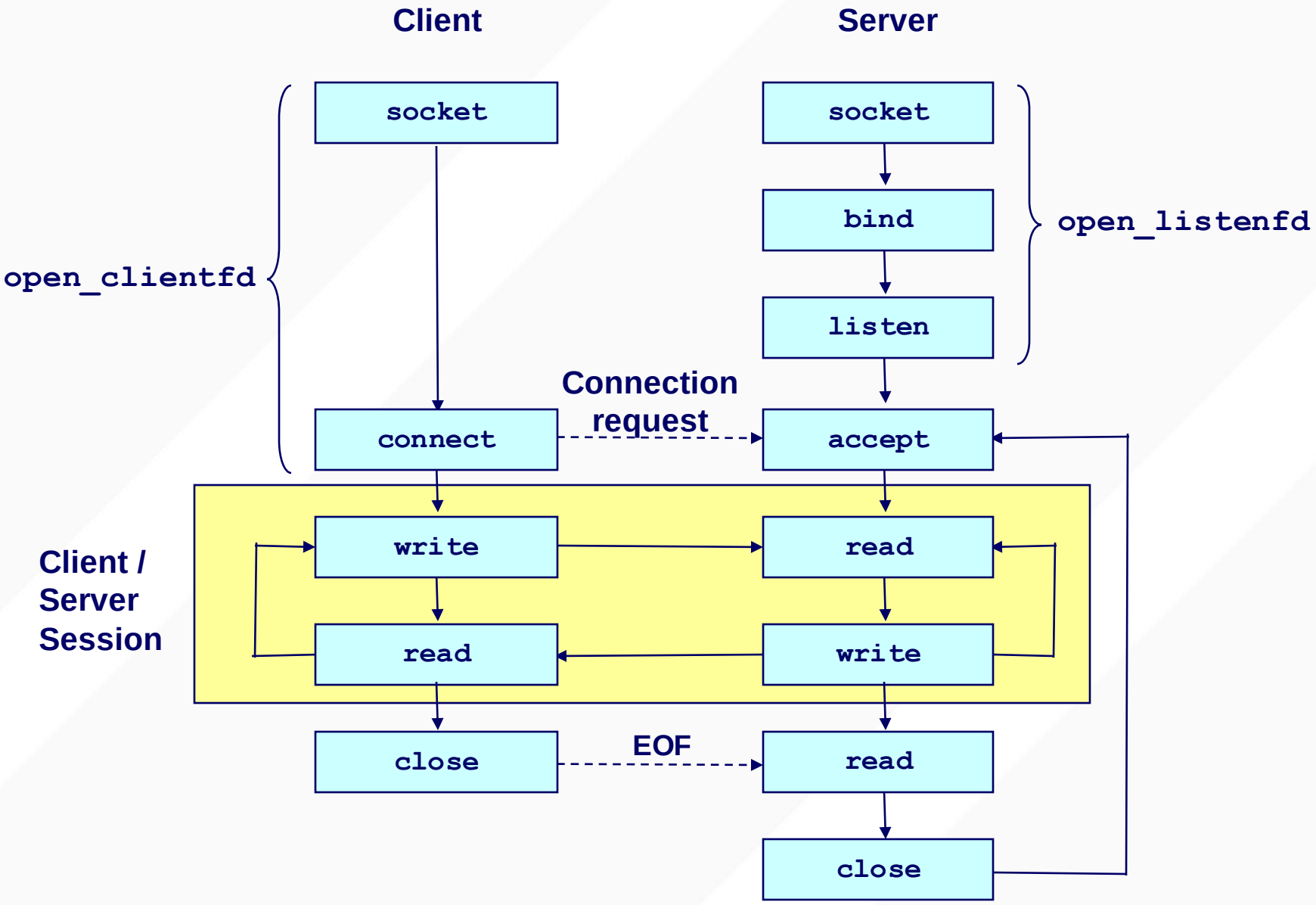
- Socket is active, by default
- We need to make it passive to get connections.

```
if (listen(sock, back_log) < 0) {
  perror("listen failed");
  abort();
}
```

- **listen()**: converts an active socket to passive

- **back_log**: connection-waiting queue size. (e.g., 32)
  - Busy server may need a large value (e.g., 1024, …)

CLIENT AND SERVER SOCKETS (SYSTEM CALLS)



CONNECTION ESTABLISHMENT (ON THE CLIENT)

```
struct sockaddr_in sin;
memset(&sin, 0 ,sizeof(sin));

sin.sin_family   = AF_INET;
sin.sin_addr.s_addr = inet_addr("128.32.132.214");
sin.sin_port = htons(80);

if (connect(sock, (struct sockaddr *) &sin, sizeof(sin)) < 0) {
   perror("connection failed");
   abort();
}
```

- **Connect()** : waits until connection establishes/fails
- **inet_addr()** : converts an IP address string into a 32bit address number (network byte order).

CONNECTION ESTABLISHMENT (ON THE SERVER)

```
struct sockaddr_in client_sin;
int addr_len = sizeof(client_sin);
int client_sock = accept(listening_sock,
                         (struct sockaddr *) &client_sin,
                         &addr_len);
if (client_sock < 0) {
   perror("accept failed");
   abort();
}
```

- **`accept()`**: returns a new socket descriptor for a client connection in the connection-waiting queue.
  - This socket descriptor is to communicate with the client
  - The passive socket (listening_sock) is not to communicate with a client

SENDING DATA (BOTH CLIENT AND SERVER)

```
char *data_addr = "hello, world";
int data_len = 12;

int sent_bytes = send(sock, data_addr, data_len, 0);
if (sent_bytes < 0) {
   perror("send failed");
}
```

- **send()**: sends data, returns the number of sent bytes
  - Also OK with `write()`, `writev()`
- **data_addr**: address of data to send
- **data_len**: size of the data

- With blocking sockets (default), send() blocks until it sends all the data.
- With non-blocking sockets, **sent_bytes** may not equal to **data_len**
  - If kernel does not have enough space, it accepts only partial data
  - You must retry for the unsent data

RECEIVING DATA (BOTH CLIENT AND SERVER)

```
char buffer[4096];
int expected_data_len = sizeof(buffer);

int read_bytes = recv(sock, buffer, expected_data_len, 0);
if (read_bytes == 0) {  // connection is closed
    …
} else if (read_bytes < 0) { // error
   perror("recv failed");
} else {    // OK. But no guarantee read_bytes == expected_data_len
   …
}
```

- **recv()**: reads bytes from the socket and returns the number of read bytes.
  - Also OK with **read()** and **readv()**

- **read_bytes** may not equal to **expected_data_len**
  - If no data is available, it blocks
  - If only partial data is available, read_bytes < expected_data_len
  - On socket close, expected_data_len equals to 0 (not error!)
  - If you get only partial data, you should retry for the remaining portion.

CLOSING CONNECTION (BOTH CLIENT AND SERVER)

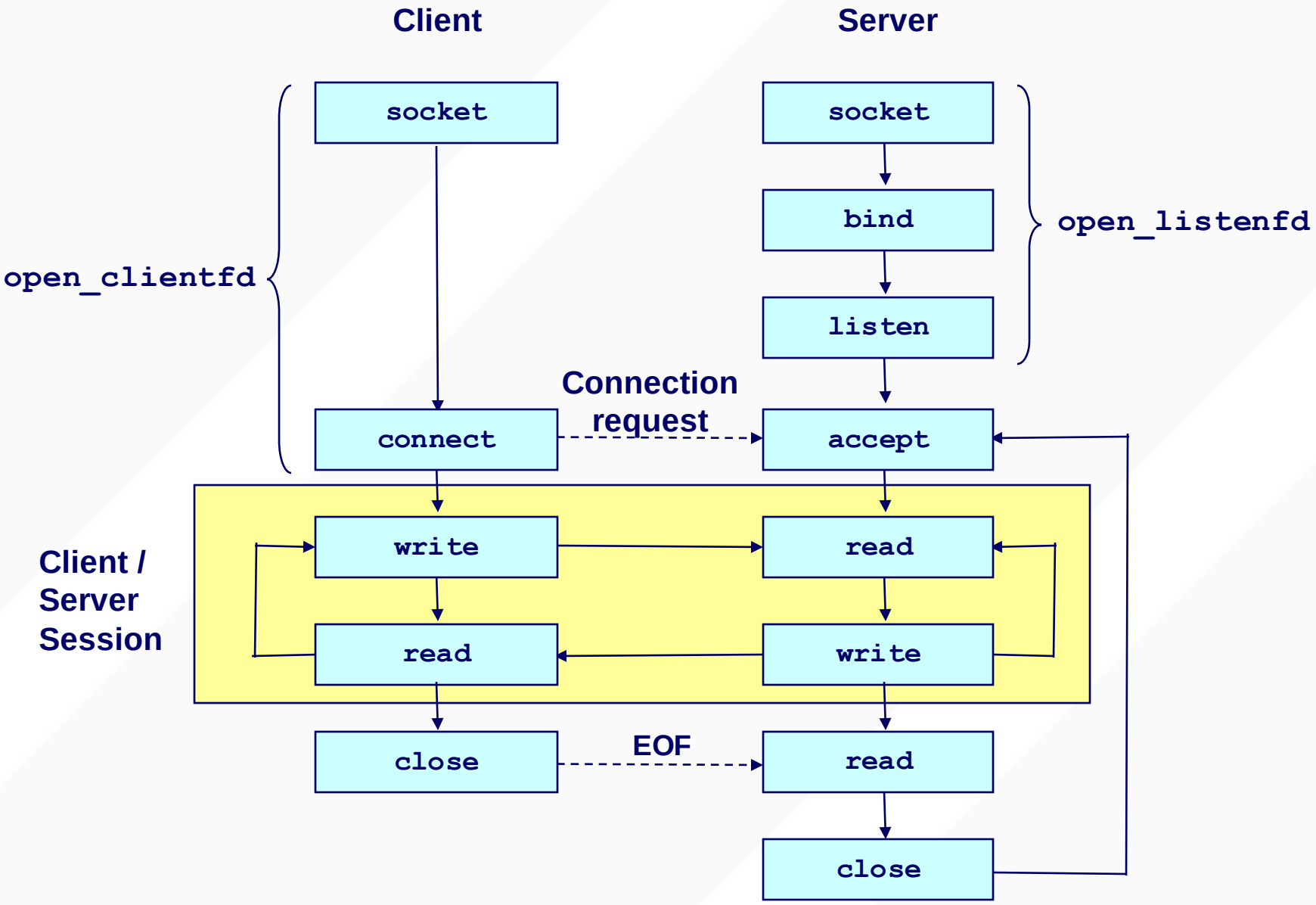
```
// after use the socket
close(sock);
```

- **`close()`**: closes the socket descriptor

- We cannot open files/sockets more than 1024*
  - We must release the resource after use

* Super user can overcome this constraint, but regular user cannot.

CLIENT AND SERVER SOCKETS (SYSTEM CALLS)



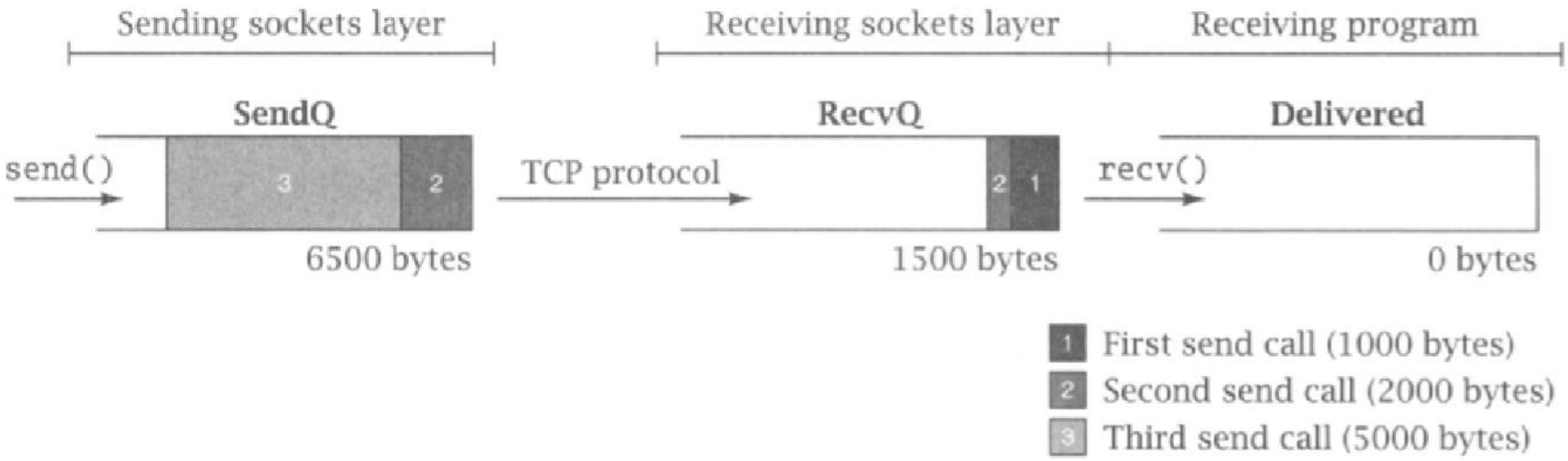
Today's agenda

- Let's write a couple Go programs that send/receive data over the network using the TCP protocol
- Then we'll go back and take a deep dive on why they work and what is going on "under the engine hood"
- TCP and "blocking" in the OS
- Wrap-up/Q&A

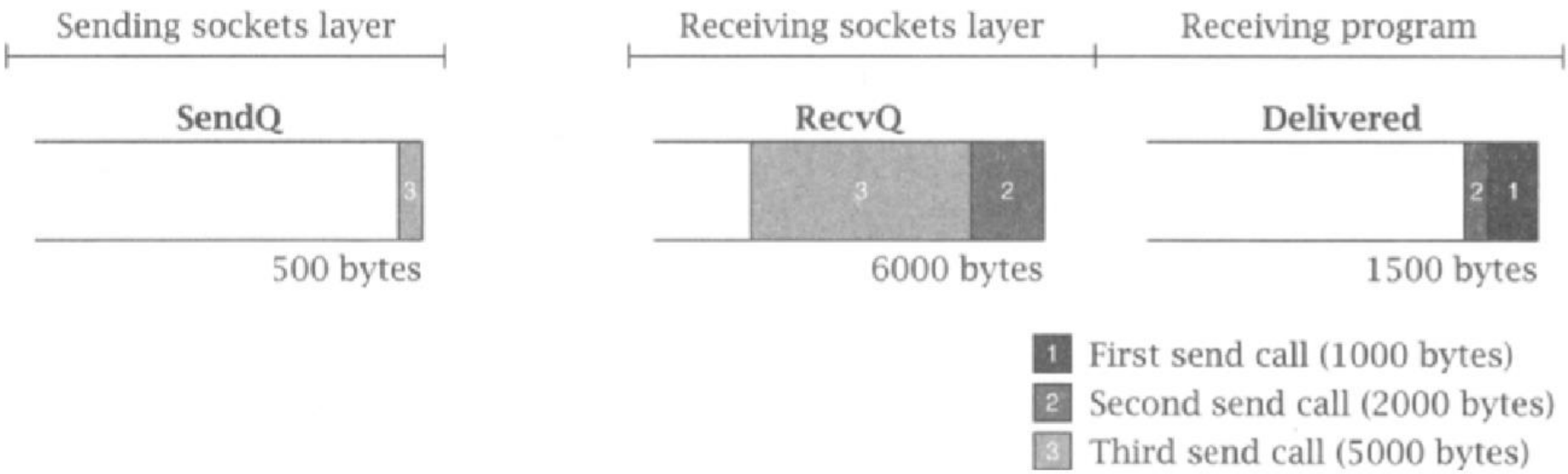
DIGGING INTO SEND() A BIT MORE

```
rv = connect(s,...);
.
.
.
rv = send(s,buffer0,1000,0);
.
.
.
rv = send(s,buffer1,2000,0);
.
.
.
rv = send(s,buffer2,5000,0);
.
.
.
close(s);
```

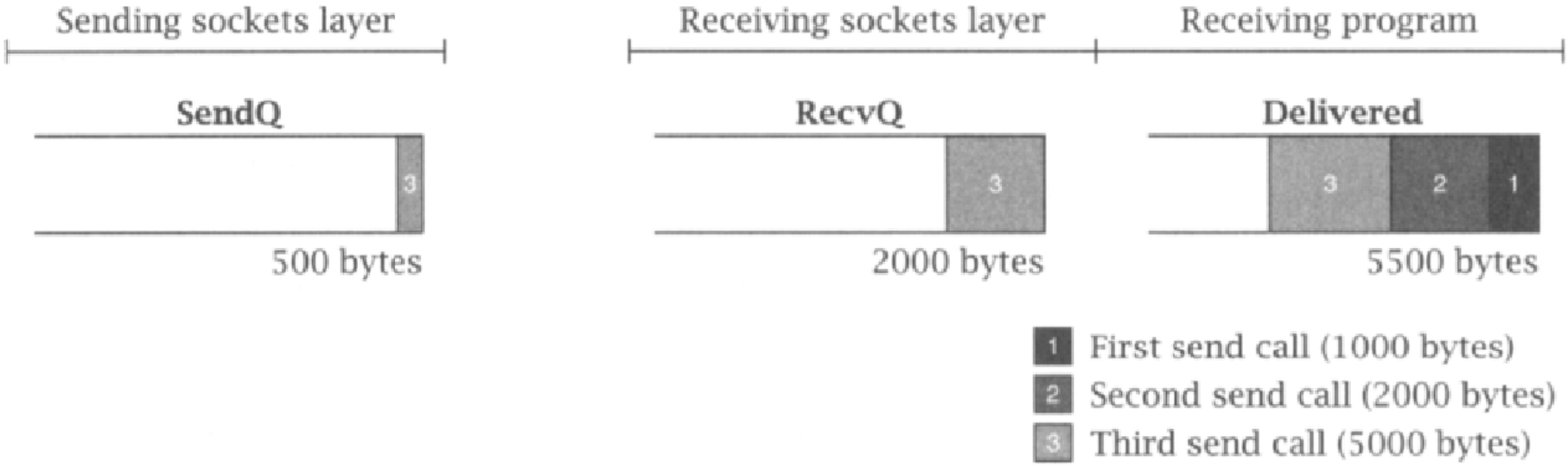
AFTER 3 SEND() CALLS



AFTER FIRST RECV()



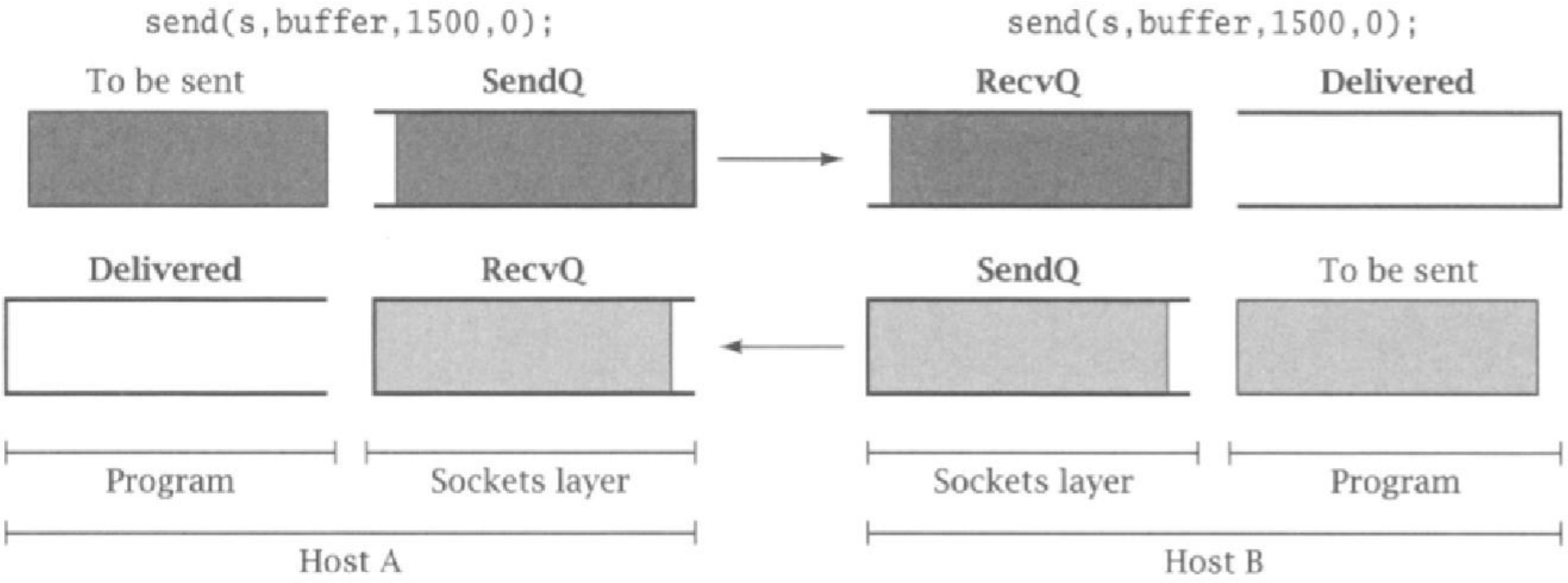
AFTER ANOTHER RECV()



WHEN DOES BLOCKING OCCUR?

- SendQ size: SQS
- RecvQ size: RQS
- send(s, buffer, **n**, 0);
  - n>SQS: blocks until (n – SQS) bytes xfered to RecvQ
  - If n>(SQS+RQS), blocks until receiver calls recv() enough to read in n-(SQS+RQS) bytes
- How does this lead to deadlock?
  - Trivial cause: both sides call recv() w/o sending data

MORE SUBTLE REASON FOR DEADLOCK



- SendQ size = 500; RecvQ size = 500

Today's agenda

- Let's write a couple Go programs that send/receive data over the network using the TCP protocol
- Then we'll go back and take a deep dive on why they work and what is going on "under the engine hood"
- TCP and "blocking" in the OS
- Wrap-up/Q&A

UC San Diego