CSMC 412

Computer Networks

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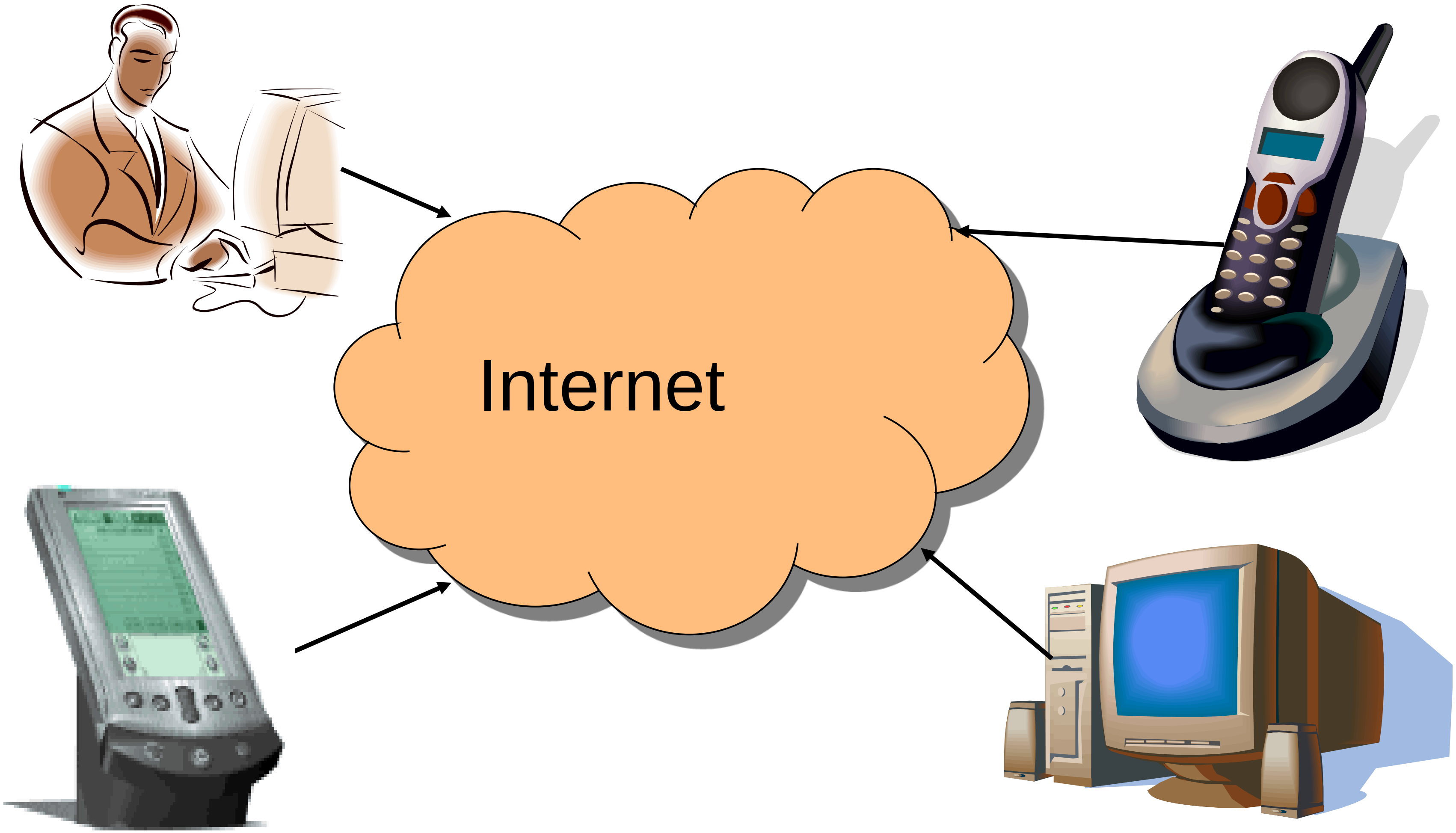
Set 2

Contents

- Client-server paradigm
  - End systems
  - Clients and servers
- Sockets
  - Socket abstraction
  - Socket programming in UNIX
- File-Transfer Protocol (FTP)
  - Uploading and downloading files
  - Separate control and data connections

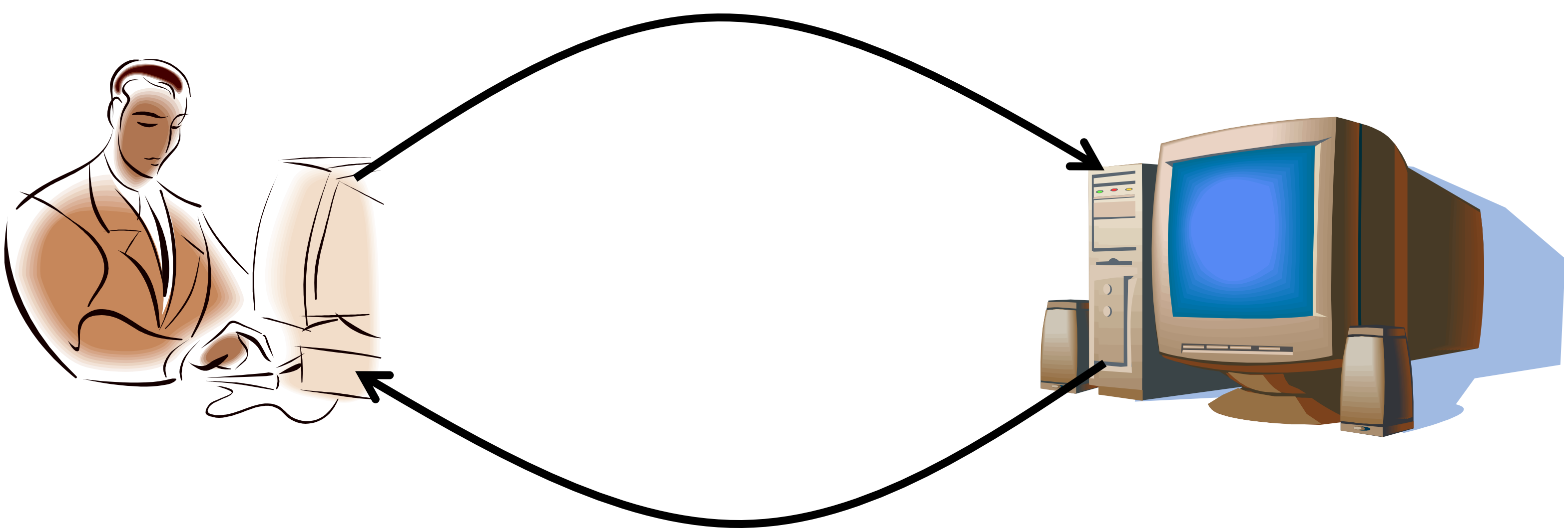
End System: Computer on the ‘Net



Also known as a “host”…

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

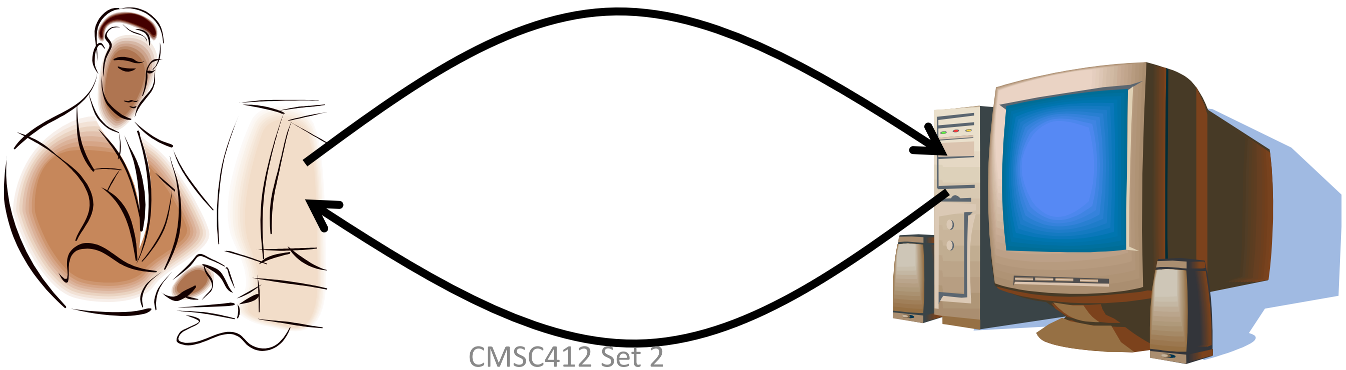


Clients Are Not Necessarily Human

- 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 the 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 a fixed, well-known address



Peer-to-Peer Communication

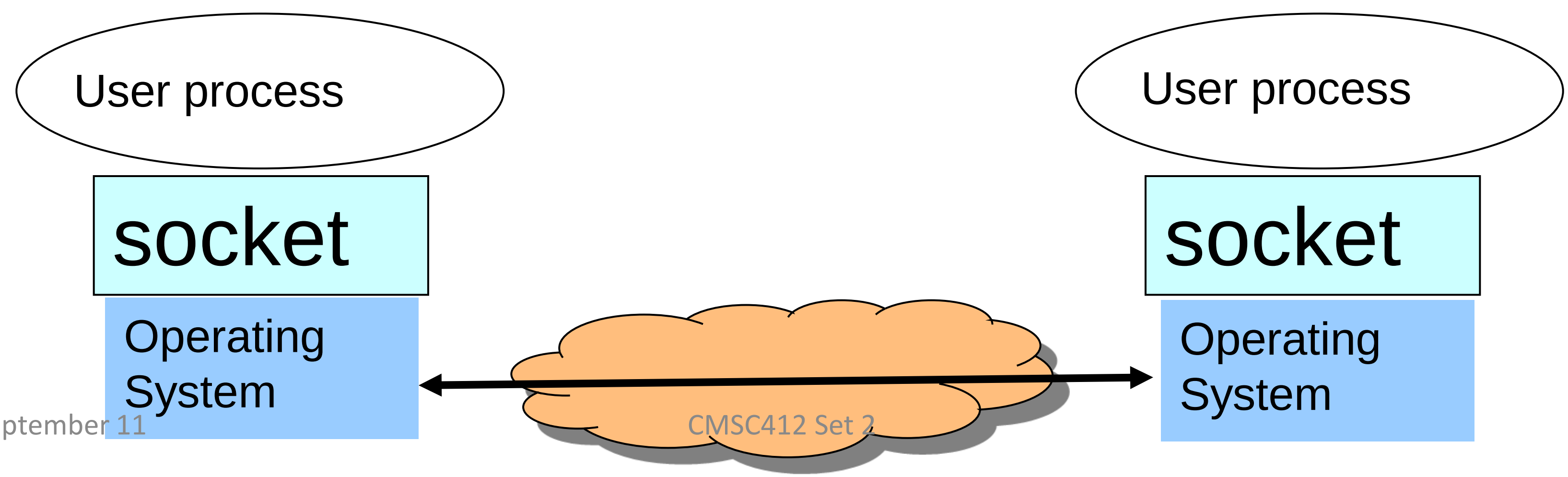
- No always-on server at the center of it all
  - Hosts can come and go, and change addresses
  - Hosts may have a different address each time
- Example: peer-to-peer file sharing
  - Any host can request files, send files, query to find where a file is located, respond to queries, and forward queries
  - Scalability by harnessing millions of peers
  - Each peer acting as both a client and server

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

Socket: End Point of Communication

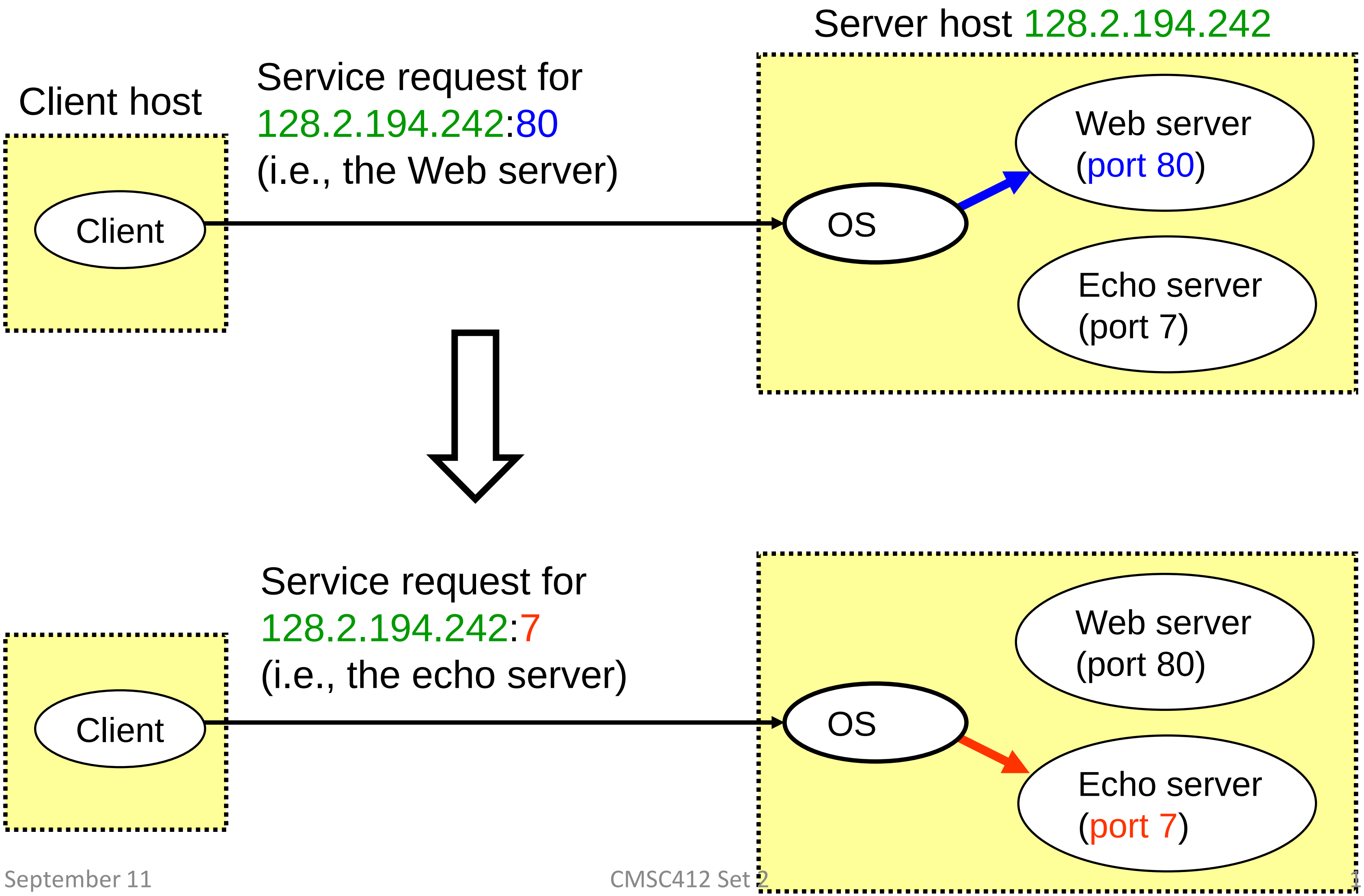
- Sending message from one process to another
  - Message must traverse the underlying network
- Process sends and receives through a “socket”
  - In essence, the doorway leading in/out of the house
- Socket as an Application Programming Interface
  - Supports the creation of network applications



Identifying the Receiving Process

- Sending process must identify the receiver
  - Name or address of the receiving end host
  - Identifier that specifies the receiving process
- Receiving host
  - Destination address that uniquely identifies the host
  - An IP address is a 32-bit quantity
- Receiving process
  - 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
  - Well-known ports listed at http://www.iana.org
- Well-known vs. ephemeral ports
  - Server has a well-known port (e.g., port 80)
    - Between 0 and 1023
  - Client picks an unused ephemeral (i.e., temporary) port
    - Between 1024 and 65535
- Uniquely identifying the traffic between the hosts
  - Two IP addresses and two port numbers
  - Underlying transport protocol (e.g., TCP or UDP)

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 protocol and destination port #
- Application
  - Read data from the socket
  - Interpret the data (e.g., render a Web page)

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
- System calls for sockets
  - Client: create, connect, write, read, close
  - Server: create, bind, listen, accept, read, write, close

Typical Client Program

- Prepare to communicate
  - Create a socket
  - Determine server address and port number
  - Initiate the connection to the server
- Exchange data with the server
  - Write data to the socket
  - Read data from the socket
  - Do stuff with the data (e.g., render a Web page)
- Close the socket

Creating a Socket: socket()

- Operation to create a socket
  - *int socket(int domain, int type, int protocol)*
  - Returns a descriptor (or handle) for the socket
  - Originally designed to support any protocol suite
- Domain: protocol family
  - PF_INET for the Internet
- Type: semantics of the communication
  - SOCK_STREAM: reliable byte stream
  - SOCK_DGRAM: message-oriented service
- Protocol: specific protocol
  - UNSPEC: unspecified
  - (PF_INET and SOCK_STREAM already implies TCP)

Connecting the Socket to the Server

- Translating the server's name to an address
  - *struct hostent *gethostbyname(char *name)*
  - Argument: the name of the host (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")
- 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

Sending and Receiving 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 characters written, and -1 on error
- 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
- Closing the socket
  - *int close(int sockfd)*

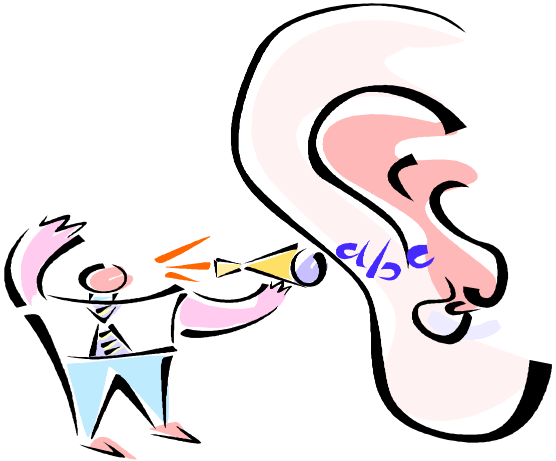
Byte Ordering: Little and Big Endian

- Hosts differ in how they store data
  - E.g., four-byte number (byte3, byte2, byte1, byte0)
- Little endian ("little end comes first") ← Intel PCs!!!
  - Low-order byte stored at the lowest memory location
  - Byte0, byte1, byte2, byte3
- Big endian ("big end comes first")
  - High-order byte stored at lowest memory location
  - Byte3, byte2, byte1, byte 019IP is big endian (aka "network byte order")
  - Use htons() and htonl() to convert to network byte order
  - Use ntohs() and ntohl() to convert to host order

Why Can't Sockets Hide These Details?

- Dealing with endian differences is tedious
  - Couldn't the socket implementation deal with this
  - … by swapping the bytes as needed?
- No, swapping depends on the data type
  - Two-byte short int: (byte 1, byte 0) vs. (byte 0, byte 1)
  - Four-byte long int: (byte 3, byte 2, byte 1, byte 0) vs. (byte 0, byte 1, byte 2, byte 3)
  - String of one-byte charters: (char 0, char 1, char 2, …) in both cases
- Socket layer doesn't know the data types
  - Sees the data as simply a buffer pointer and a length
  - Doesn't have enough information to do the swapping

Servers Differ From Clients



- Passive open
  - Prepare to accept connections
  - … but don’t actually establish one
  - … until hearing from a client
- Hearing from multiple clients
  - Allow a backlog of waiting clients
  - ... in case several try to start a connection at once
- Create a socket for each client
  - Upon accepting a new client
  - … create a *new* socket for the communication

Typical Server Program

- Prepare to communicate
  - Create a socket
  - Associate local address and port with the socket
- Wait to hear from a client (passive open)
  - Indicate how many clients-in-waiting to permit
  - Accept an incoming connection from a client
- Exchange data with the client over new socket
  - Receive data from the socket
  - Do stuff to handle the request (e.g., get a file)
  - Send data to the socket
  - Close the socket
- Repeat with the next connection request

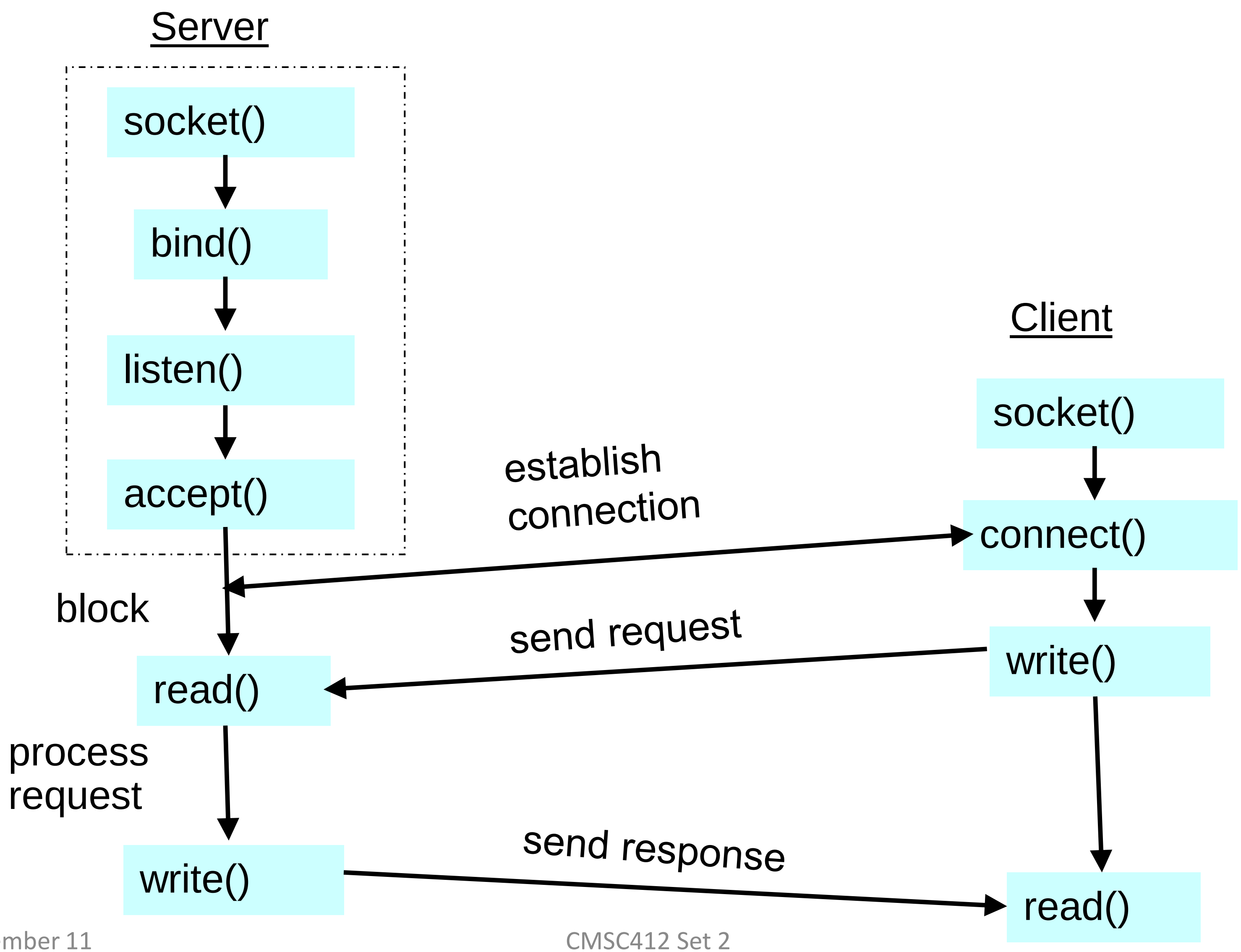
Server Preparing its Socket

- Bind socket to the local address and port number
  - *int bind (int sockfd, struct sockaddr *my_addr, socklen_t addrlen)*
  - Arguments: socket descriptor, server address, address length
  - Returns 0 on success, and -1 if an error occurs
- Define how many connections can be pending
  - *int listen(int sockfd, int backlog)*
  - Arguments: socket descriptor and acceptable backlog
  - Returns 0 on success, and -1 on error

Accepting a New Client Connection

- Accept a new connection from a client
  - *int accept(int sockfd, struct sockaddr *addr, socketlen_t *addrlen)*
  - Arguments: socket descriptor, structure that will provide client address and port, and length of the structure
  - Returns descriptor for a new socket for this connection
- Questions
  - What happens if no clients are around?
    - The *accept()* call blocks waiting for a client
  - What happens if too many clients are around?
    - Some connection requests don't get through
    - … But, that's okay, because the Internet makes no promises

Putting it All Together



Serving 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
- Need to time share the server machine
  - Alternate between servicing different requests
    - Do a little work on one request, then switch to another
    - Small tasks, like reading HTTP request, locating the associated file, reading the disk, transmitting parts of the response, etc.
  - Or, start a new process to handle each request
    - Allow the operating system to share the CPU across processes
  - Or, some hybrid of these two approaches

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/
- …

Advice for Assignment #1

- Familiarize yourself with the socket API
  - Read the online references
  - Read the manual pages (e.g., “man socket”)
  - Feeling self-referential? Do “man man”!
- Write a simple socket program first
  - E.g., simple echo program
  - E.g., simple FTP client that connects to server

File Transfer Protocol (FTP)

- Allows a user to copy files to/from remote hosts
  - Client program connects to FTP server
  - … and provides a login id and password
  - … and allows the user to explore the directories
  - … and download and upload files with the server
- A predecessor of the Web (RFC 959 in 1985)
  - Requires user to know the name of the server machine
  - … and have an account on the machine
  - … and find the directory where the files are stored
  - … and know whether the file is text or binary
  - … and know what tool to run to render and edit the file
- That is, no URL, hypertext, and helper applications

FTP Protocol

- Control connection (on server port 21)
  - Client sends commands and receives responses
  - Connection persists across multiple commands
- FTP commands
  - Specification includes more than 30 commands
  - Each command ends with a carriage return and a line feed ("\r\n" in C)
  - Server responds with a three-digit code and optional human-readable text (e.g., "226 transfer completed")
- Try it at the UNIX prompt
  - ftp ftp.cs.umd.edu
  - Id "anonymous" and password as your e-mail address

Example Commands

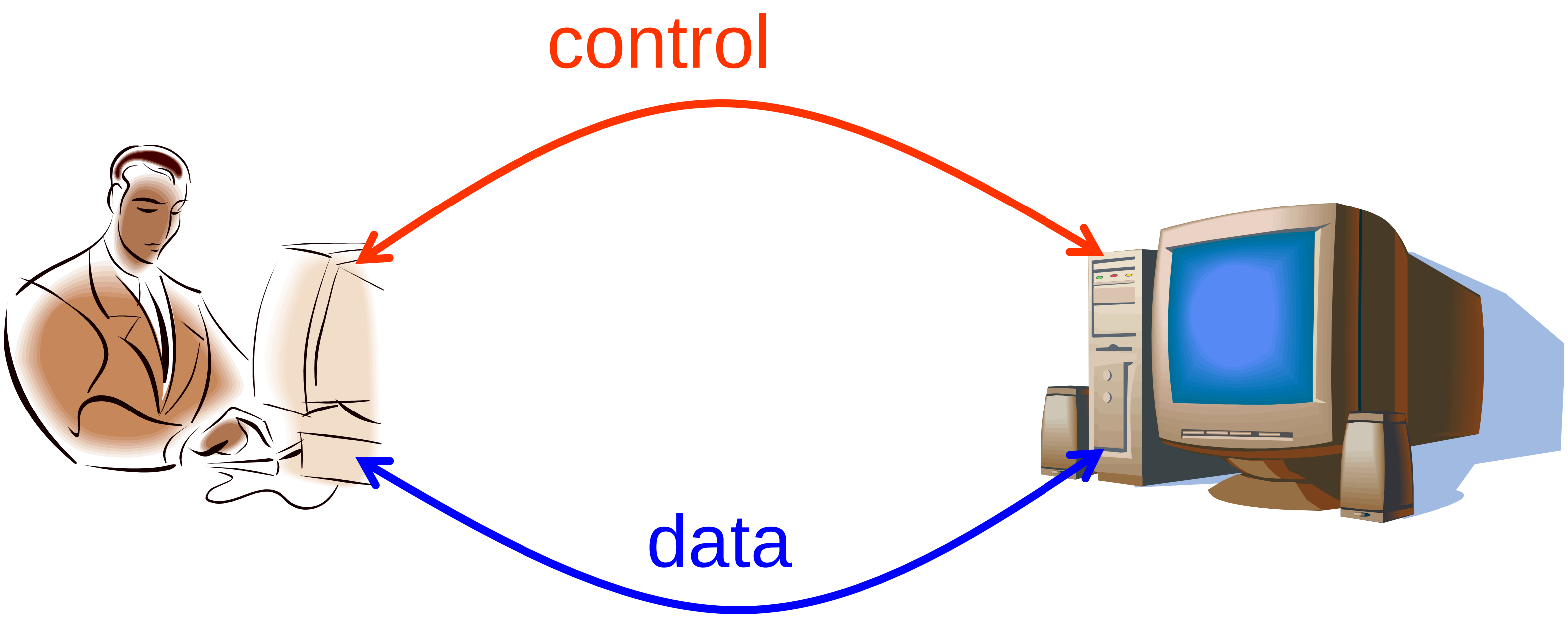
- Authentication
  - USER: specify the user name to log in as
  - PASS: specify the user's password
- Exploring the files
  - LIST: list the files for the given file specification
  - CWD: change to the given directory
- Downloading and uploading files
  - TYPE: set type to ASCII (A) or binary image (I)
  - RETR: retrieve the given file
  - STOR: upload the given file
- Closing the connection
  - QUIT: close the FTP connection

Server Response Codes

- 1xx: positive preliminary reply
  - The action is being started but expect another reply before sending the next command.
- 2xx: positive completion reply
  - The action succeeded and a new command can be sent.
- 3xx: positive intermediate reply
  - The command was accepted but another command is now required.
- 4xx: transient negative completion reply
  - The command failed and should be retried later.
- 5xx: permanent negative completion reply
  - The command failed and should not be retried.

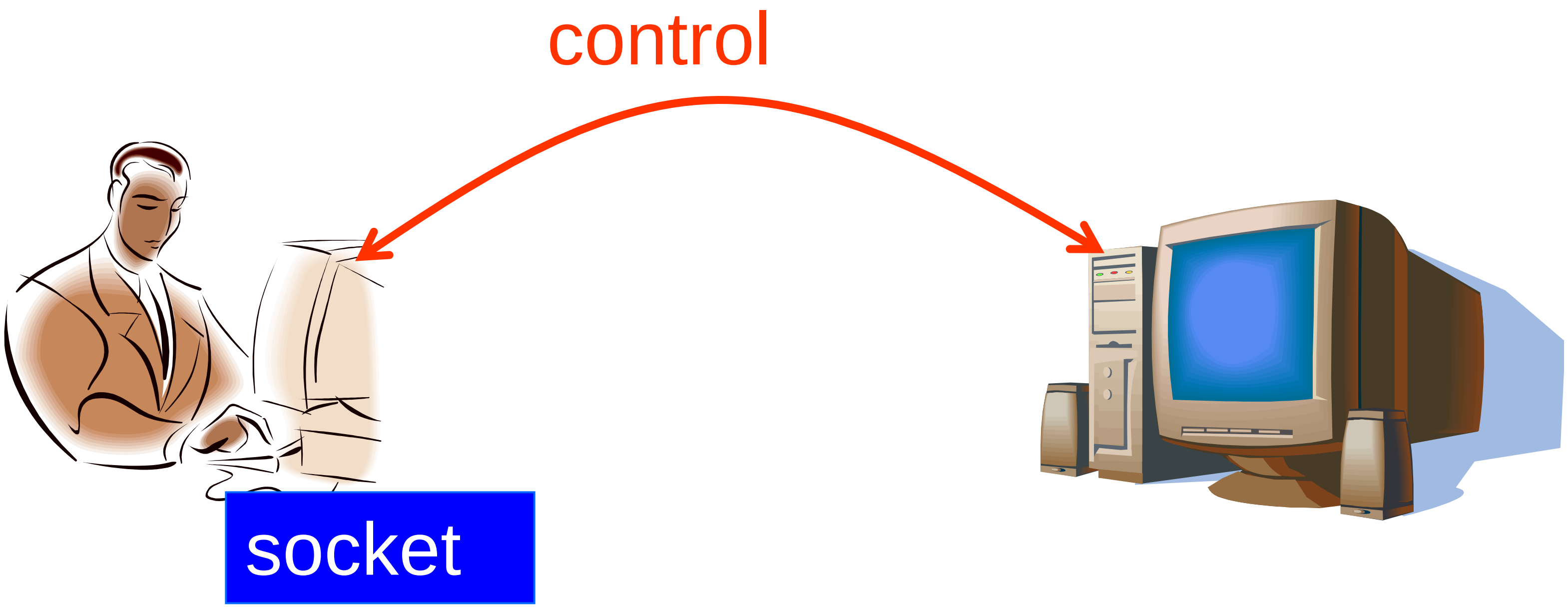
FTP Data Transfer

- Separate data connection
  - To send lists of files (LIST)
  - To retrieve a file (RETR)
  - To upload a file (STOR)



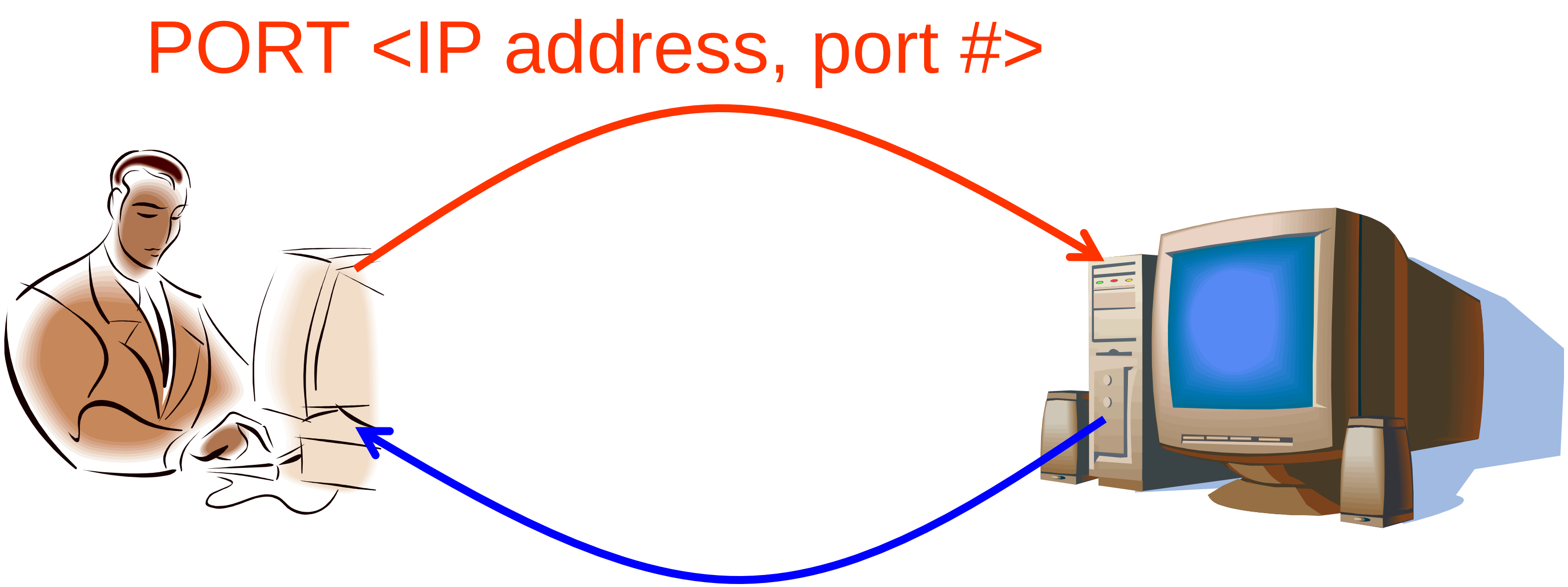
Creating the Data Connection

- Client acts like a server
  - Creates a socket
  - Client acquires an ephemeral port number
  - Binds an address and port number
  - Waits to hear from the FTP server



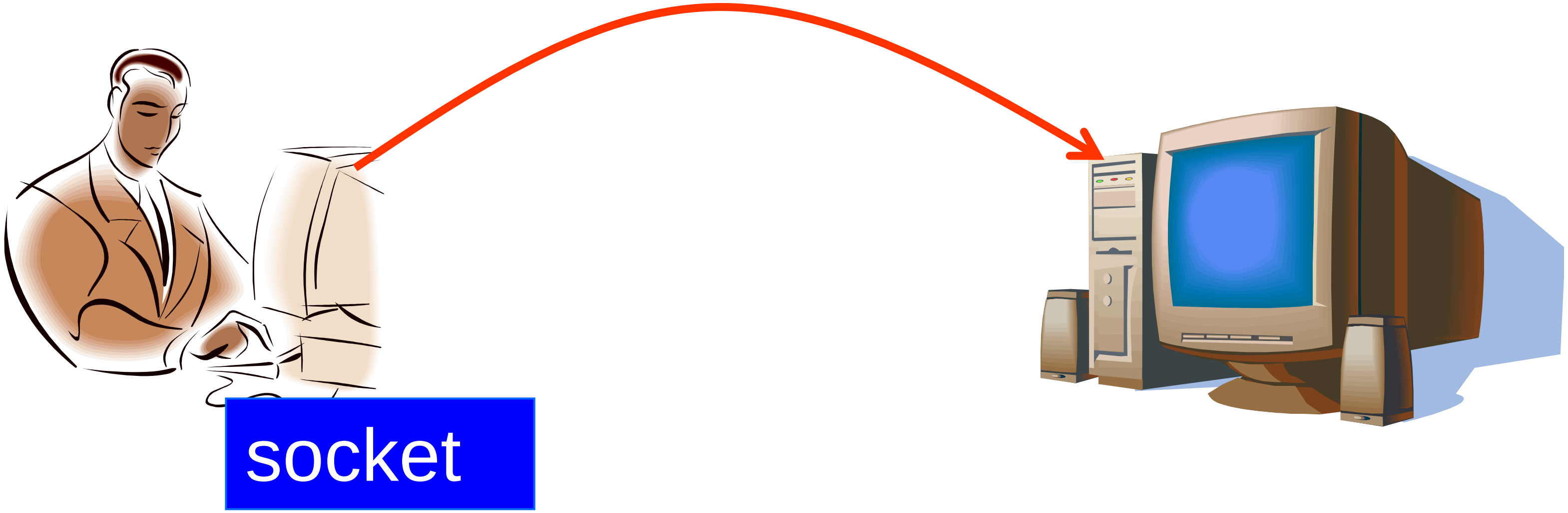
Creating Data Connection (cont.)

- But, the server doesn't know the port number
  - So, the client tells the server the port number
  - Using the PORT command on the control connection



Creating Data Connection (cont)

- Then, the server initiates the data connection
  - Connects to the socket on the client machine
  - … and the client accepts to complete the connection



Why Out-of-Band Control?

- Avoids need to mark the end of the data transfer
  - Data transfer ends by closing of data connection
  - Yet, the control connection stays up
- Aborting a data transfer
  - Can abort a transfer without killing the control connection
  - … which avoids requiring the user to log in again
  - Done with an ABOR on the control connection
- Third-party file transfer between two hosts
  - Data connection could go to a different hosts
  - … by sending a different client IP address to the server
  - E.g., user coordinates transfer between two servers

Closing

- Client-server paradigm
  - Model of communication between end hosts
  - Client asks, and server answers
- Sockets
  - Simple byte-stream and messages abstractions
  - Common application programmable interface
- File-Transfer Protocol (FTP)
  - Protocol for downloading and uploading files
  - Separate control and data connections