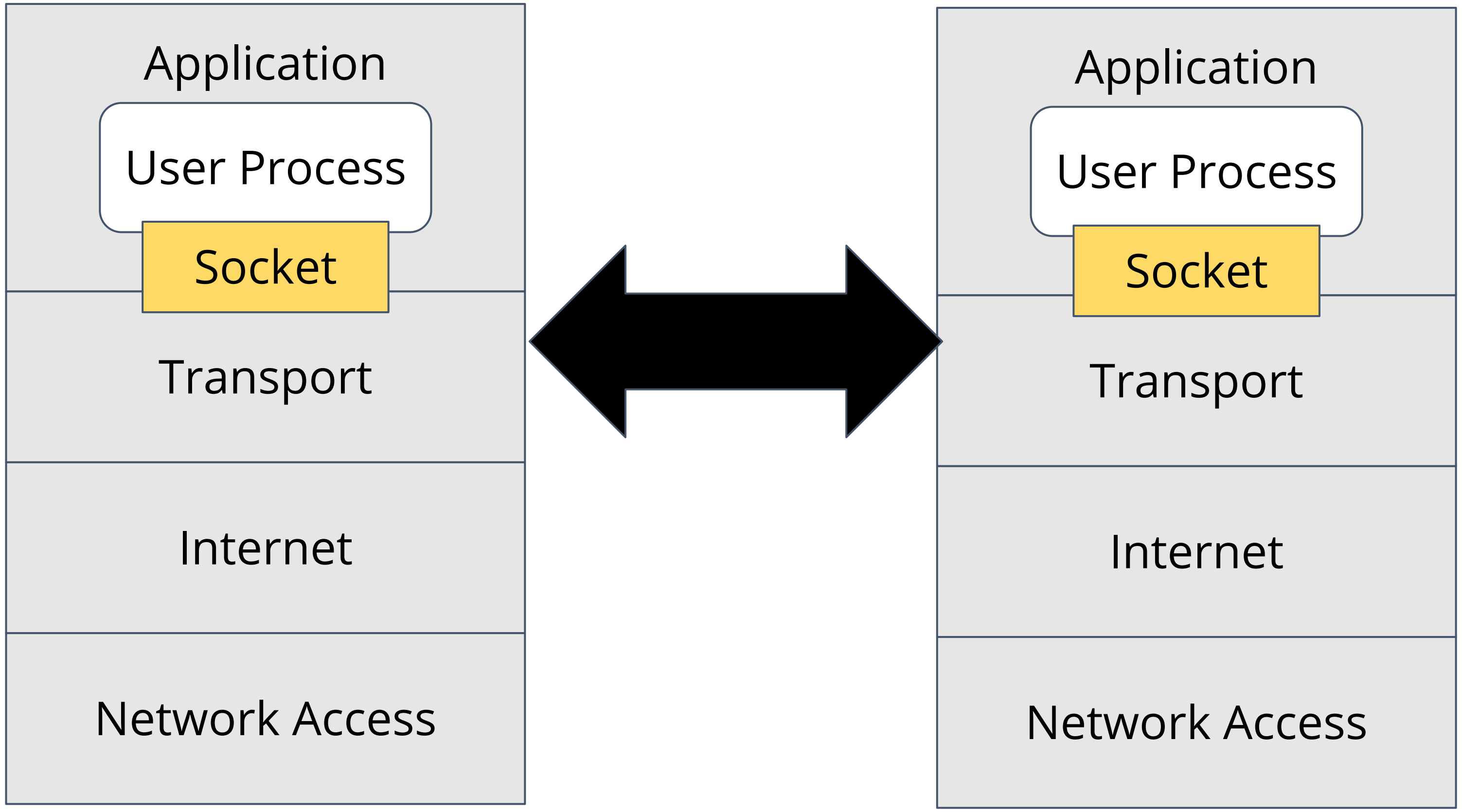
COS 316 Precept: Socket Programming

High-level Architecture

- **Application**
  - Read data from and write data to the socket
  - Interpret the data (e.g., render a Web page)
- **Transport**
  - Deliver data to the destination socket
  - Based on the destination port number (e.g., 80)
- **Internet**
  - Deliver data packet to the destination host
  - Based on the destination IP address
- **Network Access**
  - Transmit data between devices
  - Encapsulate IP packet into frames transmitted by the network
  - Map IP addresses into physical addresses



Terminology

- IP (IPv4) Addresses
  - Hosts mapped to 32 bit IP addresses: aaaaaaaa.bbbbbbbb.cccccccc.dddddd
  - E.g., 128.112.136.51
  - Various special IP addresses, e.g., 127.0.0.1

- Domain names
  - IP addresses are mapped to an identification string
  - E.g., www.cs.princeton.edu
  - E.g., localhost

- Port - a unique communication end point on a host, named by a 16-bit integer, and associated with a process

- Connections
  - A process on one host communicates with another process on another host over a connection
  - Clients and servers communicate by sending streams of bytes over connections
  - E.g., using TCP or UDP

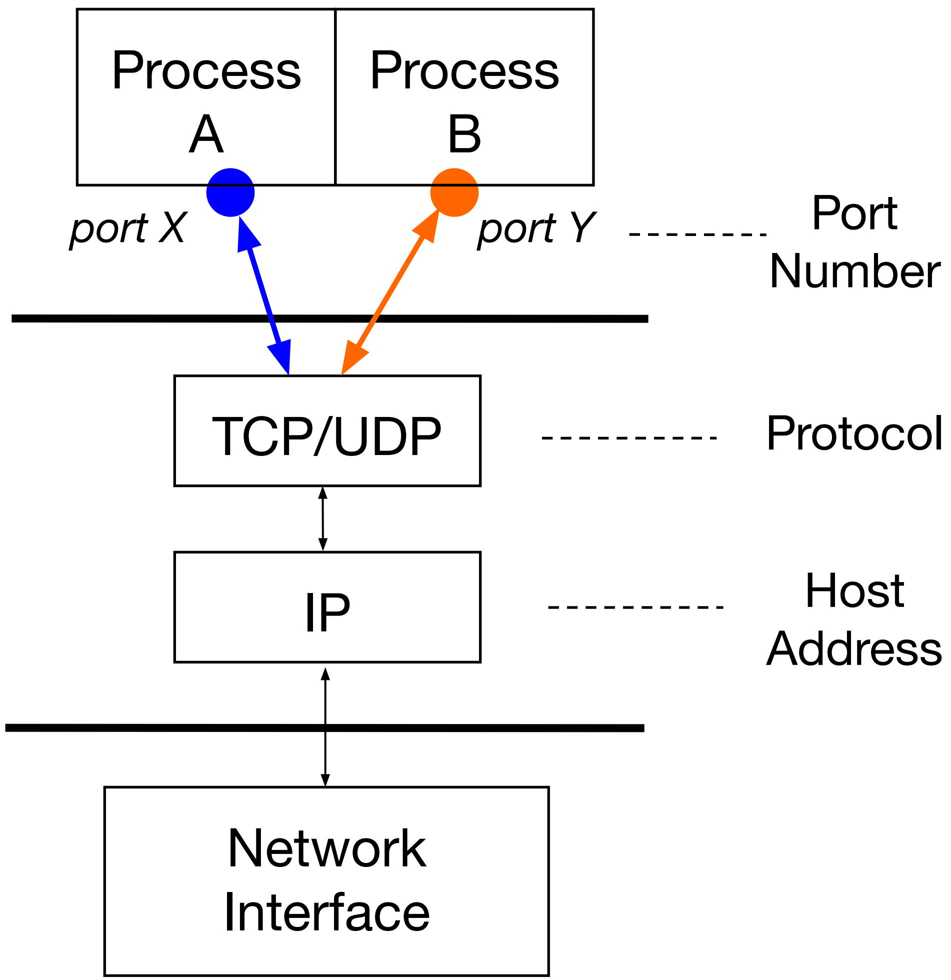
- Socket - end-point of a connection
  - Sending message from one process to another
    - Message must traverse the underlying network
  - Process sends and receives through a “socket”
    - In essence, the doorway leading in/out of the house
  - Socket as an Application Programming Interface
    - Supports the creation of network applications

- Stream Socket (TCP - Transmission Control Protocol)
  - Stream of bytes
  - Reliable
  - Connection-oriented

- Datagram Socket (UDP - User Datagram Protocol)
  - Collection of messages
  - Best effort
  - Connectionless

Socket Identification

- Receiving host
  - Destination **address** that uniquely identifies host
  - **IP address**: 32-bit quantity
- Receiving socket
  - Host may be running many different processes
  - Destination **port** that uniquely identifies socket
  - **Port number:** 16-bits



Client - Server Communication

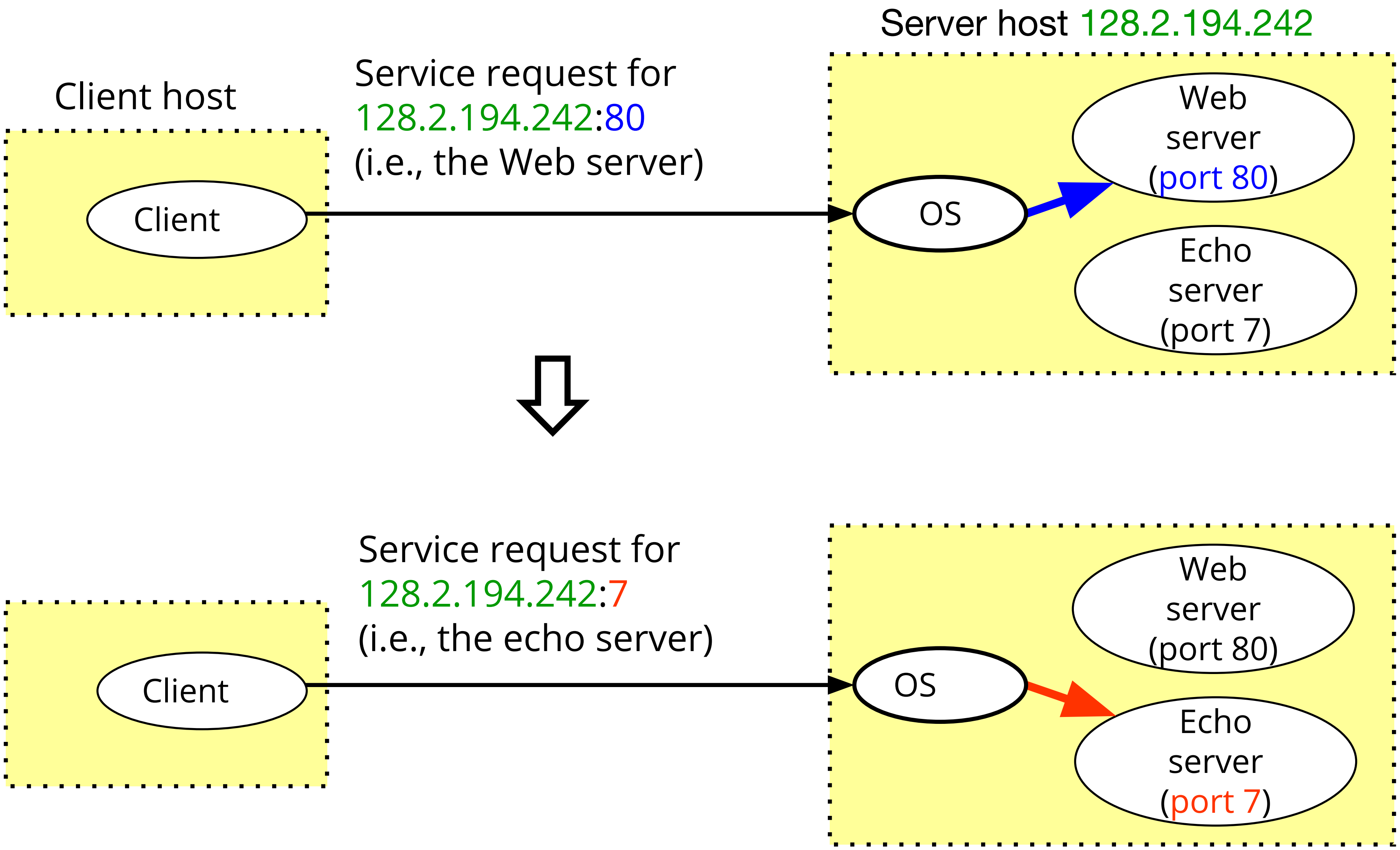
- Client “sometimes on”
  - Initiates a request to the server when interested
  - E.g., Web browser on your laptop or cell phone
  - Doesn’t communicate directly with other clients
  - Needs to know server’s address

- Server is “always on”
  - Handles services requests from many client hosts
  - E.g., Web server for the www.cnn.com Web site
  - Doesn’t initiate contact with the clients
  - Needs fixed, known address

Knowing What Port Number To Use

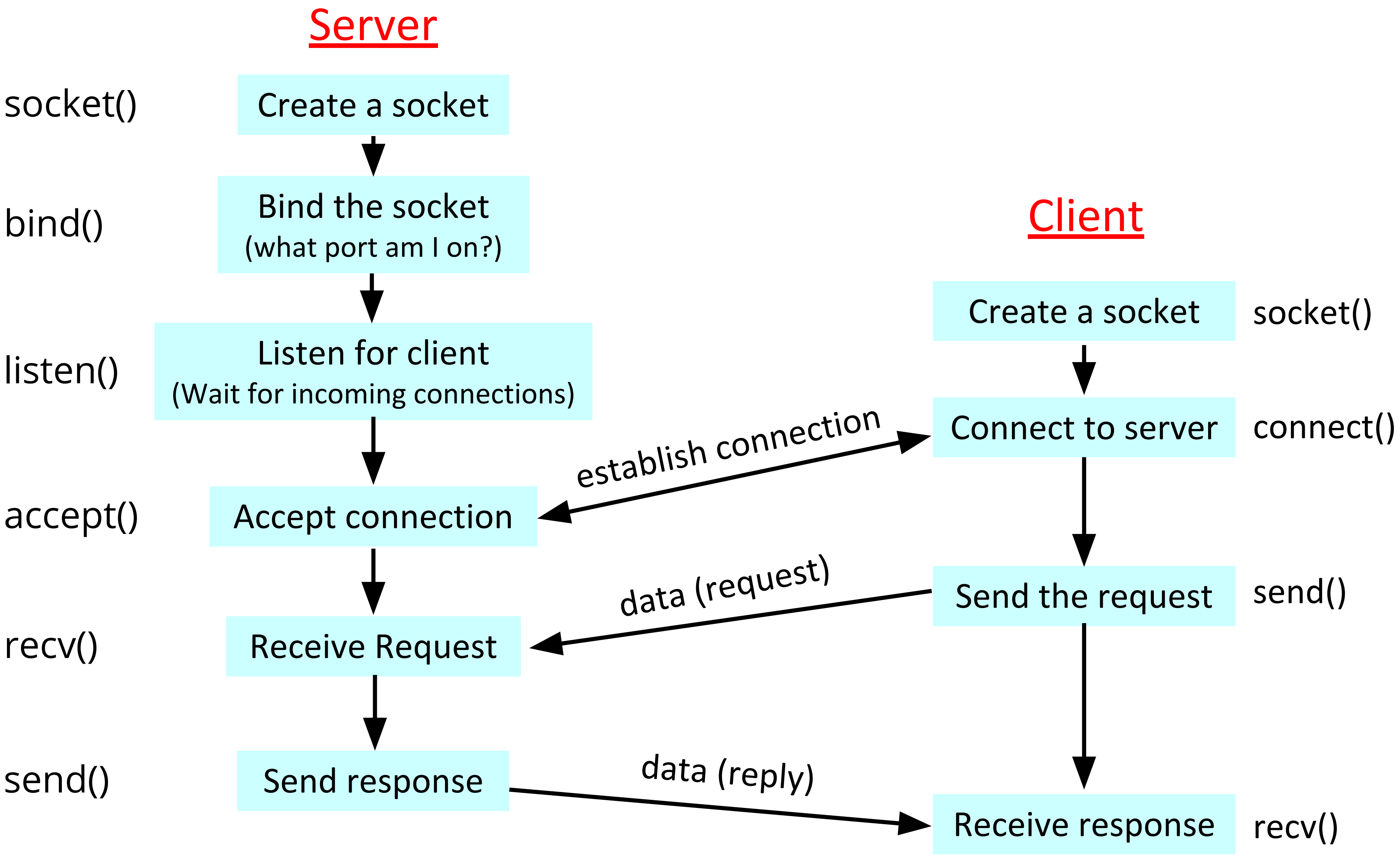
- Popular applications have well-known ports
  - E.g., port 80 for Web and port 25 for e-mail
  - See http://www.iana.org/assignments/port-numbers
- Well-known vs. ephemeral ports
  - Server has a well-known port (e.g., port 80)
    - Between 0 and 1023 (requires root to use)
  - Client picks an unused ephemeral (i.e., temporary) port
    - Between 1024 and 65535
- "5 tuple" uniquely identifies traffic between hosts
  - Two IP addresses and two port numbers
  - + underlying transport protocol (e.g., TCP or UDP)

Using Ports to Identify Services

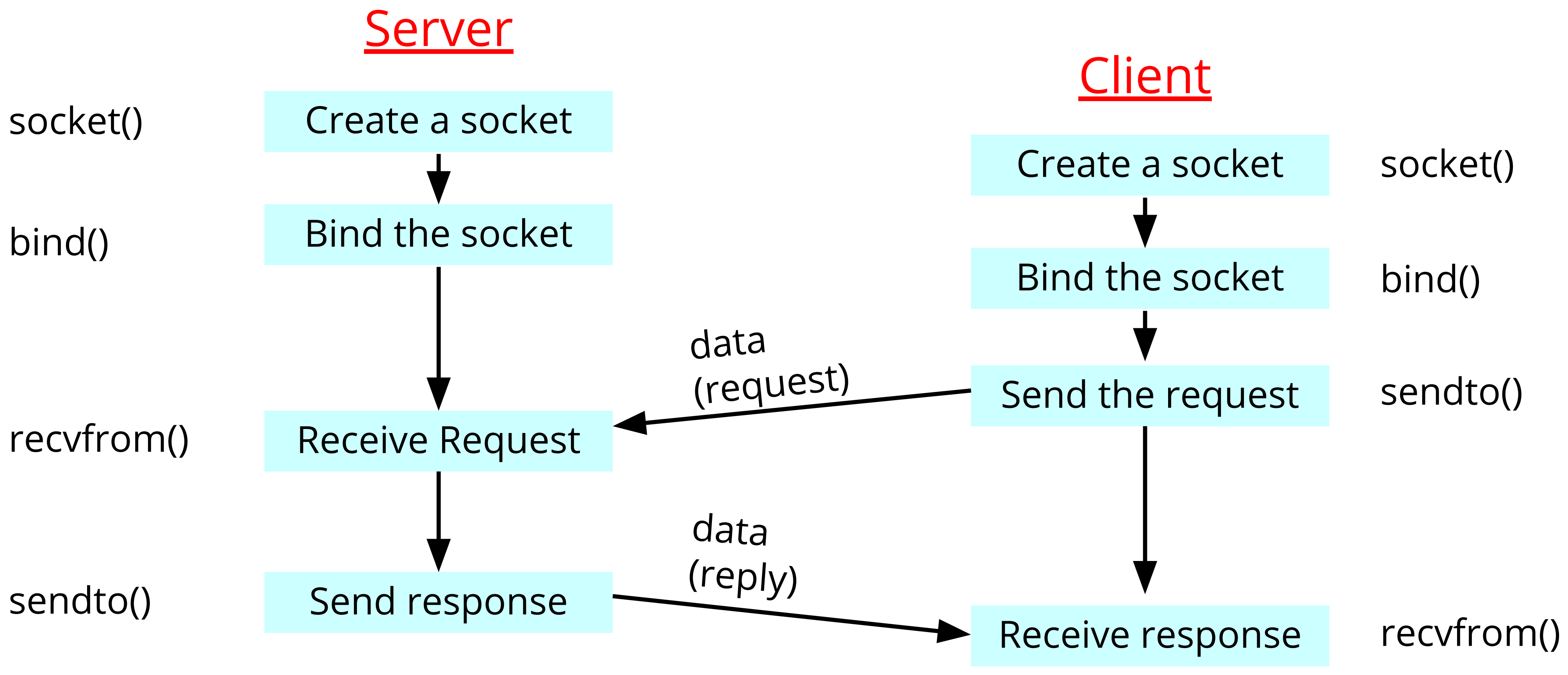


Worksheet

Stream Sockets (TCP): Connection-oriented



Datagram Sockets (UDP): Connectionless



Example C Server and Client

Byte Order

- Network byte order
  - Big Endian
- Host byte order
  - Big Endian *or* Little Endian
- Functions to deal with this
  - `htons() & htonl()` (host to network short and long)
  - `ntohs() & ntohl()` (network to host short and long)
- When to worry?
  - putting data onto the wire
  - pulling data off the wire

Server: Server Preparing its Socket

- Create a socket
  - `int socket(int domain,int type, int protocol)`

- Bind socket to the local address and port number
  - `int bind(int sock_fd, struct sockaddr *server_address,`
    `socklen_t addrlen   )`

Server: Allowing Clients to Wait

- Many client requests may arrive
  - Server cannot handle them all at the same time
  - Server could reject the requests, or let them wait
- Define how many connections can be pending
  - `int listen(int socket_fd, int backlog)`
  - Arguments: socket descriptor and acceptable backlog
  - Returns a 0 on success, and -1 on error
  - Listen is **non-blocking**: returns immediately
- What if too many clients arrive?
  - Some requests don't get through
  - The Internet makes no promises…
  - And the client can always try again

Server: Accepting Client Connection

- Now all the server can do is wait…
  - Waits for connection request to arrive
  - **<u>Blocking</u>** until the request arrives
  - And then accepting the new request

- Accept a new connection from a client
  - ```
    int accept(int sockfd,struct sockaddr *addr,
               socketlen_t *addrlen)
    ```
  - Arguments: sockfd, structure that will provide client address and port, and length of the structure
  - Returns descriptor of socket for this new connection
    ```

Client and Server: Closing Connection

- Once the connection is open
  - Both sides and read and write
  - Two unidirectional streams of data
  - In practice, client writes first, and server reads
  - … then server writes, and client reads, and so on
- Closing down the connection
  - Either side can close the connection
  - … using the `int close(int sockfd)`
- What about the data still “in flight”
  - Data in flight still reaches the other end
  - So, server can `close()` before client finishes reading

Server: One Request at a Time?

- Serializing requests is inefficient
  - Server can process just one request at a time
  - All other clients must wait until previous one is done
  - What makes this inefficient?
- May need to time share the server machine
  - Alternate between servicing different requests
    - Do a little work on one request, then switch when you are waiting for some other resource (e.g., reading file from disk)
    - “Nonblocking I/O”
  - Or, use a different process/thread for each request
    - Allow OS to share the CPU(s) across processes
  - Or, some hybrid of these two approaches

Handle Multiple Clients using `fork()`

- Steps to handle multiple clients
  - Go to a loop and accept connections using `accept()`
  - After a connection is established, call `fork()` to create a new child process to handle it
  - Go back to listen for another socket in the parent process
  - `close()` when you are done.

- Want to know more?
  - Checkout out *Beej's guide to network programming*

Sockets in Go

The `net` package

- `net.Listen` receives the ip, port, and protocol, and returns a `net.Listener`

- `net.Accept` waits for connections from clients
  - Once a client connects, `net.Accept` returns a `net.Conn` to be used for communication

- `net.Dial` connects to the given ip and port, with the specified protocol.
  - Once it is connected, `net.Dial` returns a `net.Conn` to be used for communication

Socket Server/Client: Go

SERVER

- `socket, err := net.Listen("tcp4", "127.0.0.1:8080")`
  - `net.Listen` performs the C `socket`, `bind` and `listen` system calls
  - socket is of type `net.Listener`
- `connection, err := server.Accept()`
  - `net.Accept` accepts an incoming client request
  - `connection` is of type `net.Conn`

CLIENT

- `connection, err := net.Dial("tcp4", "127.0.0.1:8080")`
  - Creates a TCP socket, establish connection
  - `connection` is of type `net.Conn`

`net.Conn`

- `net.Conn.Read` reads from the connection
  - Wrap the connection in `bufio.Reader`
- `net.Conn.Write` writes to the connection
- `net.Conn.Close` closes the connection

`net/http` (Useful in Future)

- A collection of useful functions for handling and processing http requests