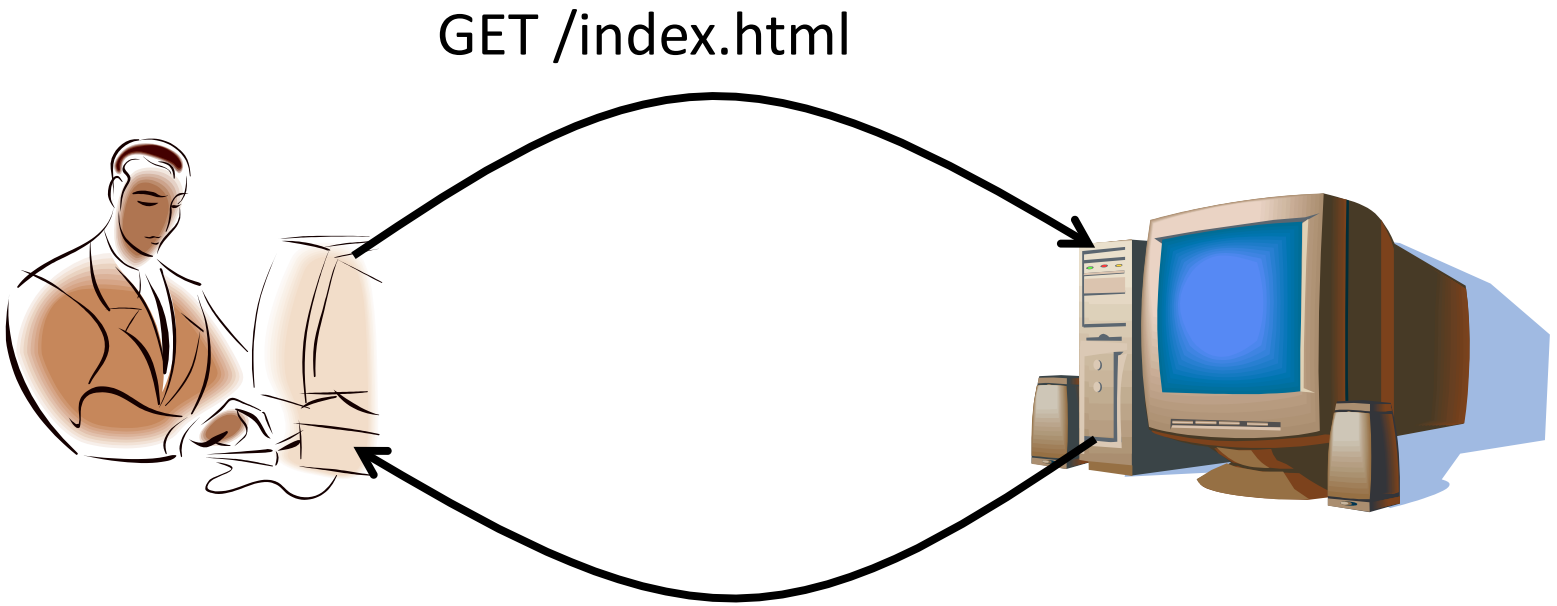
UNIX Sockets

COS 461 Precept 1

Clients and Servers

- Client program
  - Running on end host
  - Requests service
  - E.g., Web browser
- Server program
  - Running on end host
  - Provides service
  - E.g., Web server

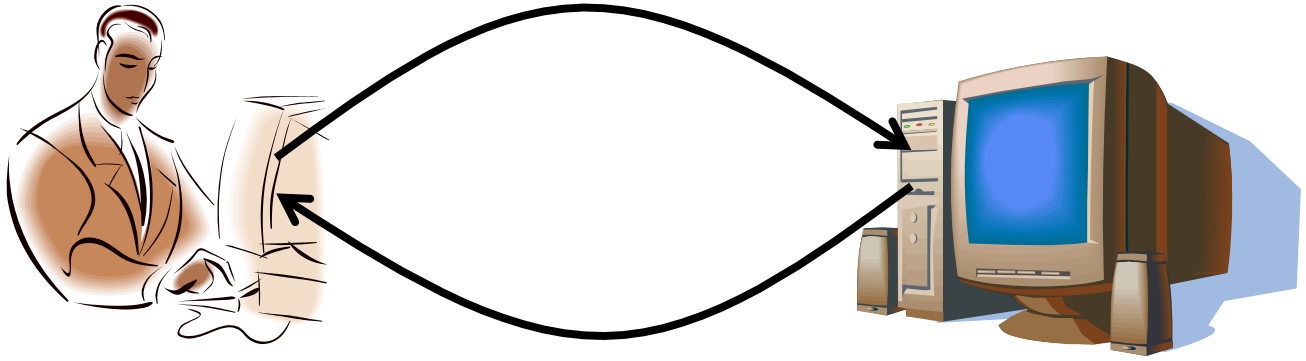


Clients Are Not Necessarily Human

- Example: Web crawler (or spider)
  - Automated client program
  - Tries to discover & download many Web pages
  - Forms the basis of search engines like Google
- Spider client
  - Start with a base list of popular Web sites
  - Download the Web pages
  - Parse the HTML files to extract hypertext links
  - Download these Web pages, too
  - And repeat, and repeat, and repeat…

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"
  - 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



Client and Server Processes

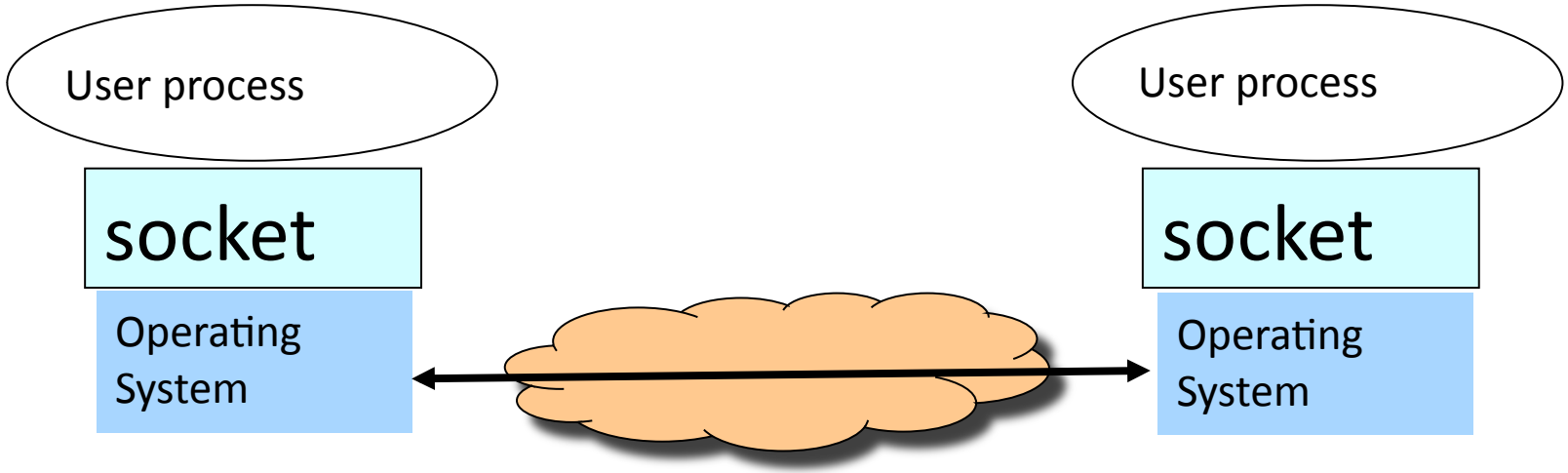
- Program vs. process
  - Program: collection of code
  - Process: a running program on a host
- Communication between processes
  - Same end host: inter-process communication
    - Governed by the operating system on the end host
  - Different end hosts: exchanging messages
    - Governed by the network protocols
- Client and server processes
  - Client process: process that initiates communication
  - Server process: process that waits to be contacted

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

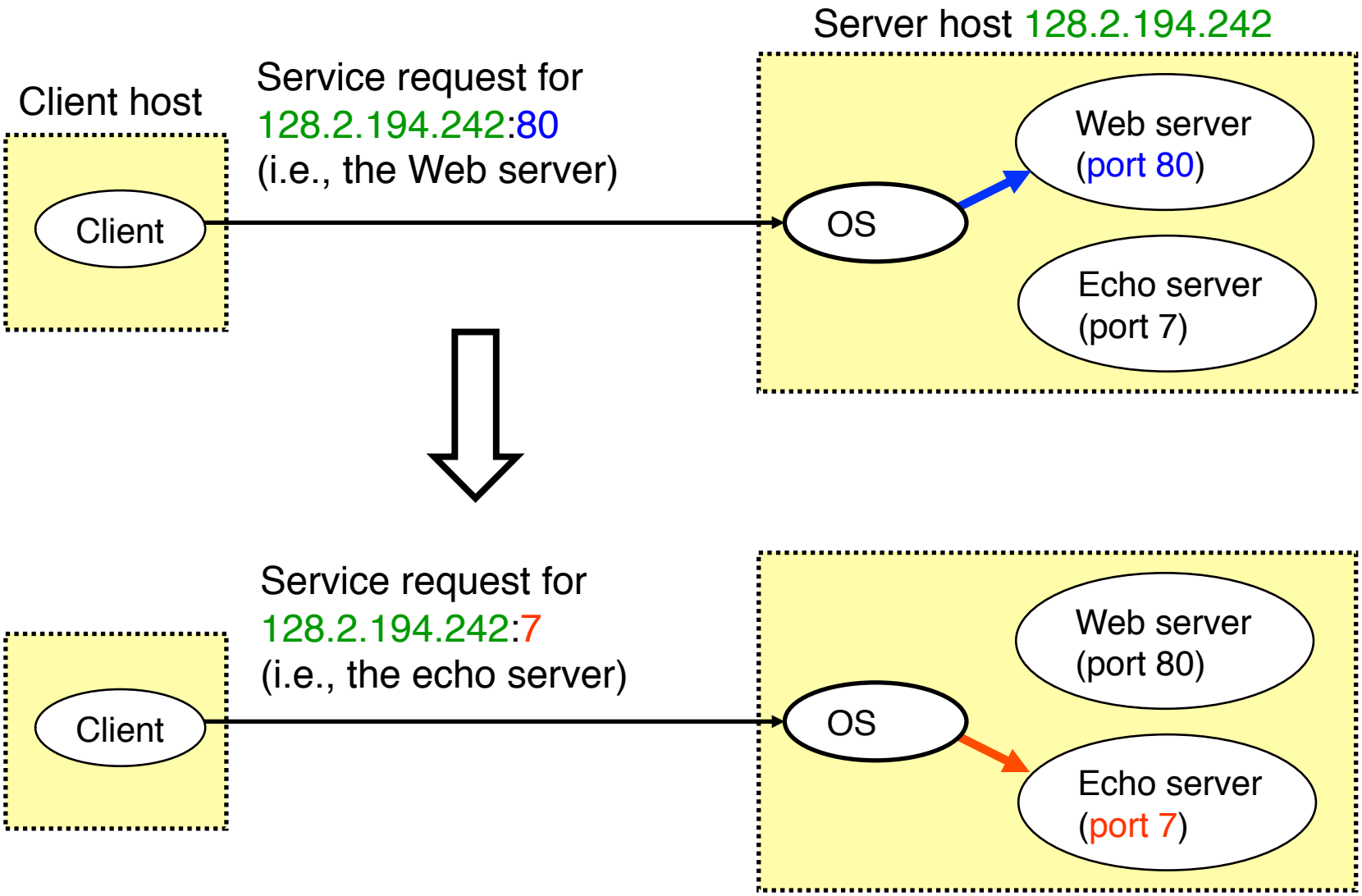
- Sending message from one process to another
  - Message must traverse the underlying network
- Process sends and receives through a "socket"
  - In essence, the doorway leading in/out of the house
- Socket as an Application Programming Interface
  - Supports the creation of network applications



Identifying the Receiving Process

- Sending process must identify the receiver
  - The receiving end host machine
  - The specific socket in a process on that machine
- Receiving host
  - Destination address that uniquely identifies the host
  - An IP address is a 32-bit quantity
- Receiving socket
  - Host may be running many different processes
  - Destination port that uniquely identifies the socket
  - A port number is a 16-bit quantity

Using Ports to Identify Services



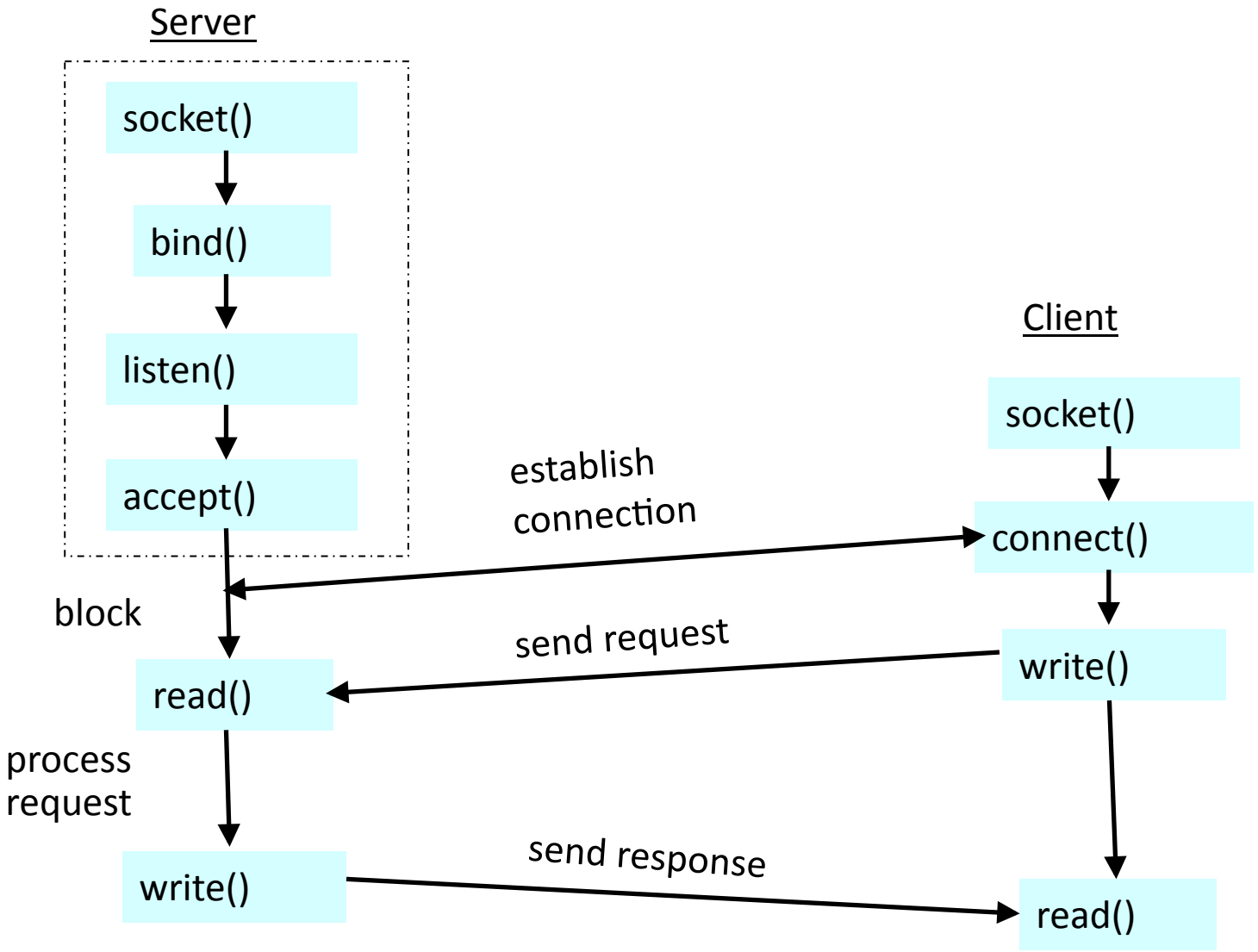
Knowing What Port Number To Use

- 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
- Uniquely identifying traffic between the hosts
  - Two IP addresses and two port numbers
  - Underlying transport protocol (e.g., TCP or UDP)
  - This is the "5-tuple" I discussed last lecture

UNIX Socket API

- Socket interface
  - Originally provided in Berkeley UNIX
  - Later adopted by all popular operating systems
  - Simplifies porting applications to different OSes
- 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, read, write, close, …

Putting it All Together



Client Creating a Socket: socket()

- Creating a socket
  - **`int socket(int domain, int type, int protocol)`**
  - Returns a file descriptor (or handle) for the socket
  - Originally designed to support any protocol suite

- Domain: protocol family
  - PF_INET for the Internet (IPv4)
- 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)

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"

- Translating the server's name to an address
  - **`struct hostent *gethostbyname(char *name)`**
  - Argument: host name (e.g., "www.cnn.com")
  - Returns a structure that includes the host address

- Identifying the service's port number
  - **`struct servent *getservbyname(char *name, char *proto)`**
  - Arguments: service (e.g., "ftp") and protocol (e.g., "tcp")
  - Static config in `/etc/services`

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

- Establishing the connection
  - **`int connect (int sockfd,`**
    `struct sockaddr *server_address,`
    `socketlen_t addrlen)`
  - Arguments: socket descriptor, server address, and address size
  - Returns 0 on success, and -1 if an error occurs

Client: Sending Data

- Sending data
  - **`ssize_t write`**
    `(int sockfd, void *buf, size_t len)`
  - 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

Client: Receiving Data

- Receiving data
  - **`ssize_t read`**
    `(int sockfd, void *buf, size_t len)`
  - 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?

- Closing the socket
  - **`int close(int sockfd)`**

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 (and hopefully no other process is already using it!)
  - Choose port "0" and let kernel assign ephemeral port

- 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)`**
  - Arguments: sockfd, server address, address length
  - Returns 0 on success, and -1 if an error occurs

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
- 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

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

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 **`close()`** system call
- What about the data still "in flight"
  - Data in flight still reaches the other end
  - So, server can **`close()`** before client finishes reading

Wanna See Real Clients and Servers?

- Apache Web server
  - Open source server first released in 1995
  - Name derives from “a patchy server” ;-)
  - Software available online at http://www.apache.org
- Mozilla Web browser
  - http://www.mozilla.org/developer/
- Sendmail
  - http://www.sendmail.org/
- BIND Domain Name System
  - Client resolver and DNS server
  - http://www.isc.org/index.pl?/sw/bind/
- …