Computer Systems and Networks

ECPE 170 – Jeff Shafer – University of the Pacific

Networking Fundamentals

Lab Schedule

Activities

- **This Week**
  - Network programming
  - **Lab 8 – Network Programming**

Assignments Due

- **Lab 8**
  - **Due by 3rd OCT, 5:00am**
- **Lab 9**
  - **Due by NOV 9th, 5:00am**

Computer Networks

Disclaimer

- **These topics take an entire semester of COMP 177 (Computer Networking) to explore!**
- A few days *(most of which is lab time)* is only sufficient for the briefest of overviews…

Network Model

Application Layer
(Myriad examples: Web browser, web server, etc…)

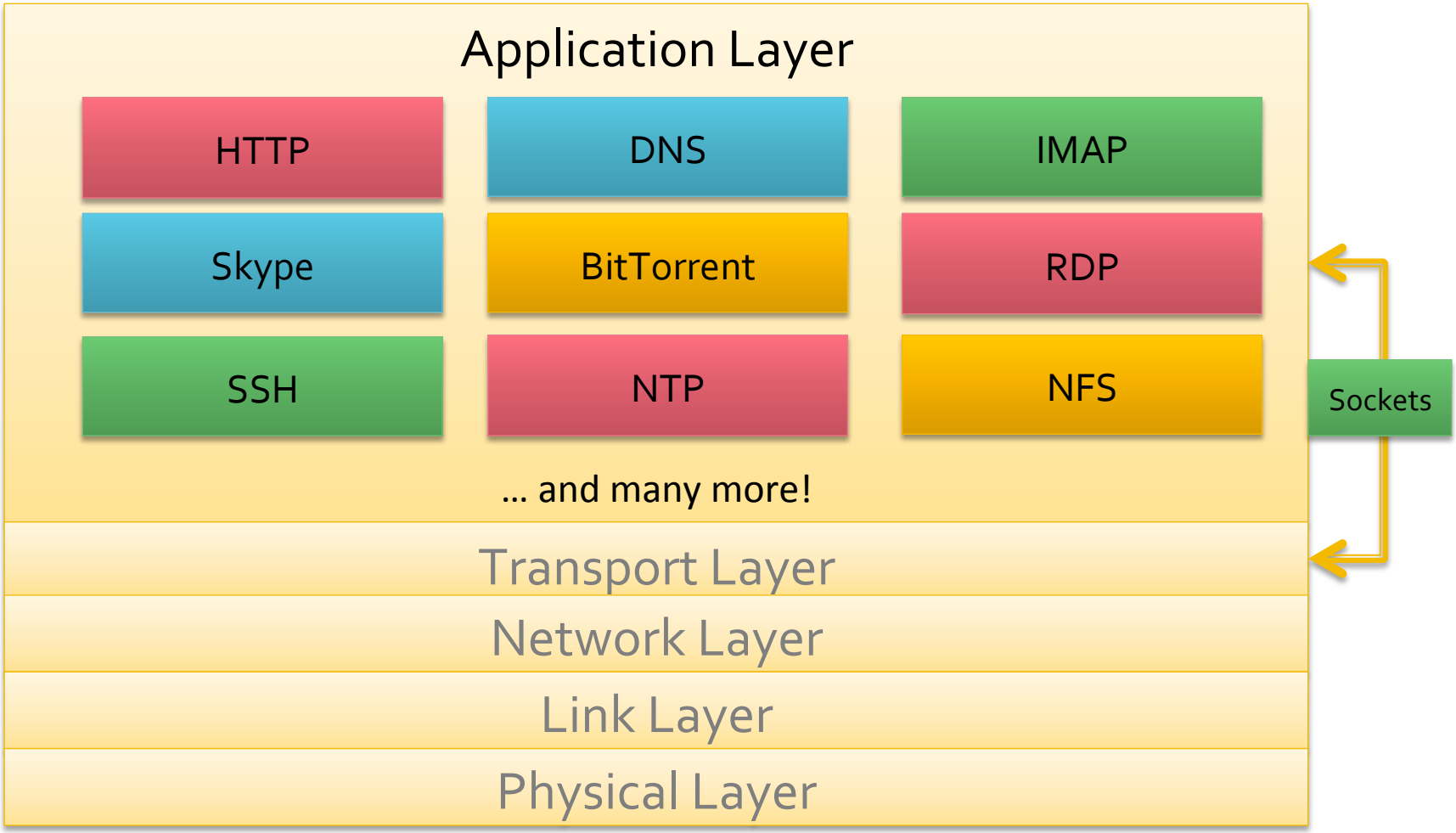
Transport Layer
(Reliability – e.g. TCP)

Network Layer
(Global Network – e.g. IP)

Link Layer
(Local Area Network – e.g. Ethernet)

Physical Layer
("Bit on a Wire")

Application Layer



Application Layer

- The **application layer** programmer can make many (fantastic) assumptions about the network
  - The network is reliable
    - Messages are not lost
    - Messages are received in the order they are sent
  - The network can transfer data of infinite length (you can send as much data as desired)
  - You can deliver messages directly to a specific application on a specific computer anywhere on the planet
- The lower layers (transport, network, link, …) do all the heavy-lifting to make these assumptions true

Client-Server Architecture

Server

- Always-on host
- Always has a known IP address
- Lots of bandwidth
- **Server process**: process that waits to be contacted

Client

- Communicate with server
- May be intermittently connected
- May have dynamic IP addresses
- Do not communicate directly with each other
- **Client process**: process that initiates communication

Why Do We Have Sockets?

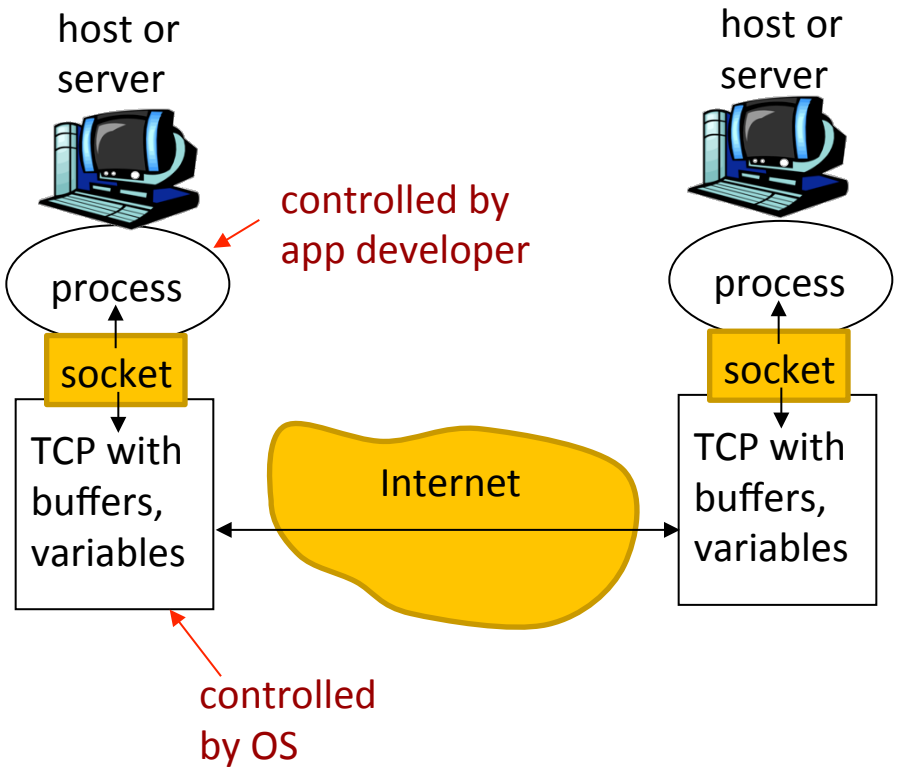
- Challenge – **Inter-process communication**
- A **process** is an independent program running on a host
  - Separate memory space
- How do processes communicate with other processes
  - On the same host?
  - On different hosts?
- Send **messages** between each other

What is a Socket?

- An interface between process (application) and network
  - The application creates a socket
  - The socket *type* dictates the style of communication
    - Reliable vs. best effort
    - Connection-oriented vs. connectionless
- Once configured the application can
  - Pass data to the socket for network transmission
  - Receive data from the socket (transmitted through the network by some other host)

What is a Socket?

- Process sends/receives messages to/from its socket
- Socket analogous to door
  - Sending process shoves message out door
  - Transport infrastructure on other side of door carries message to socket at receiving process
  - **Imagine you are just writing to a file…**
- API allow customization of socket
  - Choose transport protocol
  - Choose parameters of protocol

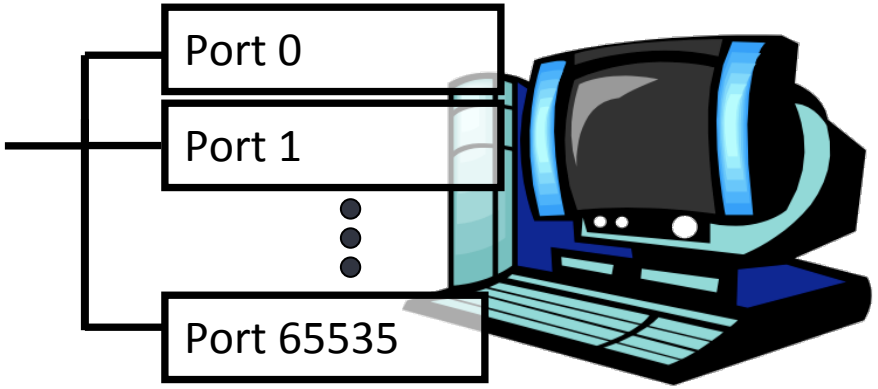


Addressing Processes

- To receive messages, each process on a host must have an **identifier**
  - IP addresses are unique
  - **Is this sufficient?**
- No, there can thousands of processes running on a single machine (with one IP address)
- Identifier must include
  - IP address
  - **and** port number (example: 80 for web)

Ports

- Each host has 65,536 ports
- Some ports are *reserved for specific apps*
  - FTP (20, 21), Telnet (23), HTTP (80), etc…



- Outgoing ports (on clients) can be dynamically assigned by OS in upper region (above 49,152) – called **ephemeral ports**
- See http://en.wikipedia.org/wiki/List_of_TCP_and_UDP_port_numbers

Socket Usage: Client Program

- Basic socket functions for **connection-oriented (TCP) clients**

1. `socket()` create the socket descriptor
2. `connect()` connect to the remote server
3. `send()`,`recv()` communicate with the server
4. `close()` end communication by closing socket descriptor

Application-Layer Protocol

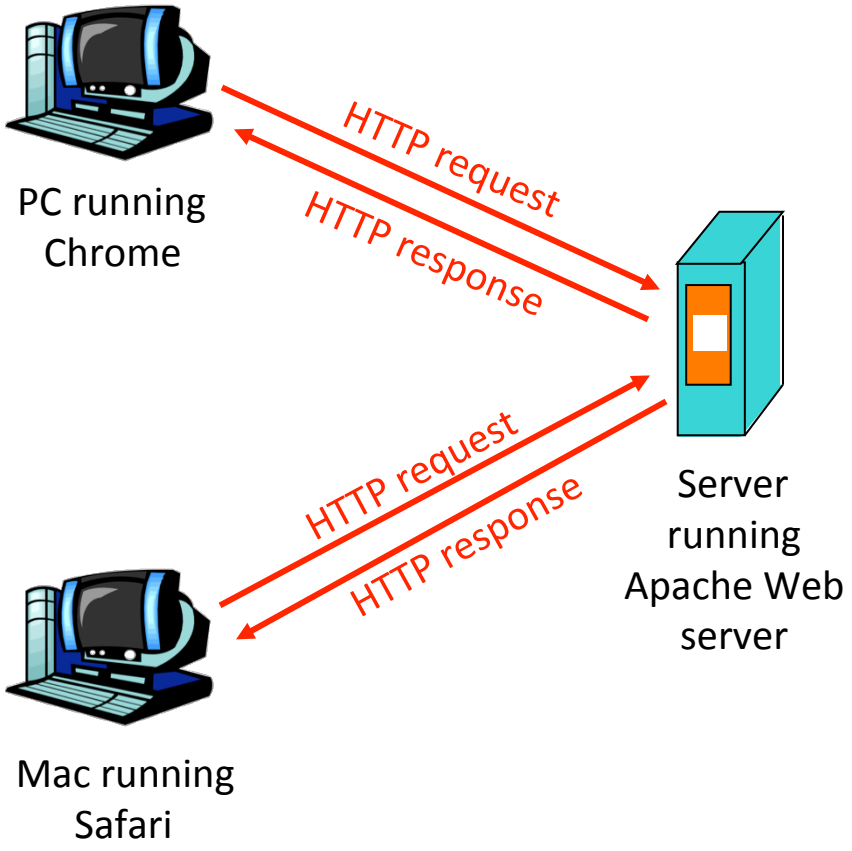
- Sockets just allow us to send raw messages between processes on different hosts
  - Transport service takes care of moving the data
- **What** exactly is sent is up to the application
  - An **application-layer** protocol
  - HTTP, NTP, IMAP, SFTP, Skype, etc…

Application-Layer Protocol

- Both the client and server speaking the protocol must agree on
  - **Types of messages exchanged**
    - e.g., request, response
  - **Message syntax**
    - What fields are in messages
    - How fields are delineated
  - **Message semantics**
    - Meaning of information in fields
  - Rules for **when** and **how** processes send and respond to messages

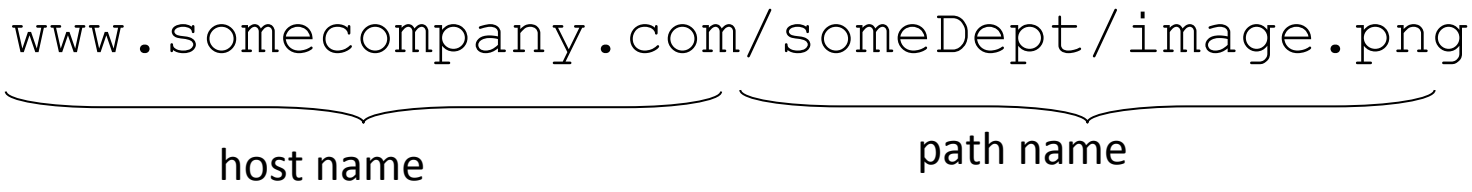
Hypertext Transfer Protocol Overview

- **HTTP** is the *application layer protocol* for the web
- It is how the client and server communicate
- Client/server model
  - **Client**: browser that requests, receives, "displays" Web objects
  - **Server**: Web server sends objects in response to requests

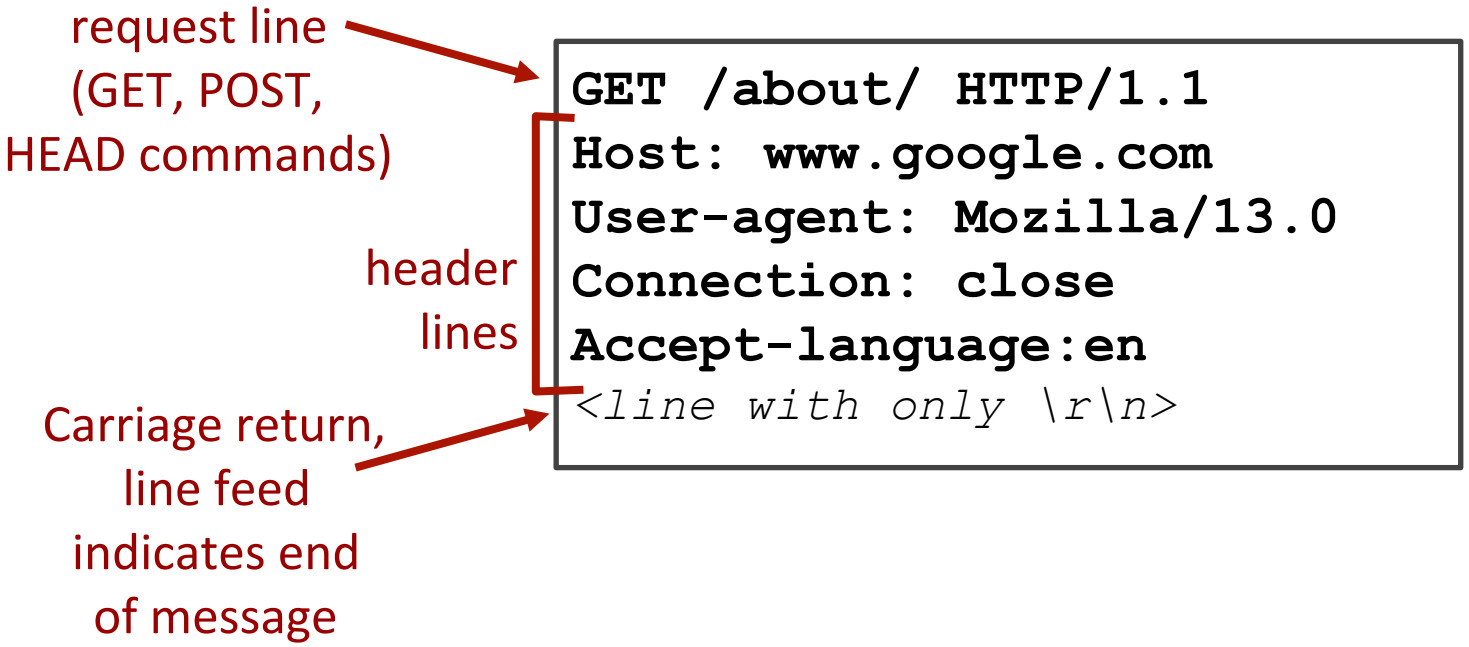


Web and HTTP

- Web **page** consists of base HTML file and (potentially) many referenced **objects**
  - HTML file, PNG image, Flash video, …
- Each object is addressable by a **URL**
- Example URL:

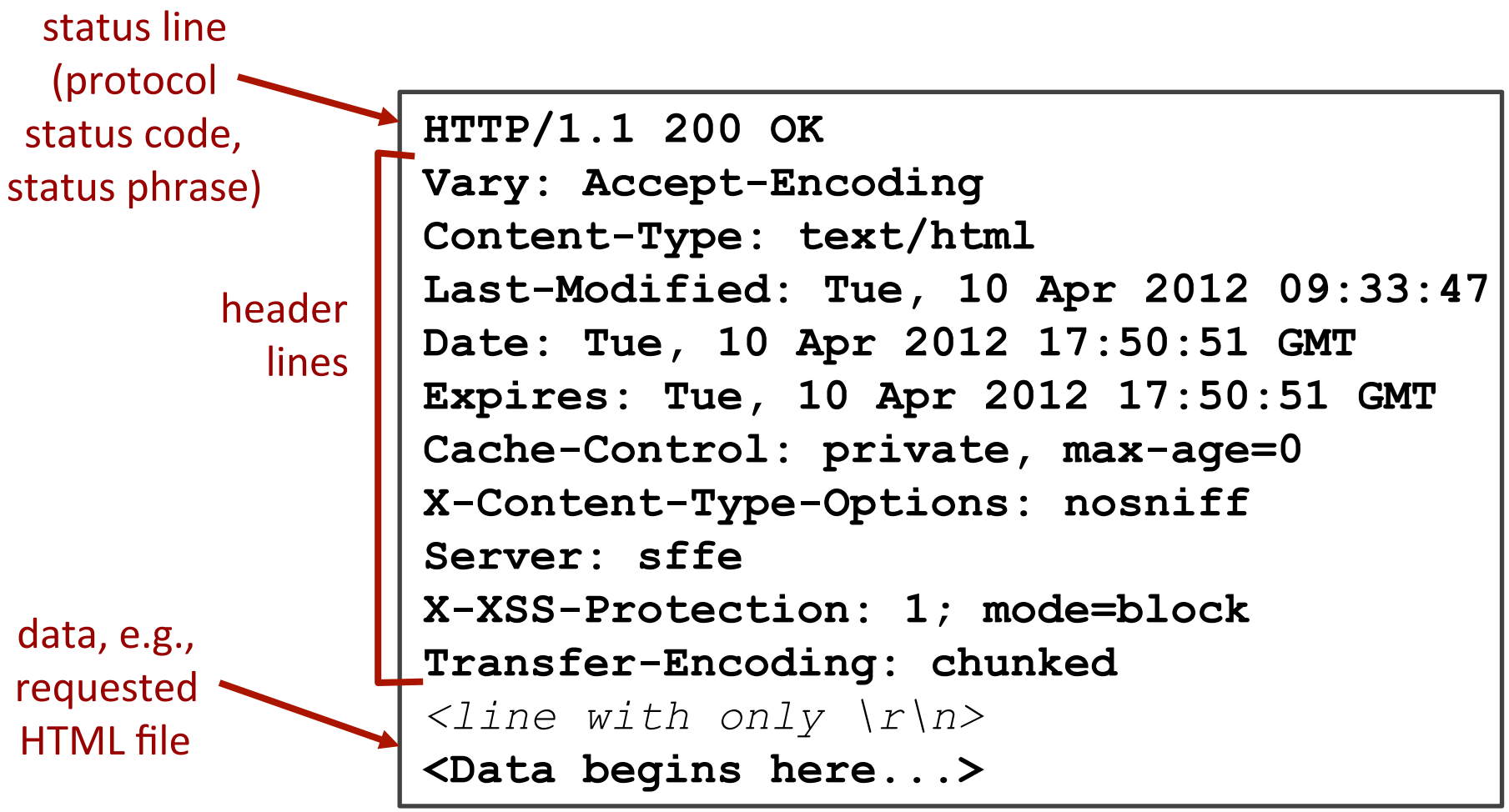


HTTP Request Message (Client->Server)



HTTP is a text-based protocol. The client sends ASCII bytes in the request, and the server responds with ASCII bytes in the reply.

HTTP Response Message (Server -> Client)



HTTP Response Status Codes

A few examples out of many!

200 OK

- Request succeeded, requested object later in this message

301 Moved Permanently

- Requested object moved, new location specified later in this message (Location:)

400 Bad Request

- Request message not understood by server

404 Not Found

- Requested document not found on this server

505 HTTP Version Not Supported

Lab 8 Tasks: display.py

Student Work #1: Build the HTTP request

1. Create an empty string. E.g.: mystring=[]
2. Append info to this string to construct HTTP request
   E.g.: `mystring.append(string-1 + string-2 +..)`

Parsed by your boilerplate code!

`mystring=`

```
GET <path> HTTP/1.1
Host: <hostname>
Connection: close
<line with only \r\n>
```

Lab 8 Tasks: display.py

Student Work #2: Connect to the server and send the entire request

1. Establish the socket. (Which socket function?)
2. Connect to the host. (Which socket function?)
3. Send the request string as bytes. (Which set of functions?)

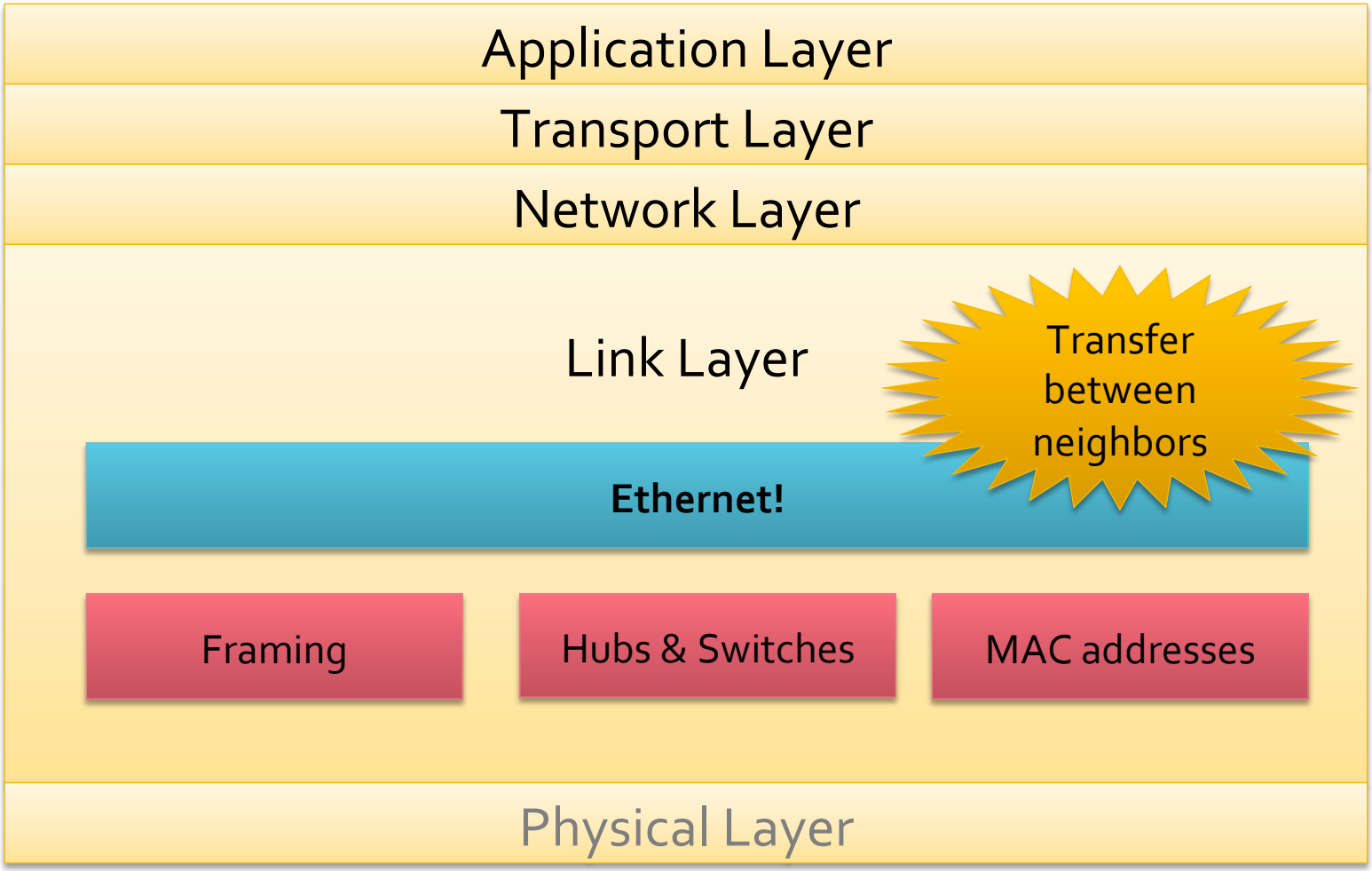
Lab 8 Tasks: display.py

Student Work #3: Continue to receive chunks of 64 KB until you receive no more

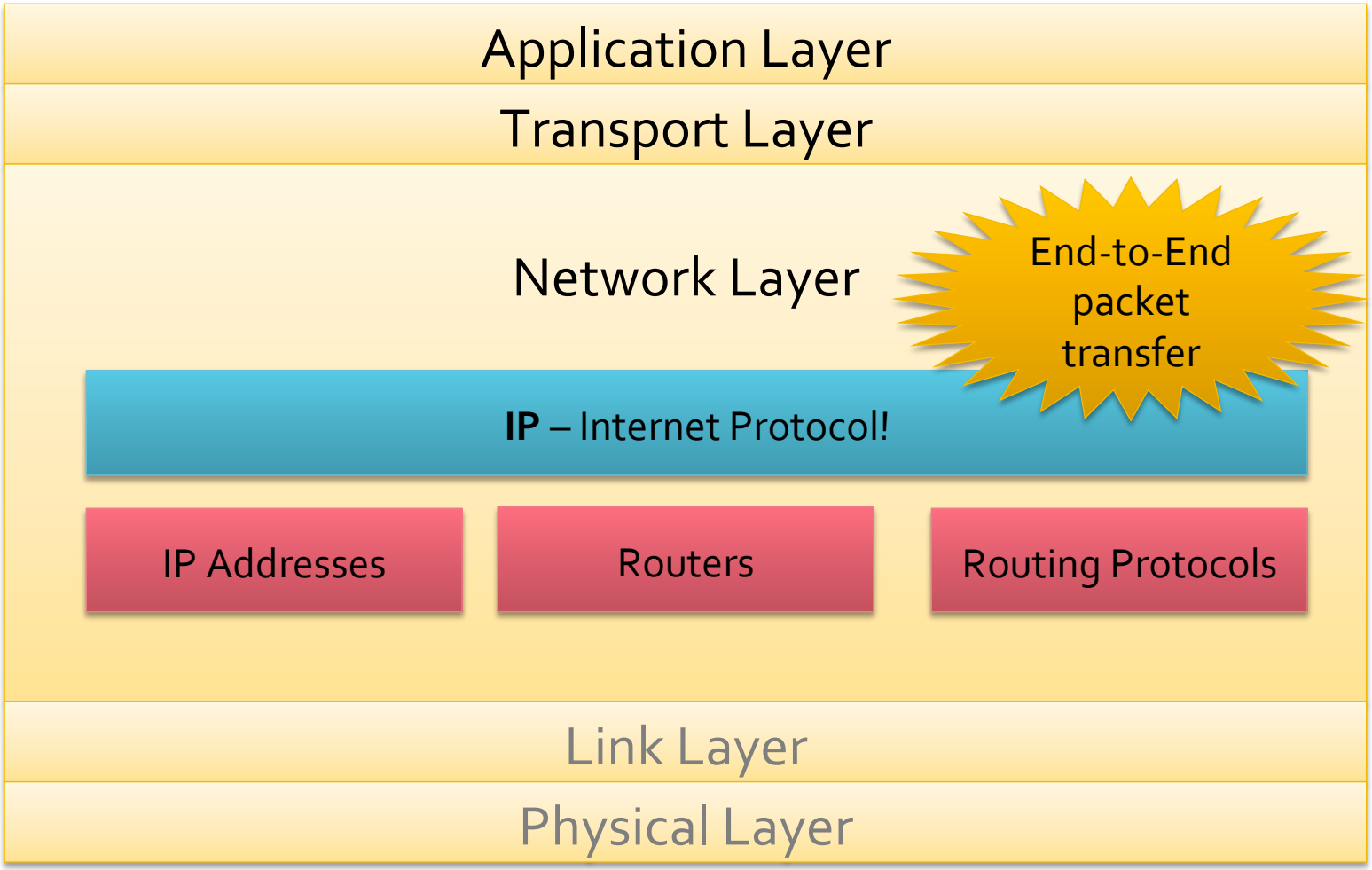
1. Which socket function to receive data from server?
2. How do you continue to receive data?
3. Which socket function to close the connection?

Other Layers

Link Layer


Application Layer
Transport Layer
Network Layer
Link Layer
Transfer between neighbors
Ethernet!
Framing
Hubs & Switches
MAC addresses
Physical Layer

Network Layer

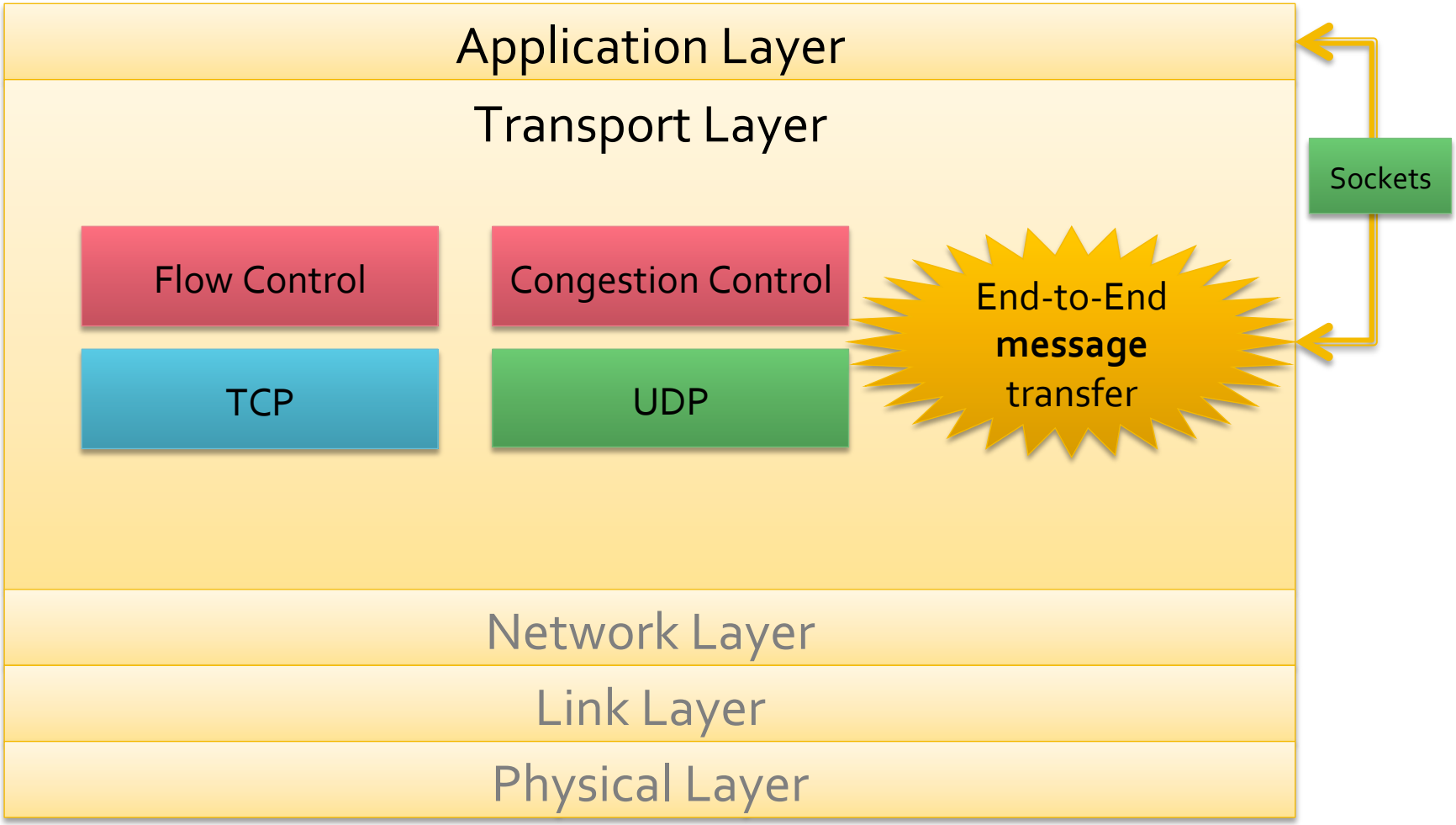


IP Properties

- **Datagram**
  - Each packet is **individually routed**
  - Packets may be **fragmented** or **duplicated** by underlying networks
- **Connectionless**
  - No guarantee of delivery in sequence
- **Unreliable**
  - No guarantee of delivery
  - No guarantee of integrity of data
- **Best effort**
  - Only drop packets when necessary
  - No time guarantee for delivery

Ethernet networks provide the same "guarantees"

Transport Layer



"Magic" of the Internet

- **IP**: Un-reliable, order not guaranteed, delivery of **individual messages**
- **TCP**: Reliable, in-order delivery of data **stream**
- Magic
  - TCP is built on top of IP!
- Great clown analogy by Joel Spolsky http://www.joelonsoftware.com/articles/LeakyAbstractions.html

Clown Delivery

Need to move clowns from Broadway to Hollywood for a new job

Broadway, NYC

Clown Delivery – Problems?

Many cars, many clowns
Bad things are guaranteed to happen to at least *some* of them

Car crash / lost

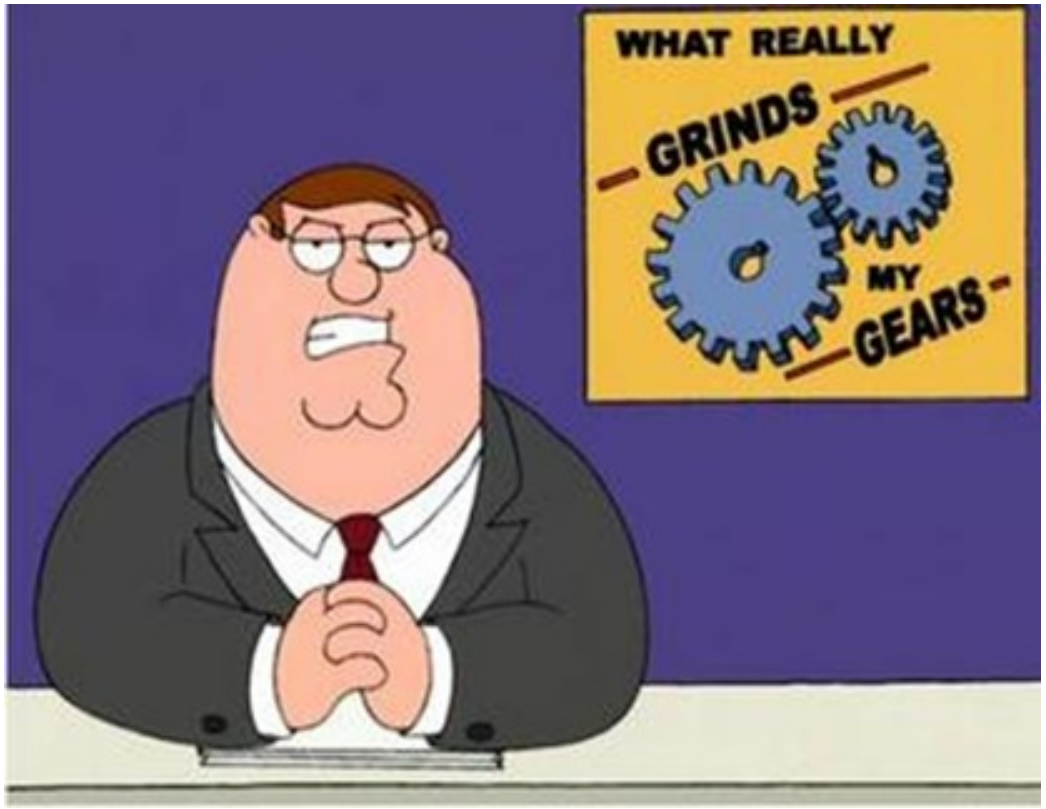
Shaved head / too ugly to work!

Different routes

Clown Delivery – Problems?

People in Hollywood get frustrated –

It's hard to make movies with clowns in this condition!



Clown Delivery - Solution

- New company
  - **Hollywood Express**
- Guarantees that all clowns
  - (1) Arrive
  - (2) In Order
  - (3) In Perfect Condition
- Mishap? Call and request clown's twin brother be sent immediately

- UFO crash in Nevada blocks highway?

- Clowns re-routed via Arizona
  - Director never even *hears* about the UFO crash
  - Clowns arrive a little more slowly

Networking Abstraction

- TCP provides a similar reliable delivery service for IP
- Abstraction has its limits
  - Ethernet cable chewed through by cat?
  - No useful error message for that problem!
  - The abstraction is "leaky" – it couldn't save the user from learning about the chewed cable

Demos

Demos

1. Impersonate web browser via Telnet
2. Walkthrough of `client.py` and `server.py` demo programs
3. Run `display.py` with example image
4. Monitor `display.py` with *Wireshark* and examine packet trace