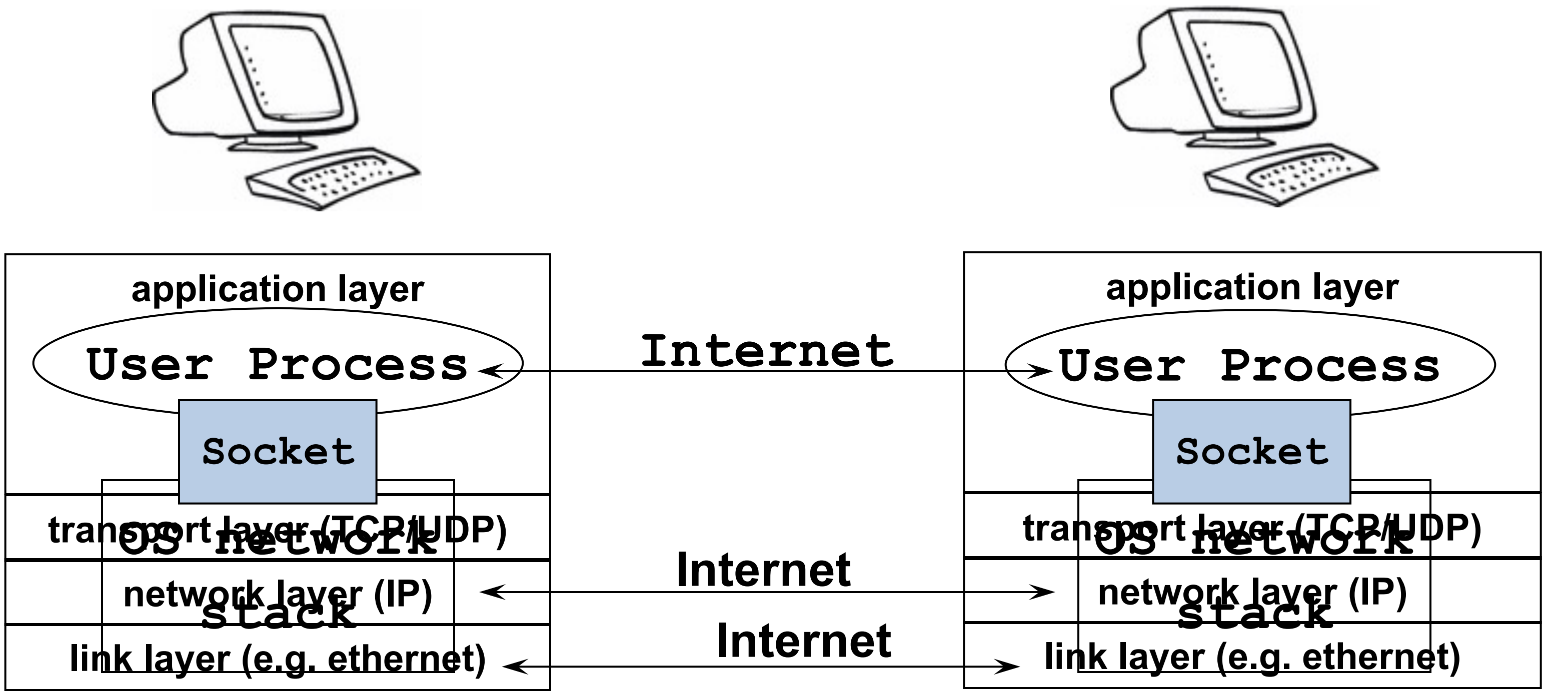
UNIX Sockets

Socket and Process Communication



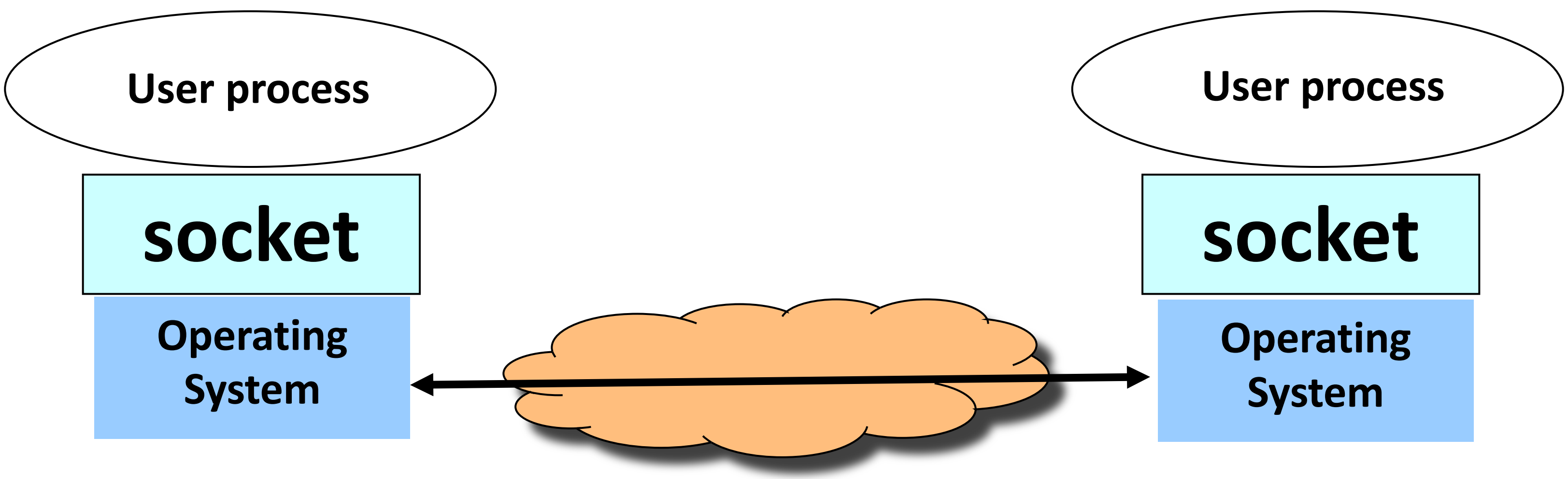
The interface that the OS provides to its networking subsystem

Delivering the Data: Division of Labor

- Network
  - Deliver data packet to the destination host
  - Based on the destination IP address
- Operating system
  - Deliver data to the destination socket
  - Based on the destination port number (e.g., 80)
- Application
  - Read data from and write data to the socket
  - Interpret the data (e.g., render a Web page)

Socket: End Point of Communication

- 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



Two Types of Application Processes Communication

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

- Stream Socket (TCP)
  - Stream of bytes
  - Reliable
  - Connection-oriented

User Datagram Protocol (UDP): Datagram Socket

UDP	Postal Mail
Single socket to receive messages	Single mailbox to receive letters
No guarantee of delivery	Unreliable
Not necessarily in-order delivery	Not necessarily in-order delivery
Datagram – independent packets	Letters sent independently
Must address each packet	Must address each mail

Example UDP applications
Multimedia, voice over IP (Skype)

Transmission Control Protocol (TCP): Stream Socket

TCP

- Reliable – guarantee delivery
- Byte stream – in-order delivery
- Connection-oriented – single socket per connection
- Setup connection followed by data transfer

Telephone Call

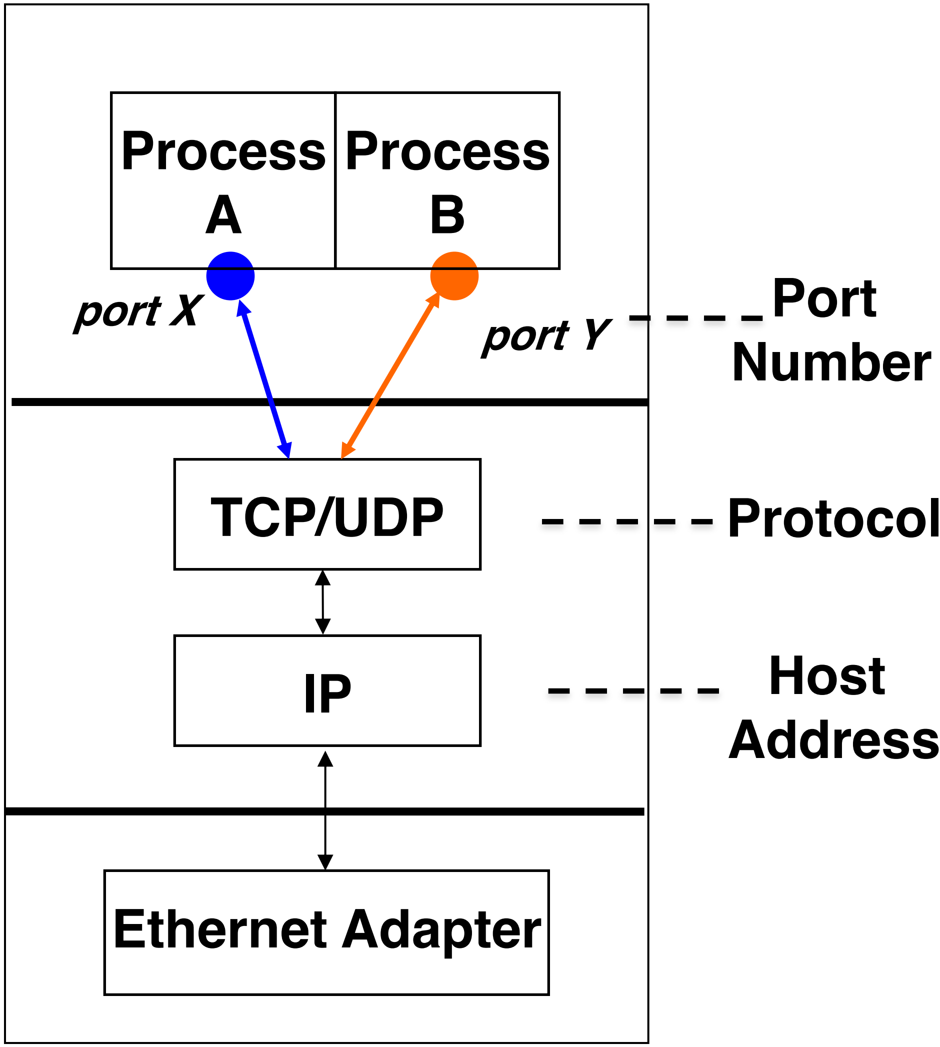
- Guaranteed delivery
- In-order delivery
- Connection-oriented
- Setup connection followed by conversation

Example TCP applications

Web, Email, Telnet

Socket Identification

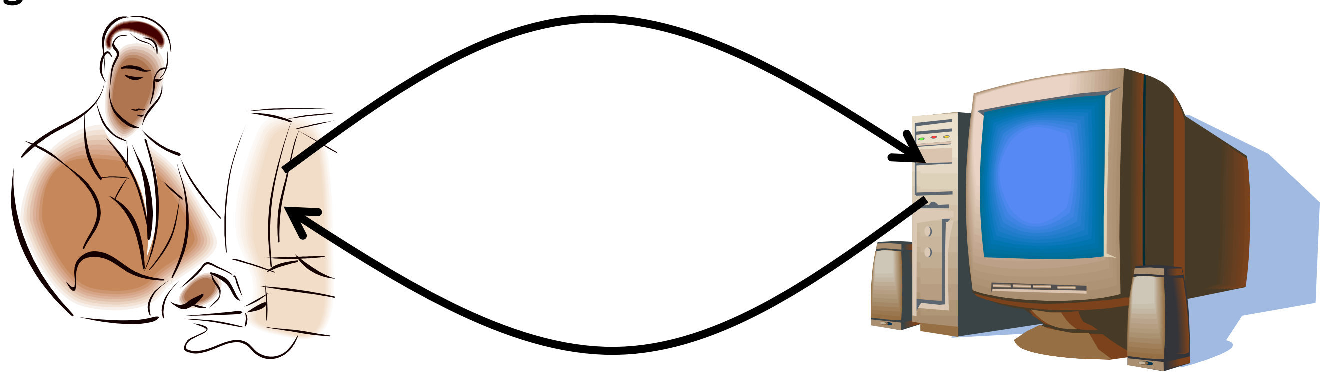
- Receiving host
  - Destination **address** that uniquely identifies host
  - **IP address**: 32-bit quantity
- Receiving socket
  - Host may be running many different processes
  - Destination **port** that uniquely identifies socket
  - **Port number:** 16-bits



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

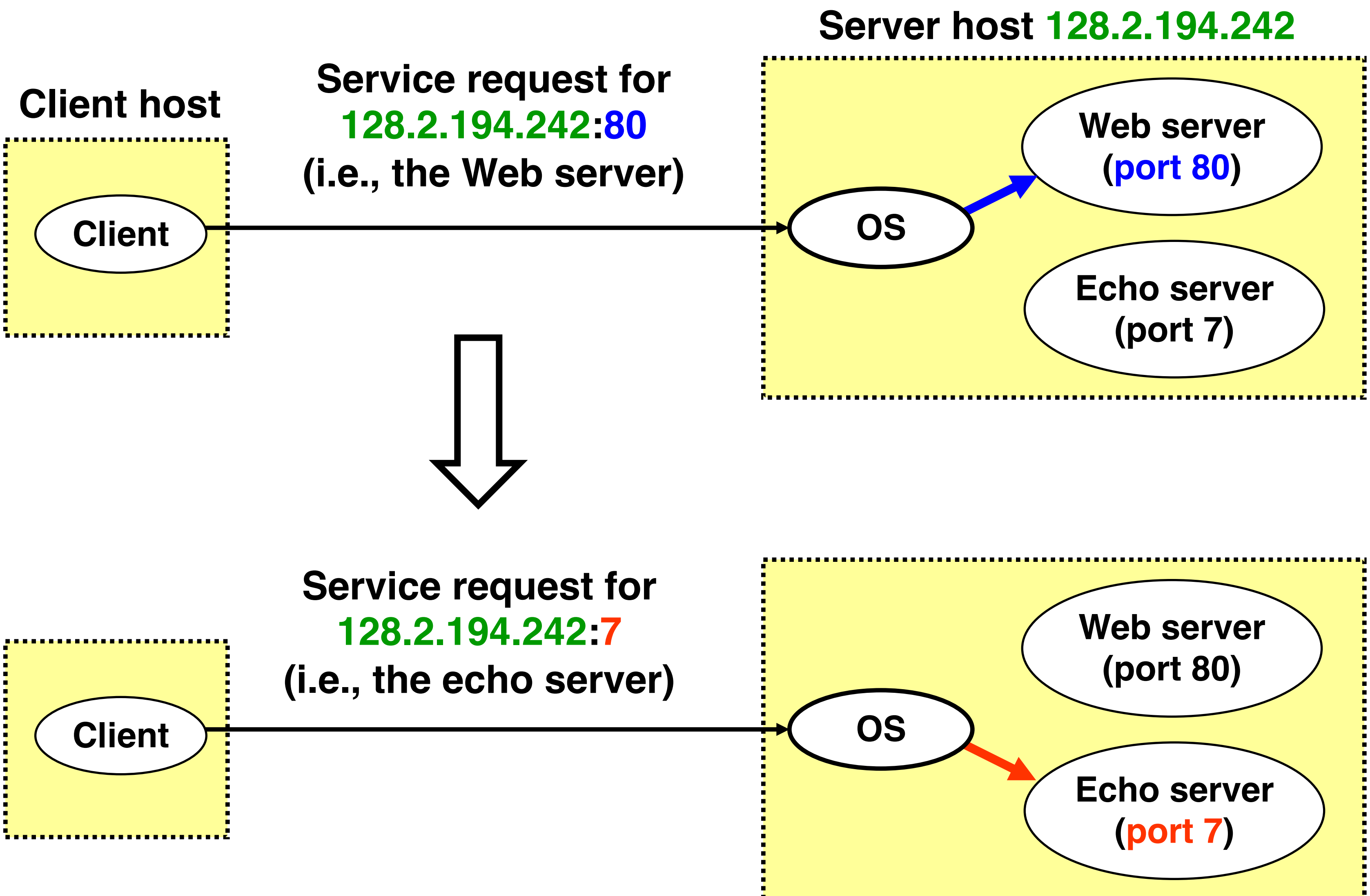
- Server is "always on"
  - Handles services requests from many client hosts
  - E.g., Web server for the www.cnn.com Web site
  - Doesn't initiate contact with the clients
  - Needs fixed, known address



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)

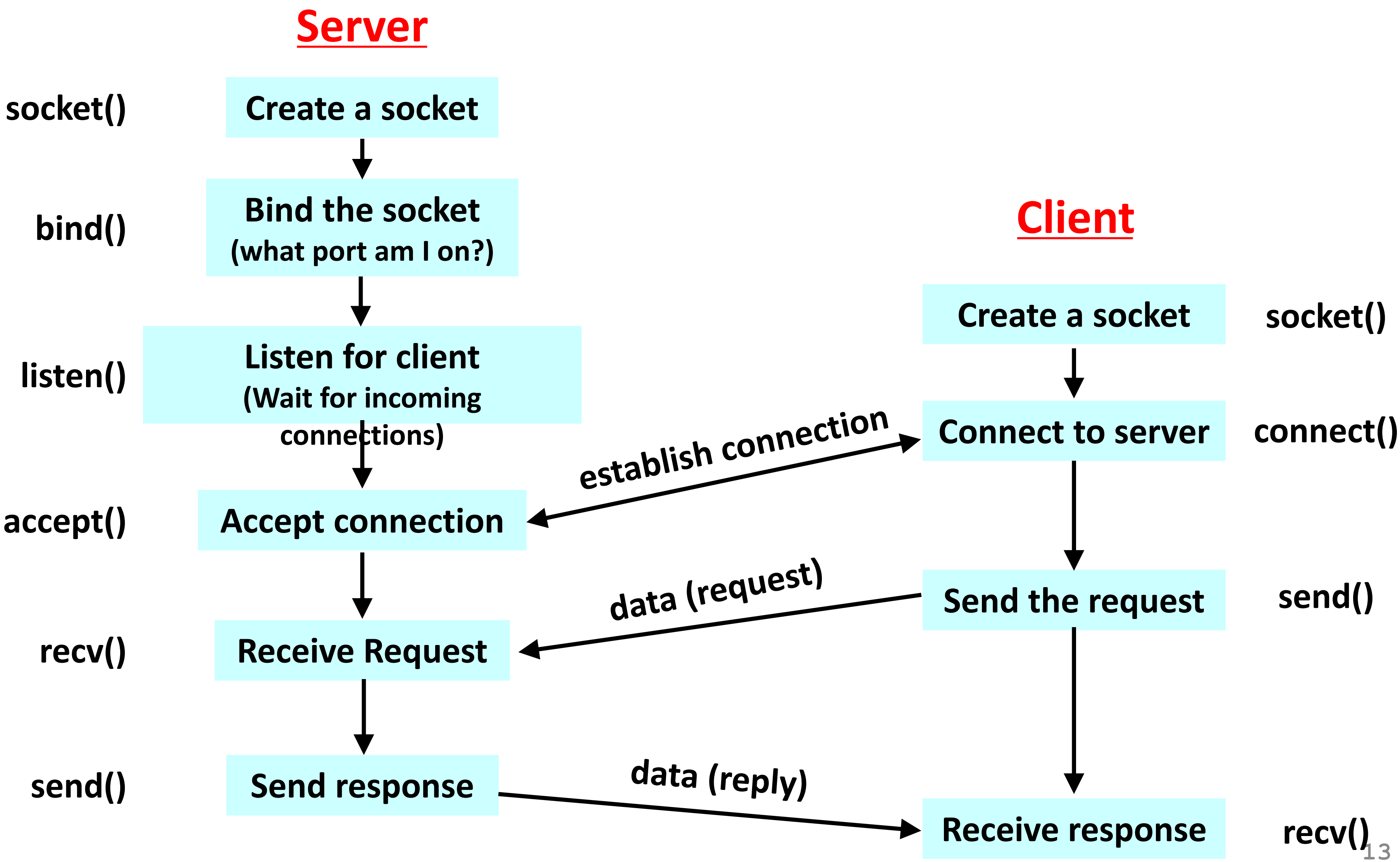
Using Ports to Identify Services



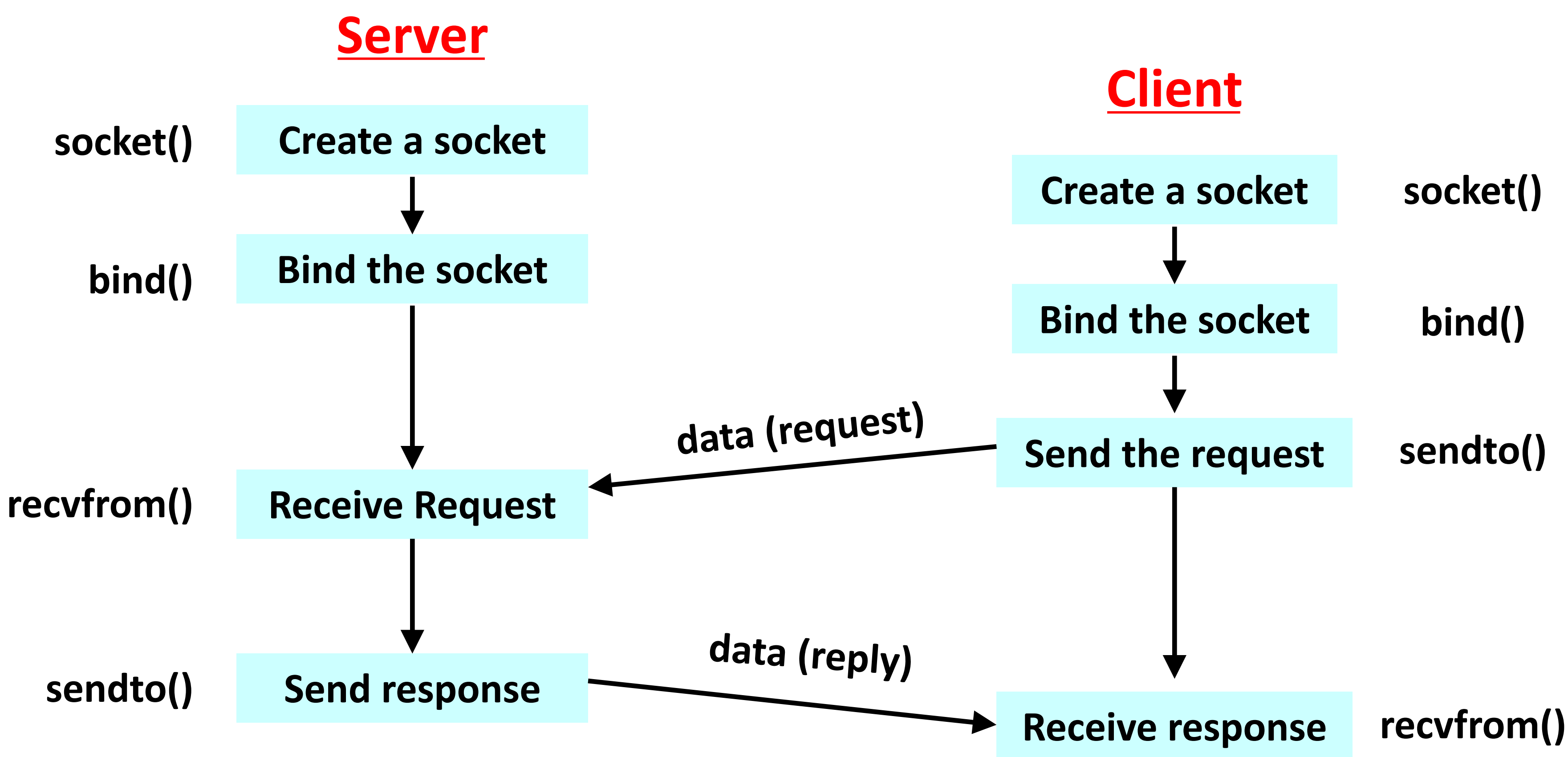
UNIX Socket API

- In UNIX, everything is like a file
  - All input is like reading a file
  - All output is like writing a file
  - File is represented by an integer file descriptor
- API implemented as system calls
  - E.g., connect, send, recv, close, …

Client-Server Communication
Stream Sockets (TCP): Connection-oriented



Client-Server Communication Datagram Sockets (UDP): Connectionless



Client: Learning Server Address/Port

- Server typically known by name and service
  - E.g., "www.cnn.com" and "http"
- Need to translate into IP address and port #
  - E.g., "64.236.16.20" and "80"

- Get address info with given host name and service
  -
```
int getaddrinfo( char *node,
                 char *service,
                 struct addrinfo *hints,
                 struct addrinfo **result)
```

  - *node: host name (e.g., "www.cnn.com") or IP address
  - *service: port number or service listed in */etc/services* (e.g. ftp)
  - hints: points to a *struct addrinfo* with known information

Client: Learning Server Address/Port (cont.)

- Data structure to host address information

```
struct addrinfo {
    int                 ai_flags;
    int                 ai_family;//e.g. AF_INET for IPv4
    int                 ai_socketype; //e.g. SOCK_STREAM for TCP
    int                 ai_protocol;  //e.g. IPPROTO_TCP
    size_t              ai_addrlen;
    char                *ai_canonname;
    struct sockaddr     *ai_addr; // point to sockaddr struct
    struct addrinfo     *ai_next;
}
```

- Example

```
hints.ai_family = AF_UNSPEC;      // don't care IPv4 or IPv6
hints.ai_socktype = SOCK_STREAM; // TCP stream sockets
int status = getaddrinfo("www.cnn.com", "80", &hints, &result);
// result now points to a linked list of 1 or more addrinfos
// etc.
```

Client: Creating a Socket

- Creating a socket
  - `int socket(int domain, int type, int protocol)`
  - Returns a file descriptor (or handle) for the socket
- Domain: protocol family
  - PF_INET for IPv4
  - PF_INET6 for IPv6
- Type: semantics of the communication
  - SOCK_STREAM: reliable byte stream (TCP)
  - SOCK_DGRAM: message-oriented service (UDP)
- Protocol: specific protocol
  - UNSPEC: unspecified
  - (PF_INET and SOCK_STREAM already implies TCP)
- Example

```
sockfd = socket(  result->ai_family,
                  result->ai_socktype,
                  result->ai_protocol);
```

Client: Connecting Socket to the Server

- Client contacts the server to establish connection
  - Associate the socket with the server address/port
  - Acquire a local port number (assigned by the OS)
  - Request connection to server, who hopefully accepts
  - connect is **<u>blocking</u>**
- Establishing the connection
  -
```
int connect( int sockfd,
             struct sockaddr *server_address,
             socketlen_t addrlen )
```
  - Args: socket descriptor, server address, and address size
  - Returns 0 on success, and -1 if an error occurs
  - E.g.
```
connect( sockfd,
         result->ai_addr,
         result->ai_addrlen);
```

Client: Sending Data

- Sending data
  - `int send( int sockfd, void *msg,`
    `size_t len, int flags)`
  - Arguments: socket descriptor, pointer to buffer of data to send, and length of the buffer
  - Returns the number of bytes written, and -1 on error
  - send is **blocking**: return only after data is sent
  - Write short messages into a buffer and send once

Client: Receiving Data

- Receiving data
  - ```
    int recv( int sockfd, void *buf,
              size_t len, int flags)
    ```
  - Arguments: socket descriptor, pointer to buffer to place the data, size of the buffer
  - Returns the number of characters read (where 0 implies "end of file"), and -1 on error
  - Why do you need len? What happens if buf's size < len?
  - recv is **blocking**: return only after data is received
    ```

Byte Order

- Network byte order
  - Big Endian
- Host byte order
  - Big Endian (IBM mainframes, Sun SPARC) *or* Little Endian (x86)
- 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

- Server creates a socket and binds address/port
  - Server creates a socket, just like the client does
  - Server associates the socket with the port number

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

- Bind socket to the local address and port number
  - ```
    int bind( int sockfd,
              struct sockaddr *my_addr,
              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 sockfd, 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
  - **Blocking** 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: Cleaning House

- 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.

```
while (1) {
  fd = accept (srv_fd, (struct sockaddr *) &caddr, &clen);
  ...
  pid = fork(); children++;
  /* child process to handle request */
  if (pid == 0) {
     /* exit(0) on success, exit(1) on error */
  }
  /* parent process */
  else if (pid > 0) {
     while ((waitpid(-1, &status, WNOHANG)) > 0)
        children--;
     if (children > MAX_PROCESSES)
        ...
  }
  else {
    perror("ERROR on fork");
    exit(1);
}}
```

Helpful Links

- Want to know more?
  - *Beej's guide to network programming,* https://beej.us/guide/bgnet/
  - Another tutorial at https://tutorialspoint.com/unix_sockets/
  - http://www.linuxhowtos.org/C_C++/socket.htm
  - https://www.geeksforgeeks.org/udp-server-client-implementation-c/
  - Also please check out the use of Netcat (NC) utility, https://www.thegeekstuff.com/2012/04/nc-command-examples/?utm_source=feedburner