Computer Networks

Schedule

- **Exam 3** – Friday, April 20th
  - Caches
  - Virtual Memory
  - Input / Output
  - Operating Systems
  - Compilers & Assemblers
  - Processor Architecture
  - **Review the lecture notes before the exam (not just the homework!)**
  - **No calculators for this exam**
- **Final Exam** – Friday, April 27th - Comprehensive
  - 8am – Regular classroom
  - **Exam is optional if you are happy with your 3 earlier exam scores!**

Review – HW #18

- Review problems
  - Register windows
  - RISC vs CISC
  - GPGPUs

Quiz 6

Quiz 6 - SSDs

- **SSD pros / cons?**
- Flash translation layer
  - **How does this improve reliability?**

Quiz 6 – RTOS

- Real-time operating systems (RTOS) can provide **predictable timing** for high-priority tasks (while still running a mix of low-priority tasks)
- The difference with a general-purpose OS is an RTOS provides a **guarantee** of predictable timing
  - General-purpose OS usually meets its timing goals, but how often have you experienced a hiccup (momentary stutter) while playing a video or listening to music?

Quiz 6 – Interrupts

- What devices send **interrupts**?
  - Network card
    - Data received or data has been successfully sent
  - USB controller
    - Mouse moved, key/button pressed, etc..
  - Real-time clock, high precision event timer, etc…
  - The processor itself!
    - Divide by zero, page fault, invalid opcode, etc…
    - These are usually called ***exceptions***, but they work the same way as external interrupts
- Some of these interrupts represent errors, but others are perfectly normal and commonplace…

Quiz 6 – Interrupts

- What happens when the processor sees an interrupt?
  - Stop! Save the current running process
  - Lookup the interrupt number in an **interrupt descriptor table** (which is stored in memory from 0x0000 to 0x03FF)
    - Table contains pointer to a subroutine that processes the interrupt (aka the **interrupt service routine**)
  - Run the interrupt service routine

Quiz 6 – Interrupt Service Routine

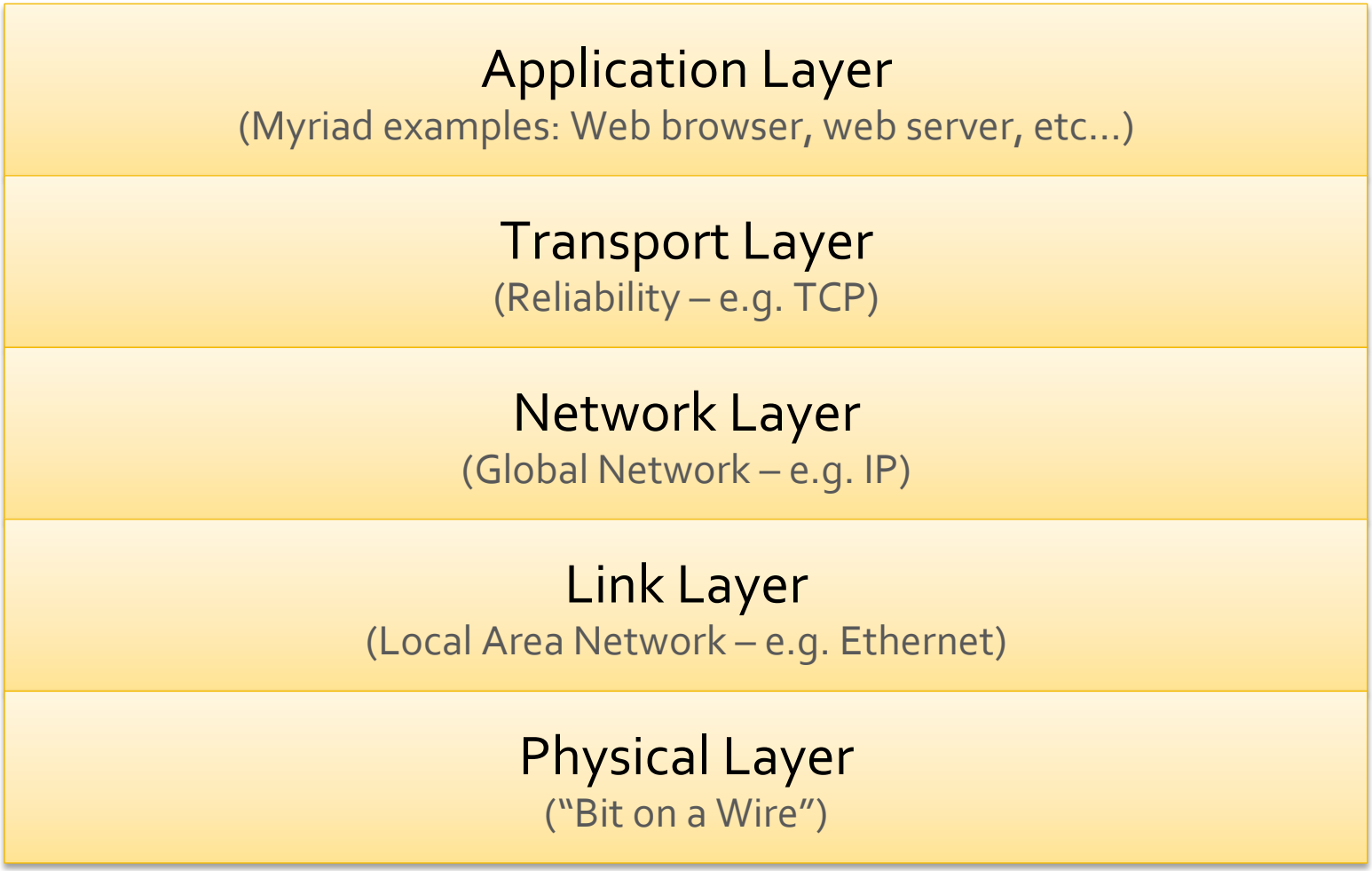
- **Interrupt service routine** - The specific subroutine that is executed whenever that interrupt number occurs
  - Tend to be small and fast (so we can get back to running the previous program quickly)
  - Examples
    - Copy packet from network card to main memory?
    - Notify OS that the mouse moved to the left 2 units?
    - Notify OS key “z” was pressed on the keyboard?
    - Notify OS of page fault for memory address 0x03813?

Computer Networks

Disclaimer

- **We spend an entire semester in COMP 177 (Computer Networking) exploring these topics!**
- One day is only sufficient for the briefest of overviews…
- Focus:
  - Compare / contrast TCP versus IP
  - Compare / contrast Ethernet switches versus IP routers
  - *Might be good exam questions…*

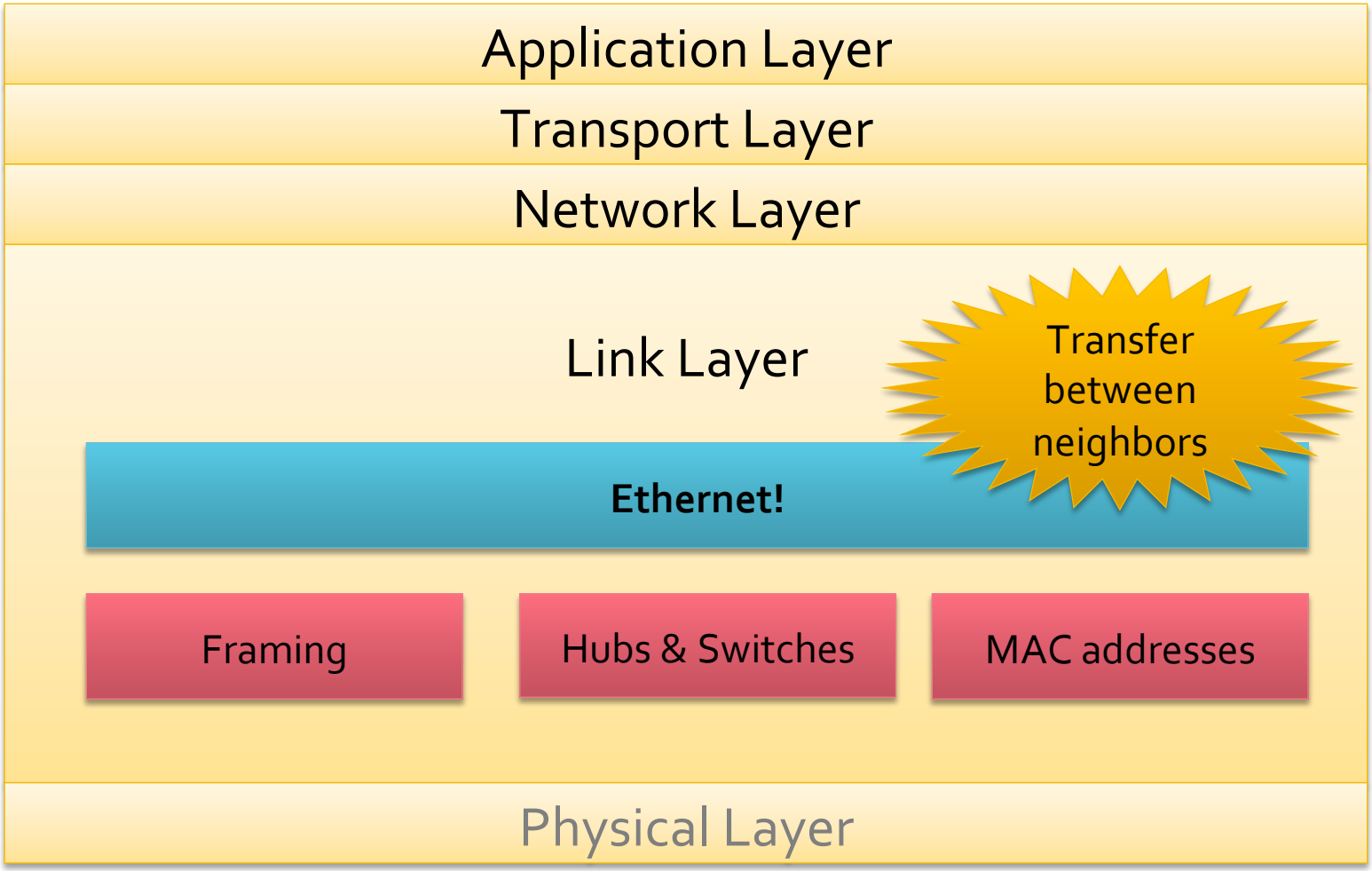
Network Model



Ethernet Basics

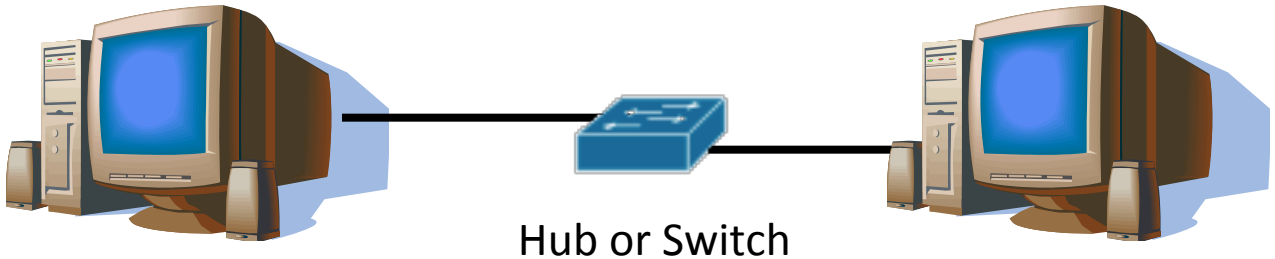
The Link Layer

Link Layer


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

Local Area Network

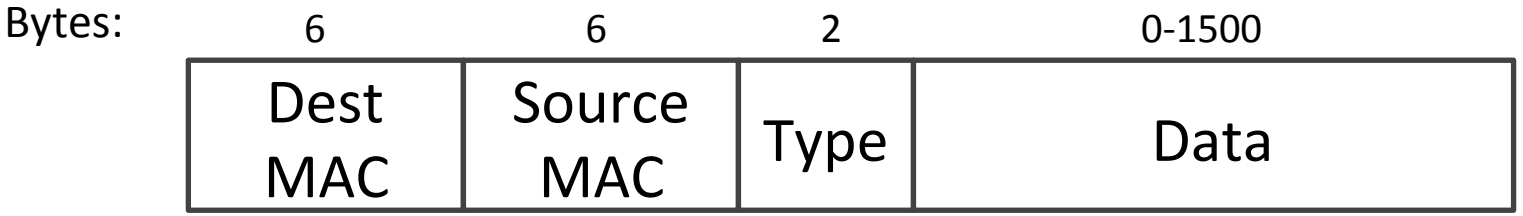
- Goal: Connect computers across a Local Area Network
  - Room?
  - Floor?
  - Building?
  - Few buildings?
- Natural size limit to Ethernet-only networks



Ethernet - Addressing

- Each device on the network needs a **unique address**
- All Ethernet devices have globally unique 48-bit address assigned by manufacturer
  - The **MAC address**
- Example: `0x 00-07-E9-CB-79-4F`
  - `0x 00-07-E9` = Intel Corp (assigned by IEEE)
    - Upper 24 bits
  - `0x CB-79-4F` = Unique address per NIC (picked by Intel)
    - Lower 24 bits

Ethernet Frame Format (Simplified)



- Two MAC addresses saved in Ethernet frame
  - **Destination MAC** – Where is this frame going to?
  - **Source MAC** – Who sent this frame?
- Other fields
  - **Type**: Indicates data type or length in bytes
  - **The Data!**

Topology

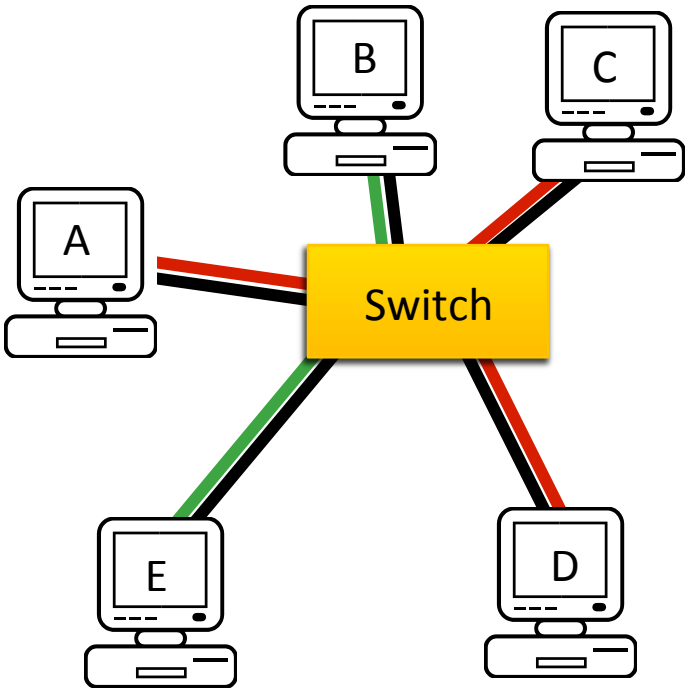
- So how do I connect dozens of computers together?
  - My cable only has two ends…

Ethernet Switch

- **Learns location** of computers on Ethernet network
  - Examine header of each arriving frame
  - What is its source MAC address? (i.e. who sent it?)
    - Note the port it came in on!
    - Save this data in **forwarding table**
- **Forwards data** out correct port
  - Search forwarding table for destination MAC address

Ethernet Switch

(assume learning already occurred)



A transmits to D

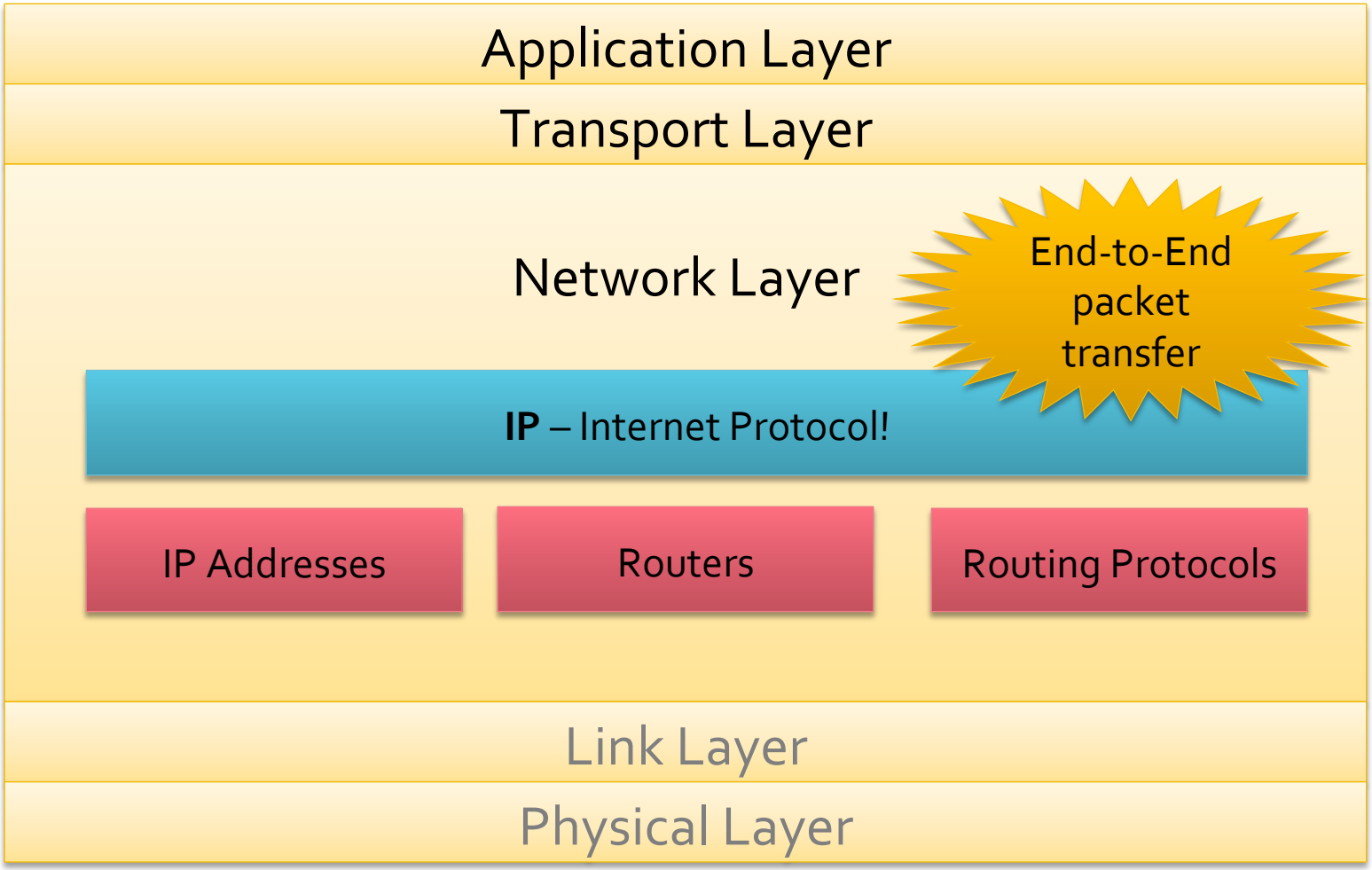
D replies to A

E transmits to B, and A to C

Internet Protocol (IP) Basics

The Network Layer

Network Layer



The Internet Protocol - Motivations

- Ethernet is sufficient for a local-area network only
  - Locates computers via broadcast only…
  - Network topology can't have loops…
- A new protocol (IP) is needed for a global network (the **Internet**!)

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"

IP Addresses

- IP version 4 addresses are 32 bits long
- Every network interface has at least one IP address
  - A computer might have 2 or more IP addresses
  - A router has many IP addresses
- IPv4 addresses are usually displayed in *dotted decimal notation*
  - Each byte represented by decimal value
  - Bytes are separated by a period
  - IP address `0x8002C2F2 = 128.2.194.242`

IP Packet Format (Simplified)

- Two IP addresses saved in packet
  - **Destination** IP address
    - Where is this packet going to?
  - **Source** IP address
    - Who sent this packet?
- Other fields are also included…
  - Checksum
  - Length
  - **The Data!**

IP and Ethernet (Simplified View)

- IP datagrams can be *encapsulated* inside Ethernet frames
- So what is sent on the *wire* is an **Ethernet frame**
  - Inside of which is an **IP packet**…
    - Inside of which is the **transport layer**…
      - Inside of which is the **application layer**…

Inside versus Outside LAN

- Your computer is able to directly contact destination computers located **inside** the local area network (LAN)
- For destinations outside your LAN, forward message to **next-hop gateway router**

Routers

- "Similar" to switches, but only at a high level
  - Packet comes in
  - Switch/router looks up the destination address
  - Packet forwarded out correct port

Routers

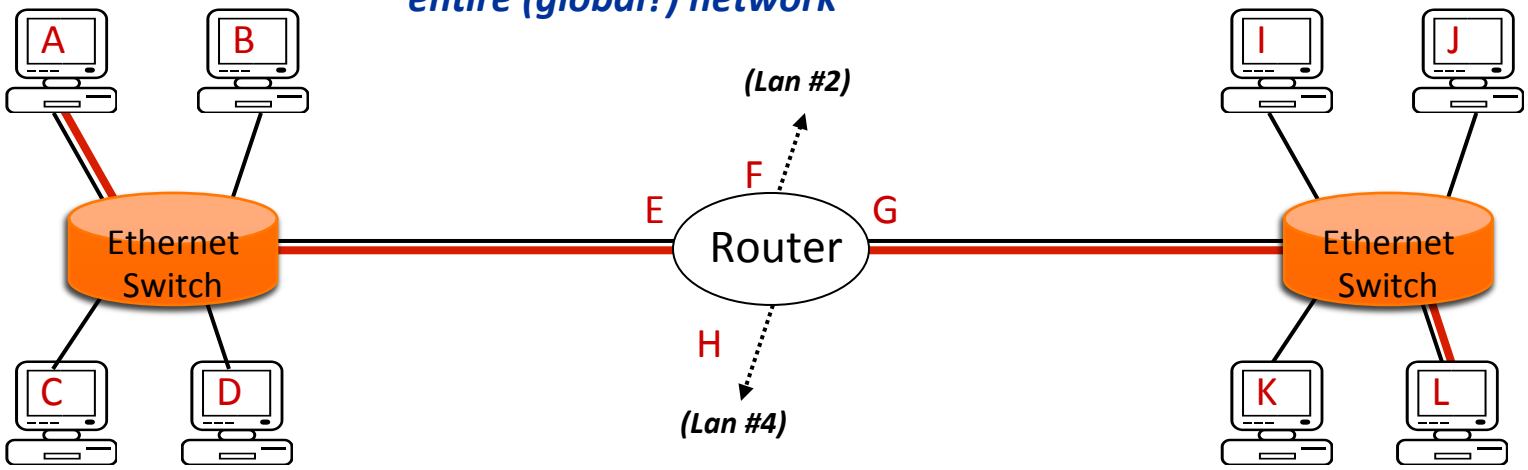
- Key difference #1: Routers forward based on IP addresses!
  - Router works at network (IP) layer
    - Router forwards based on destination IP address
  - Switch works at link (Ethernet) layer
    - Switch forwards based on destination MAC (Ethernet) address

Routing Between LANs

LAN #1

Switched Ethernet packets can only navigate within their LAN, not the entire (global?) network

LAN #3



(1) A transmits to L using higher-level protocol (e.g. IP)
Ethernet frame destination is router

Frame:

DA (E)	SA (A)	Type / Data	CRC

(2) Switch forwards frame to router

(3) Router uses higher-level protocol to determine destination, and updates Ethernet frame destination, source and CRC

Frame:

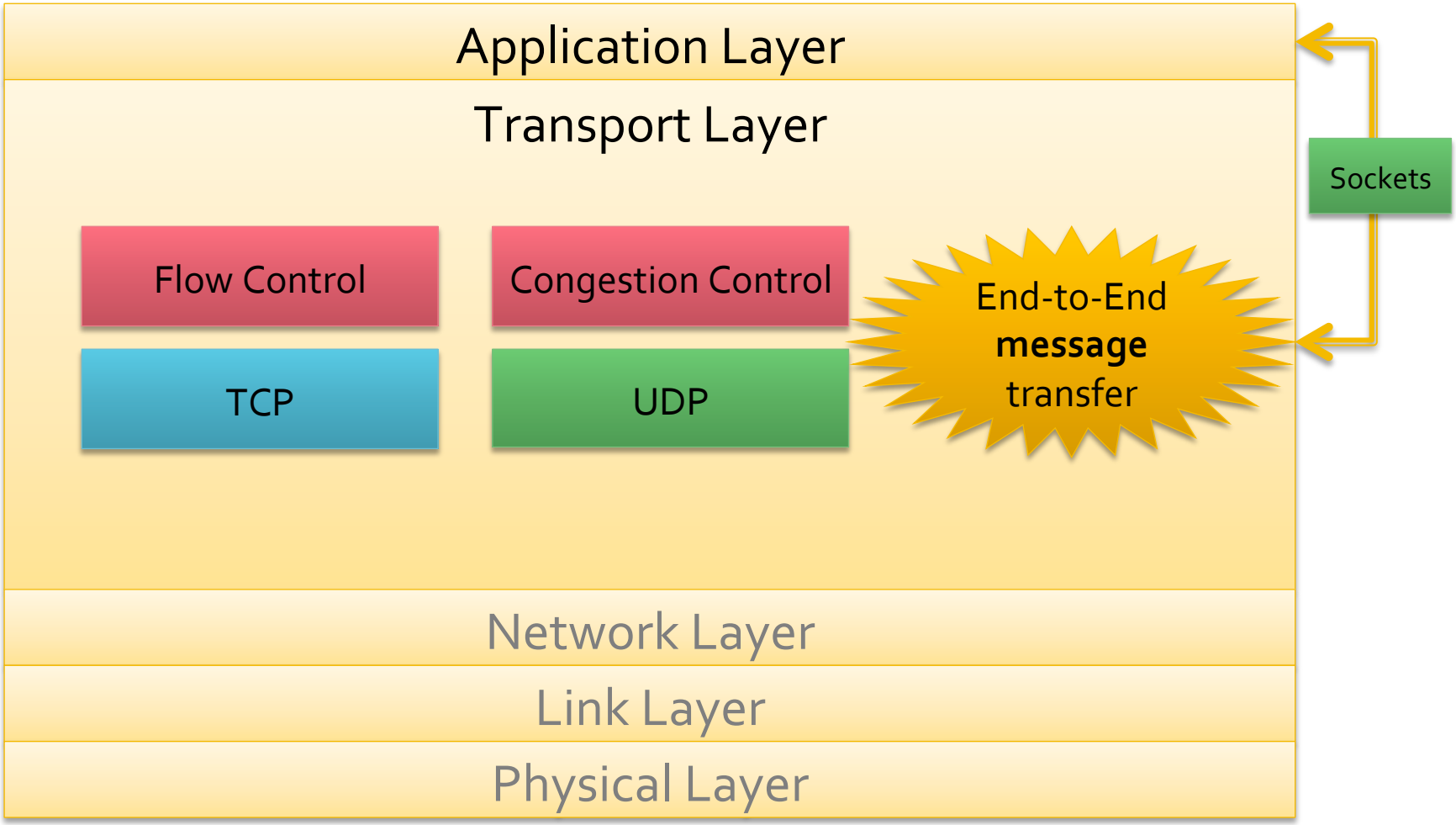
DA (L)	SA (G)	Type / Data	CRC

(4) Switch forwards frame to destination

TCP Basics

The Transport Layer

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

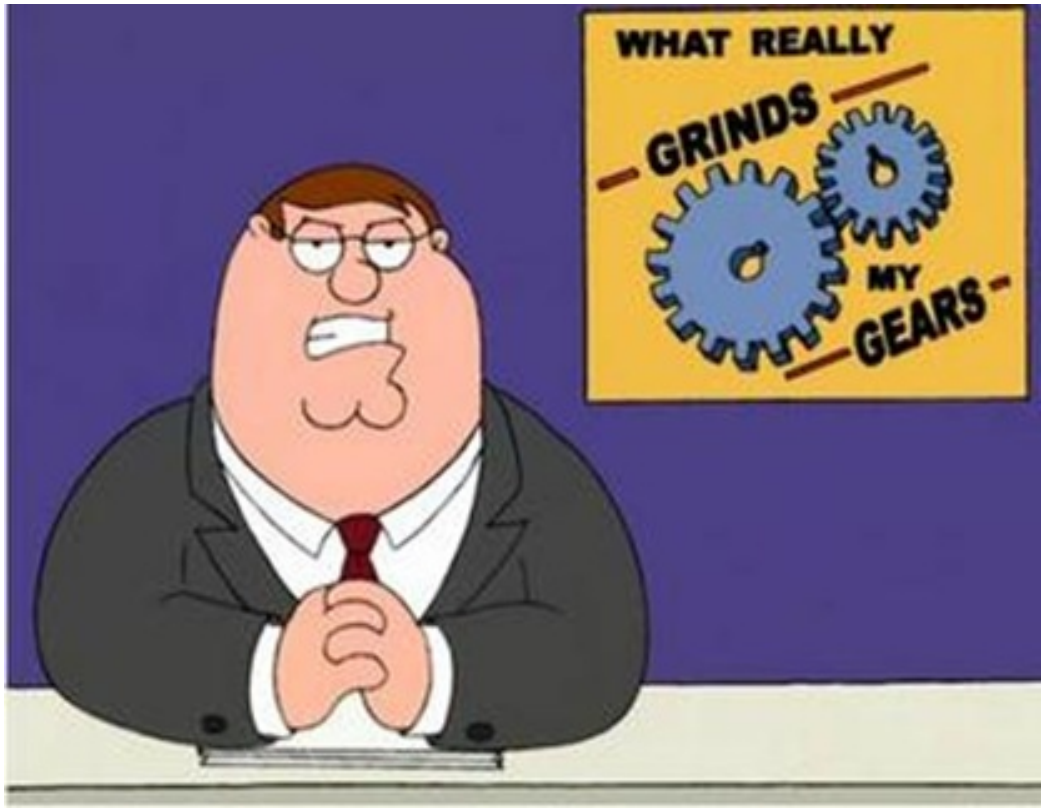
Shaved head / too ugly to work!

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?

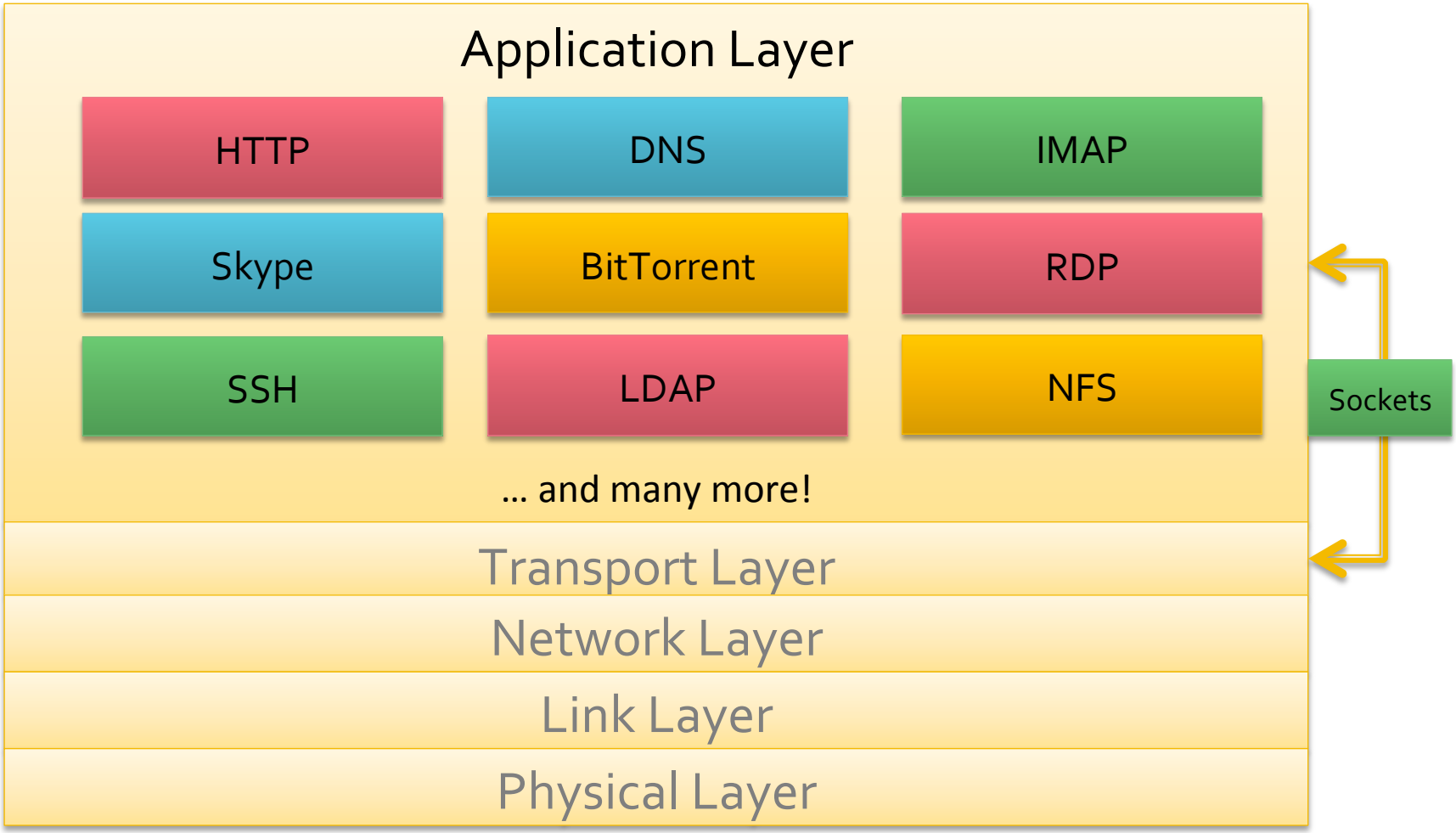
- Clowns re-routed via Arizona
  - Director never even *hears* about the UFO crash
  - Clowns arrive a little more slowly

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

The Application Layer

Application Layer



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

HTTP

- Hypertext Transport Protocol (HTTP)
- Telnet example – impersonate a web browser!

Request:

```
unix$ telnet www.google.com 80
------------------------------
GET /about/ HTTP/1.1
Host: www.google.com
```

Response:

```
HTTP/1.1 200 OK
Vary: Accept-Encoding
Content-Type: text/html
Last-Modified: Tue, 10 Apr 2012 09:33:47 GMT
Date: Tue, 10 Apr 2012 17:50:51 GMT
Expires: Tue, 10 Apr 2012 17:50:51 GMT
Cache-Control: private, max-age=0
X-Content-Type-Options: nosniff
Server: sffe
X-XSS-Protection: 1; mode=block
Transfer-Encoding: chunked

<file>
```

Recap

- TCP versus IP
  - **What features does IP provide?**
  - **What features does TCP provide?**
- Ethernet versus IP
  - **Where are source/destination MAC addresses used?**
  - **Where are source/destination IP addresses used?**
- Ethernet switch versus IP router
  - **What address does an Ethernet switch use to make a forwarding decision?**
  - **What address does an IP router use to make a forwarding decision?**