Networking Fundamentals

Network Startup Resource Center
www.nsrc.org

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Objectives

- Introduce Core Concepts & Terminology
  - Layers & Layer Models
  - Encapsulation
  - Frames, Datagrams, Segments, Packets
  - TCP/IP Protocol Suite
  - IP Addressing
  - IP Routing
  - Basic Linux Network Commands

Layers

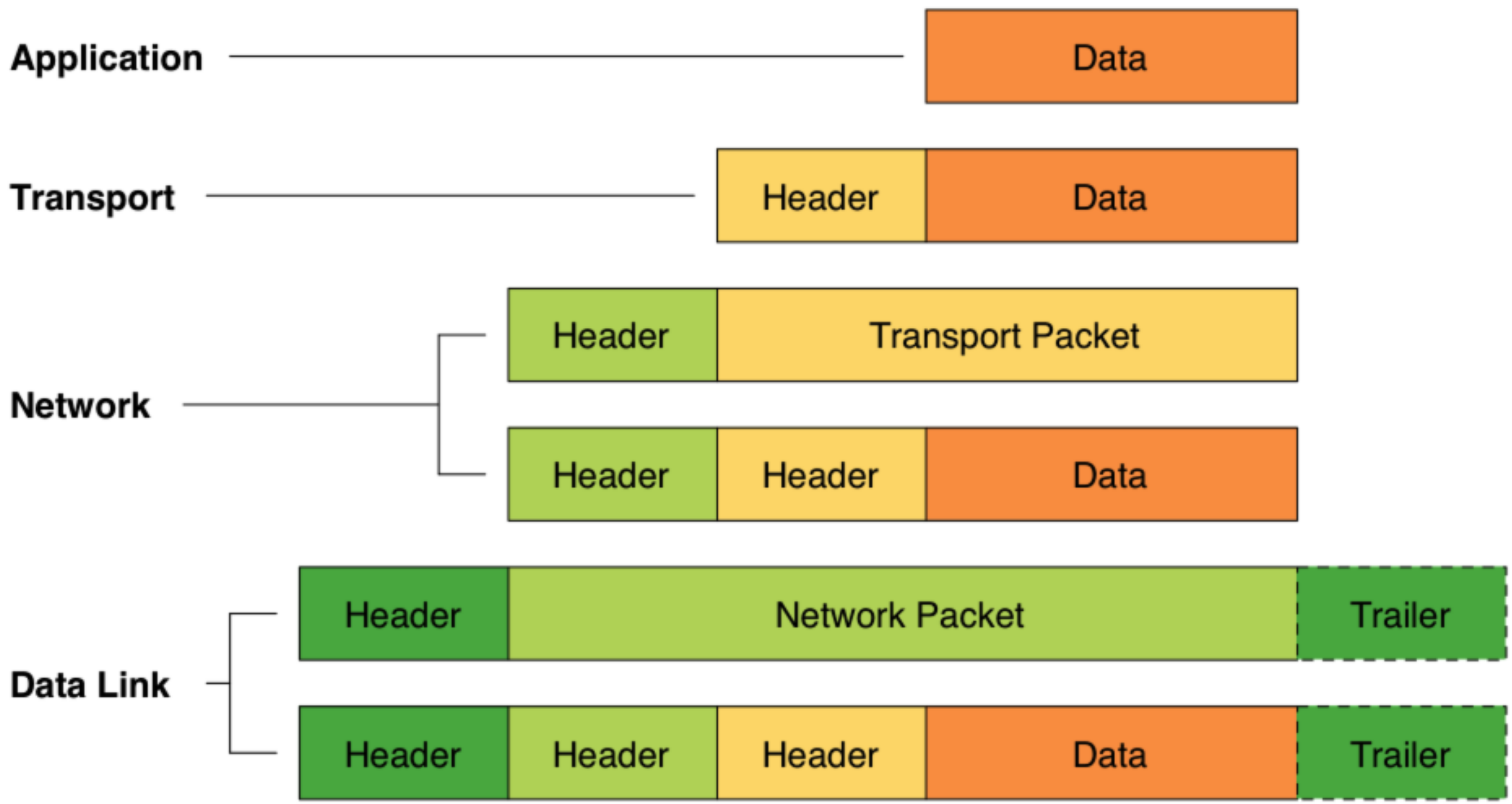
- Internet functions can be divided in layers
  - Easy to understand
  - Easy to program for
    - Change one layer without changing other layers
  - Easy to write standards for and test
- Two main models of layers are used:
  - OSI (Open Systems Interconnection) Layers
  - TCP/IP Layers
- We'll cover both models in detail

Layers & Encapsulation

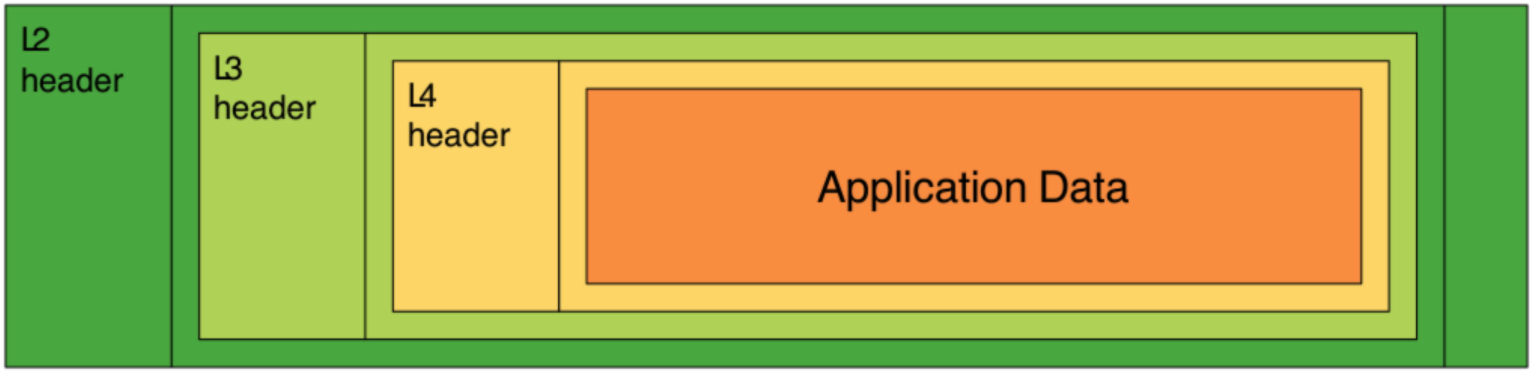
- Each layer provides services to the layer above
- Each layer makes use of the layer below
- Data from one higher layers is encapsulated in frames of the layer below

Encapsulation & Decapsulation

Lower layers add headers (& trailers) to upper layer packets



Encapsulation in Action



- L4 segment contains part of stream of application protocol
- L3 datagram contains L4 segment
- L2 frame has L3 datagram in data portion

Frame, Datagram, Segment, Packet

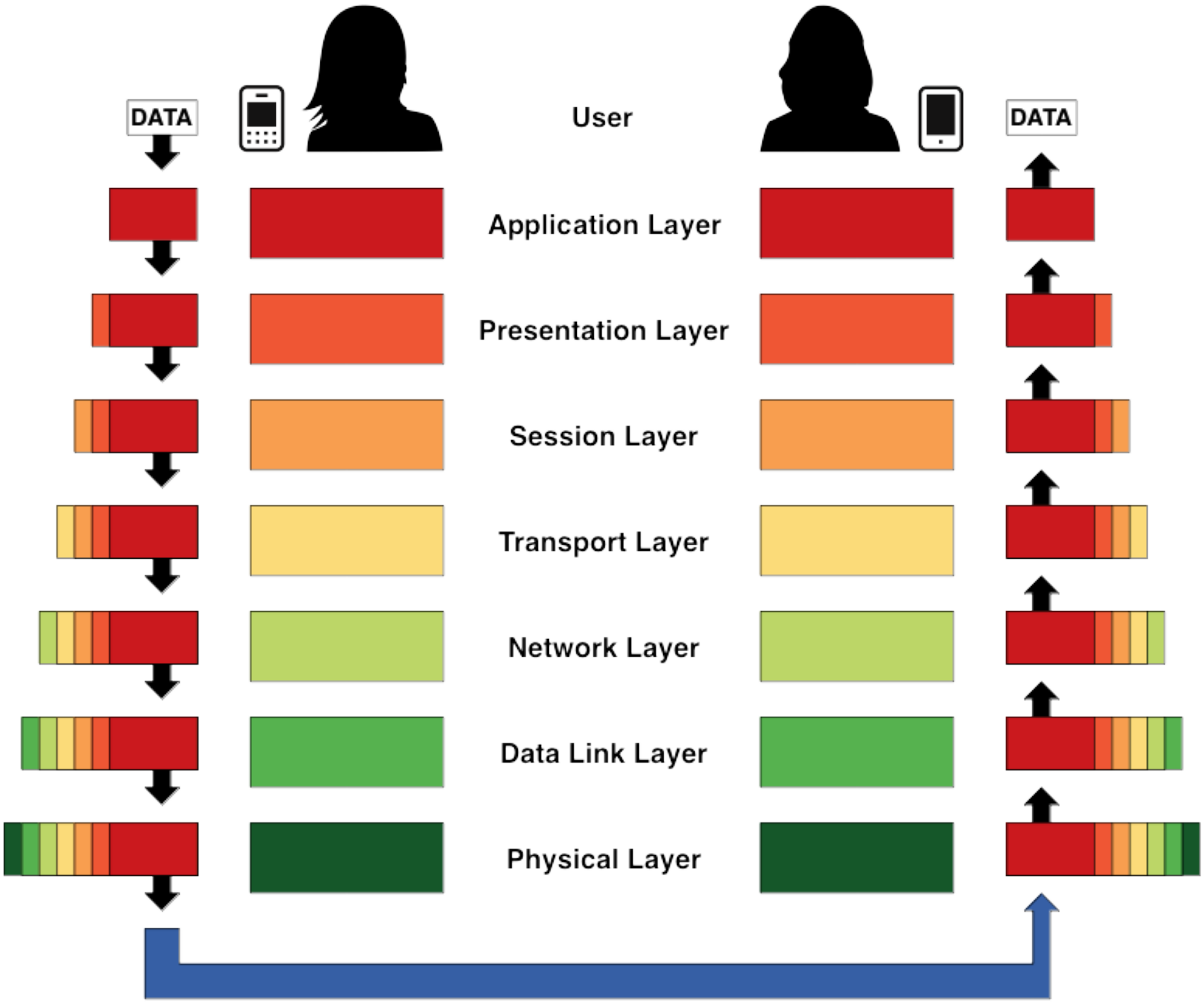
- Different names for packets at different layers
  - Link Layer = Ethernet Frame
  - Network Layer = IP Packet
  - Transport Layer = TCP Segment
- Terminology is not strictly followed
  - We often just use the term “packet” at any layer

OSI Seven Layer Model

Conceptual model developed by the International Organization for Standardization (ISO) in 1984

- Layer 7 – Application (servers & clients, web browsers, httpd)
- Layer 6 – Presentation (file formats, e.g. PDF, ASCII, JPEG)
- Layer 5 – Session (conversation initialization, termination)
- Layer 4 – Transport (inter host comm – error correction)
- Layer 3 – Network (routing – path determination, IP addresses)
- Layer 2 – Data link (switching – media access, MAC addresses)
- Layer 1 – Physical (signaling – representation of binary digits)

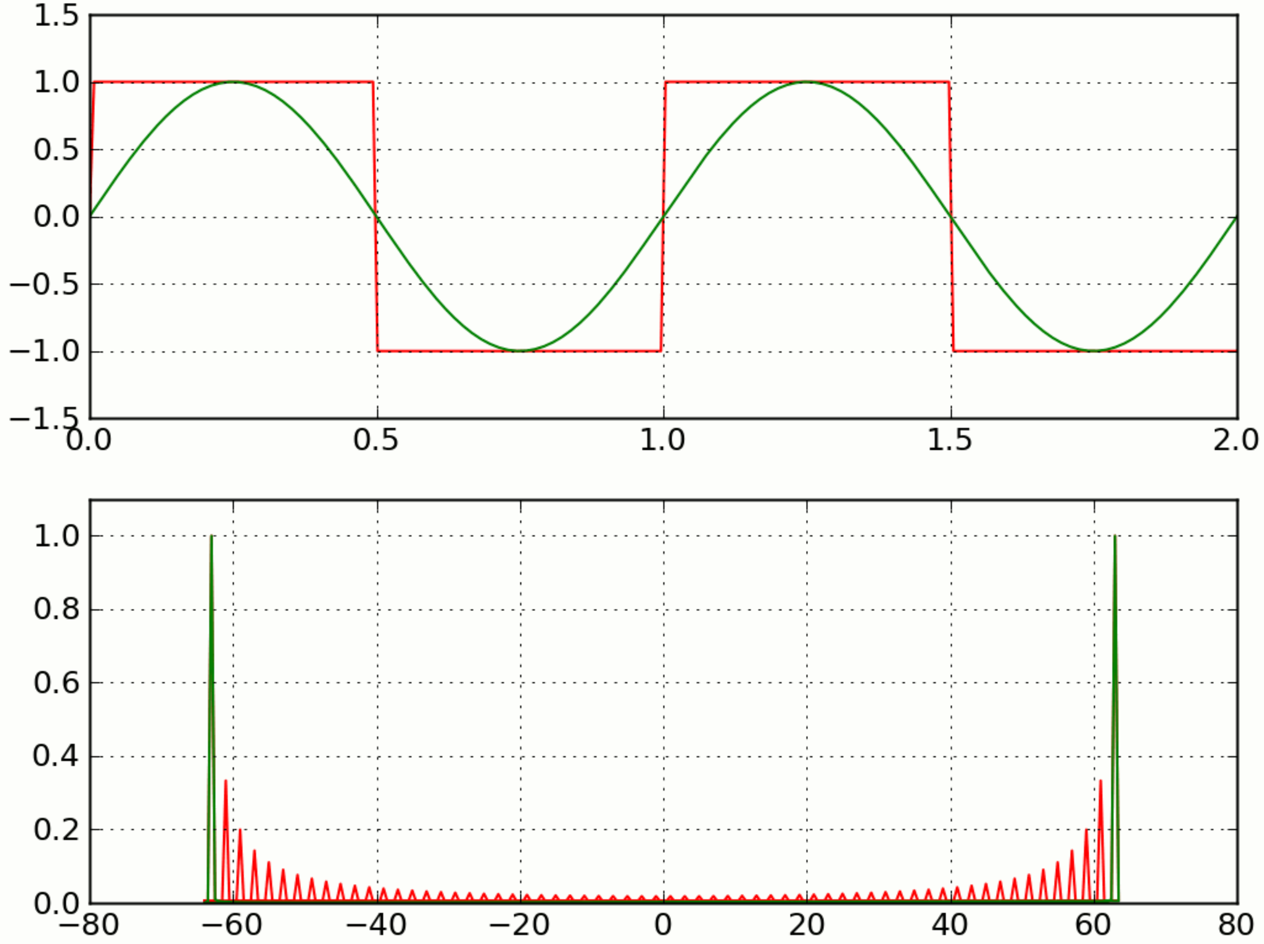
OSI Model


DATA
User
DATA
Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer

Layer 1: Physical Layer

- Transfers a stream of bits
- Defines physical characteristics
  - Connectors, pinouts
  - Cable types, voltages, modulation
  - Fibre types, lambdas
  - Transmission rate (bits per second)
- No knowledge of bytes or frames

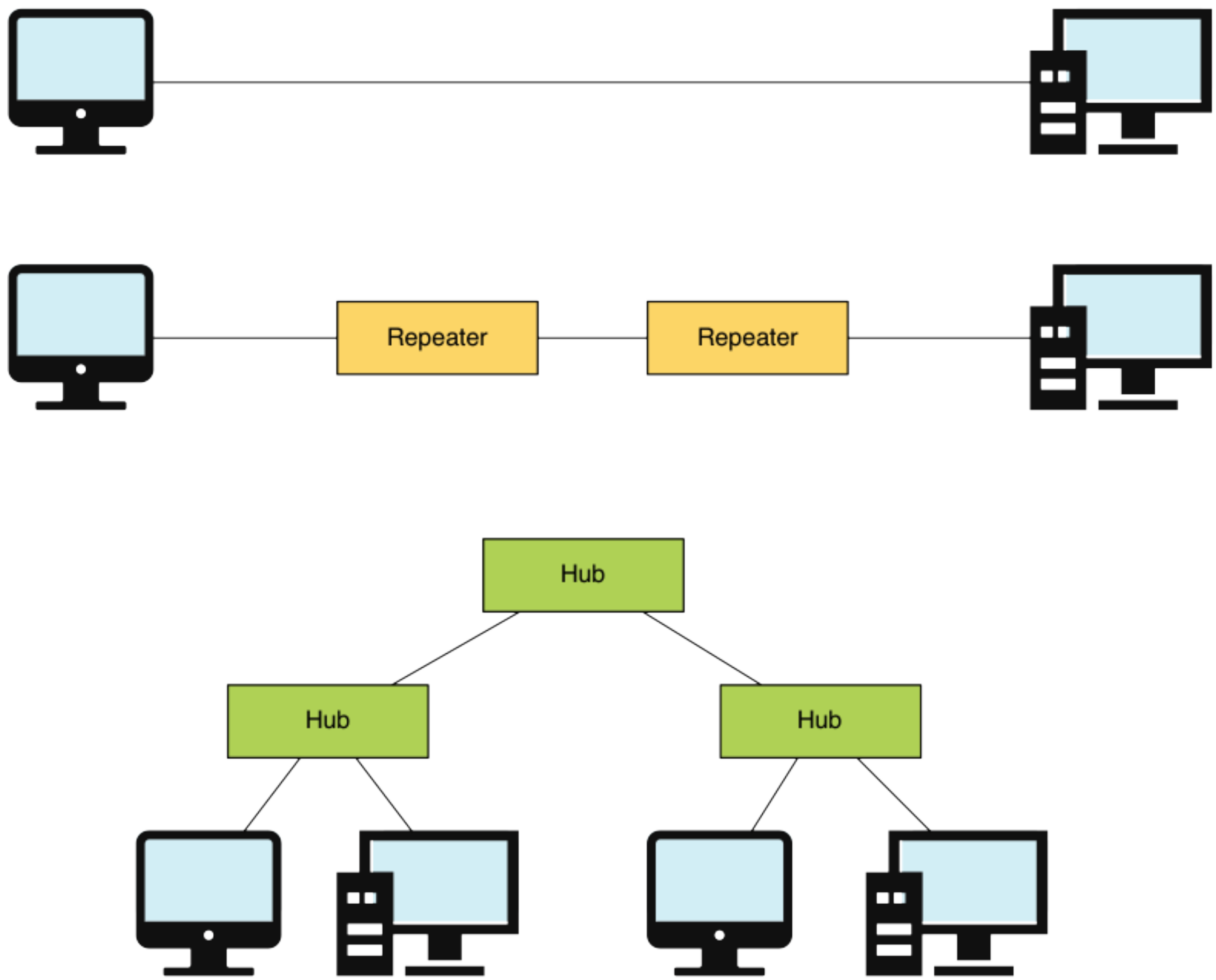
Layer 1: Physical Layer



Layer 1: Physical Layer

- Types of Equipment
  - Hub
  - Repeater
  - Media Converter
- Works at the level of individual bits
- All data sent out of all ports
- Data may go where it is not needed

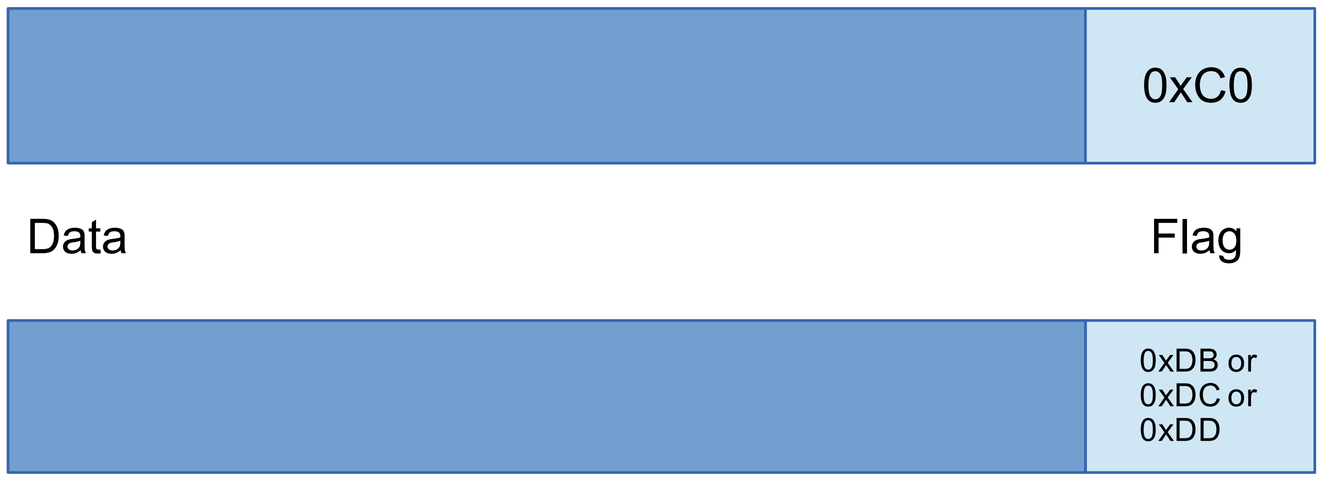
Building Networks at Layer 1



Layer 2: Data Link Layer

- Organizes data into frames
- May detect transmission errors (corrupt frames)
- May support shared media
  - Access control, collision detection
  - *Carrier Sense, Multiple Access, Collision Detect*
  - Addressing (who should receive the frame)
    - Unicast, Multicast
- Usually identifies the L3 protocol carried

Layer 2 Example: SLIP



That's it!

Layer 2 Example: PPP

Flag	Protocol	Data	FCS	Flag

- Also includes link setup and negotiation
  - Agree link parameters (LCP)
  - Authentication (PAP/CHAP)
  - Layer 3 Settings (IPCP)

Layer 2 Example: Ethernet

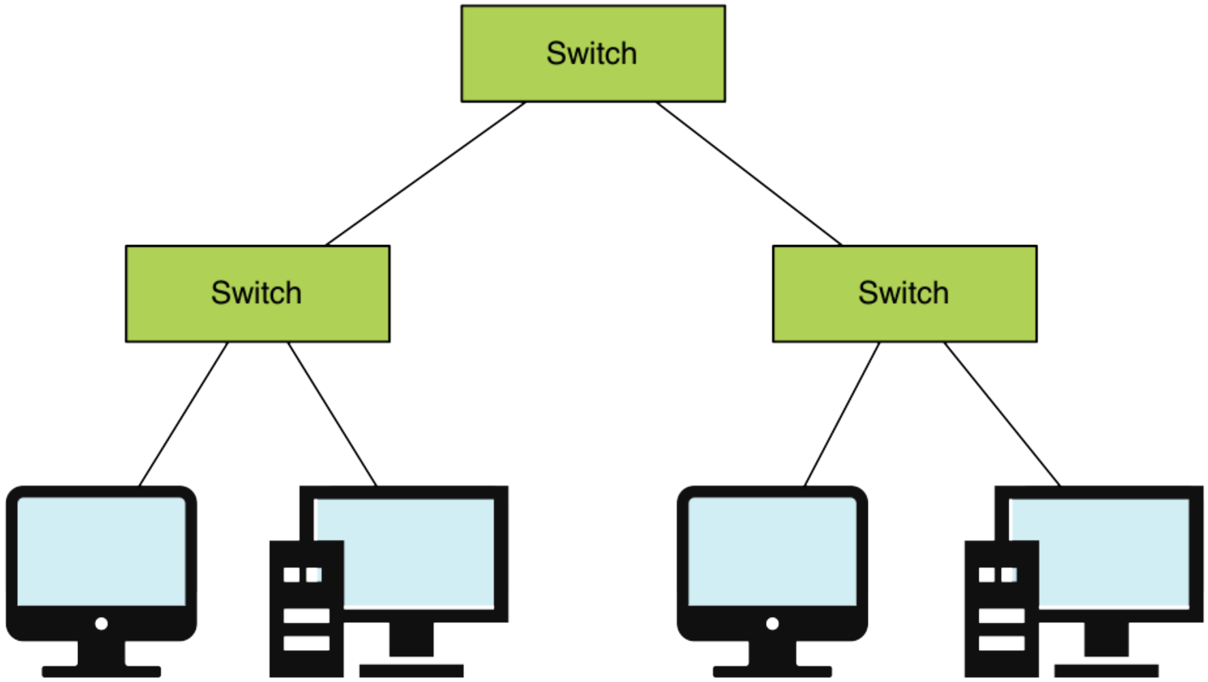
Preamble	Mac Dest	Mac Src	Proto	Data	FCS

- MAC addresses
- Protocol: 2 bytes
  - e.g. 0800 = IPv4, 0806 = ARP, 86DD = IPv6
- Preamble: Carrier Sense, Collision Detection

Layer 2: Data Link Layer

- Types of Equipment
  - Switch
  - Bridge
- Receives L2 frames & selectively retransmits
- Learns which MAC addresses on which ports
- MAC known: only sends traffic to correct port
- MAC unknown: broadcast to all ports (like hub)
- Doesn't inspect packet beyond L2 header

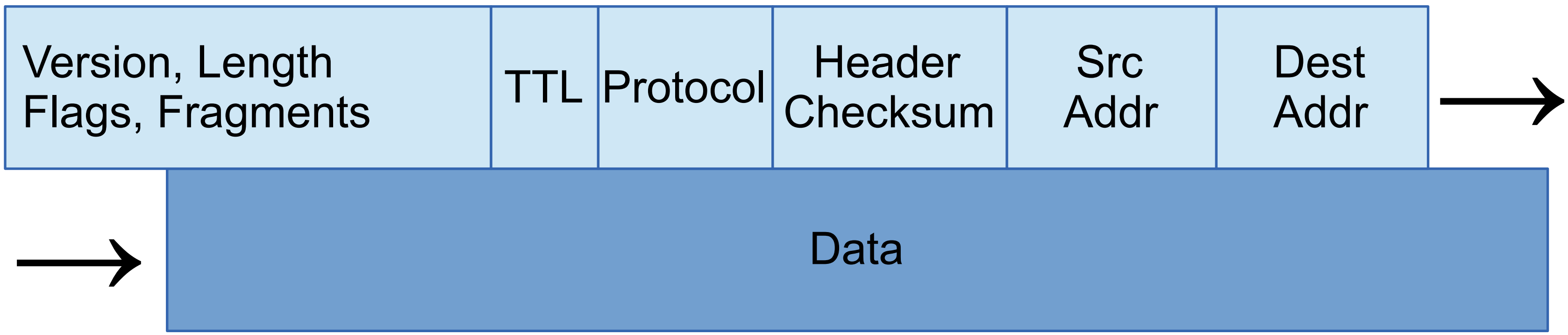
Building Networks at Layer 2



Layer 3: Network Layer

- Connects Layer 2 networks together
  - Forwards data from one network to another
- Universal frame format (datagram)
- Unified addressing scheme
  - Independent of underlying L2 networks
  - Globally organized and managed addresses
- Identifies the Layer 4 protocol being carried
- Handles fragmentation and reassembly of packets

Layer 3 Example: IPv4 Datagram

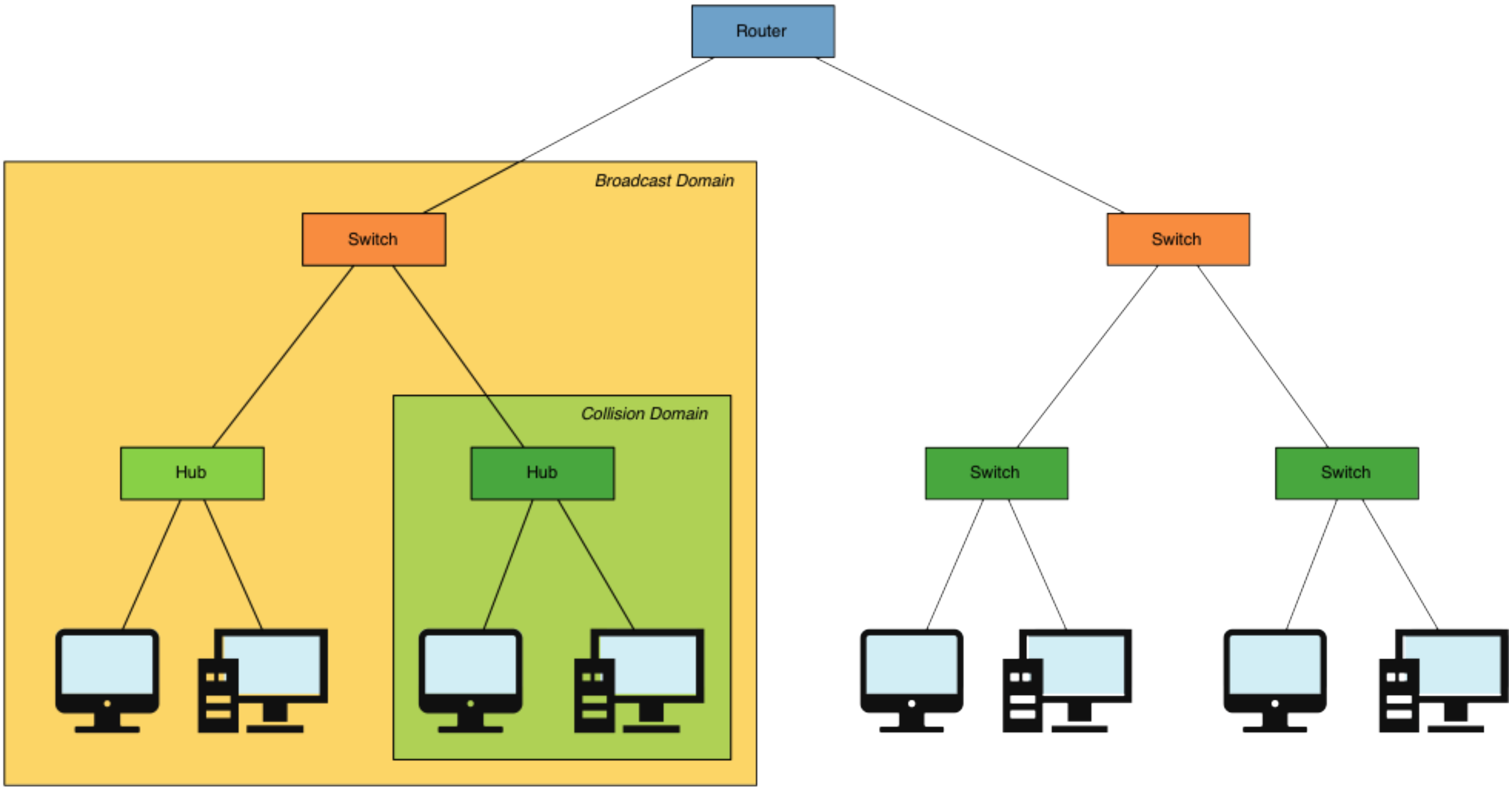


- Source, Destination: IPv4 addresses
- Protocol: 1 byte
  - e.g. 6 = TCP, 17 = UDP
  - see /etc/protocols

Layer 3: Network Layer

- Types of Equipment
  - Router
  - Layer 3 Switch Router
- Routers managed together are an Autonomous System
- Routers look at Destination IP in Forwarding Table
- Forwarding table can be static or dynamic
  - Static is built by hand, or scripted externally
  - Dynamic within an AS: Interior Gateway Protocol (IGP)
  - Dynamic between AS: Exterior Gateway Protocol (EGP)

Building Networks At Layer 3



Layer 4: Transport Layer

- Identifies the endpoint process
  - Another level of addressing (port numbers)
- May provide reliable delivery
  - Streams of unlimited size
  - Error correction & retransmission
  - In-sequence delivery
  - Flow control
- Might just be unreliable datagram transport

Layer 4: User Datagram Protocol

Src Port	Dest Port	Length	CHK	Data

- System (Well-Known) Ports < 1024
  - 53, 69, 161, 162
- User (Registered) Ports 1024 - 49151
- Dynamic (Ephemeral) Ports
  - IANA Recommends ≥ 49152, Linux uses ≥ 32768
  - Typically used for temporary, one session only
  - Other end of a conversation with a well-known port

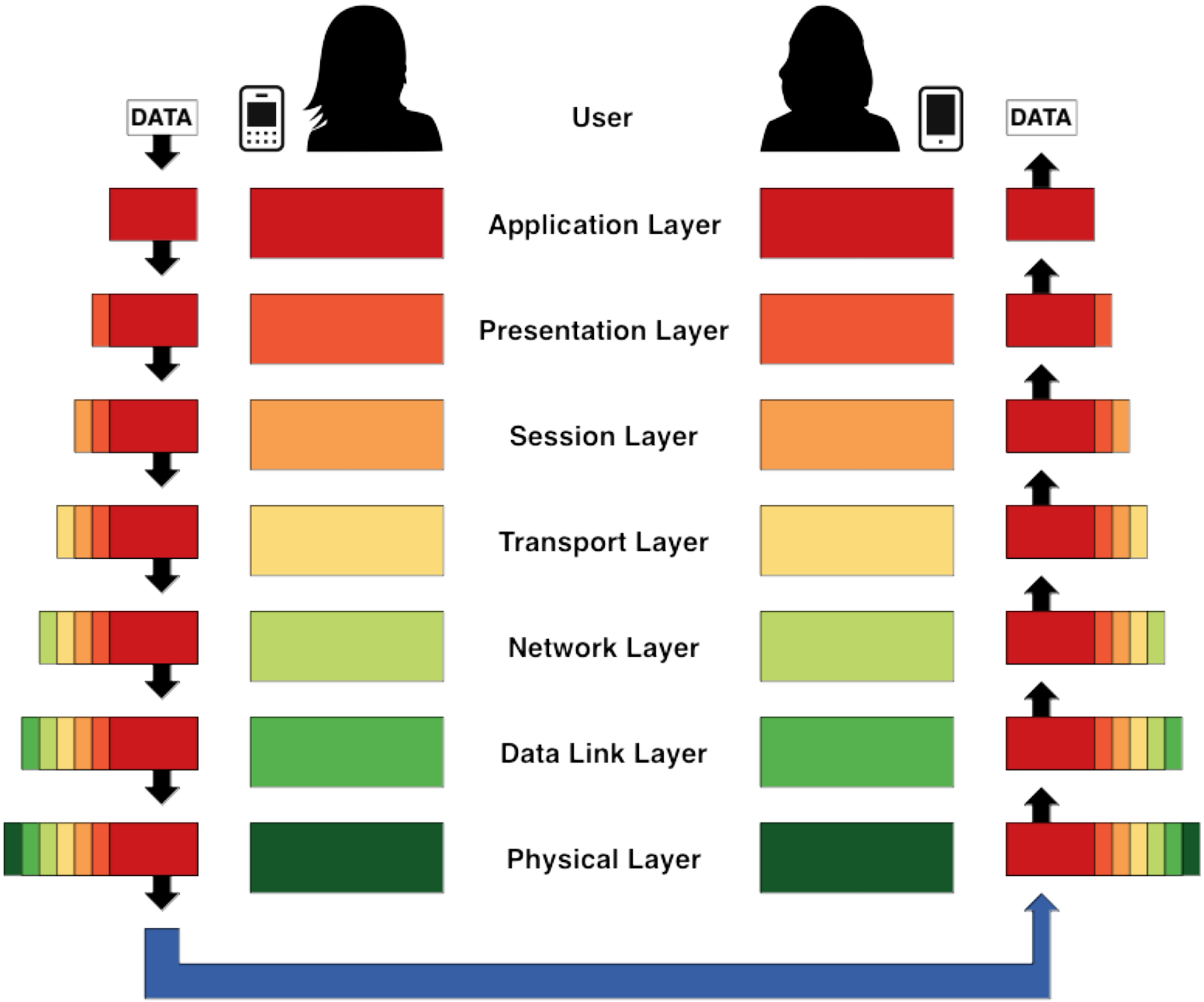
Layers 5+6: Session & Presentation

- Session Layer: long-lived sessions
  - Re-establish transport connection if it fails
  - Multiplex data across multiple connections
- Presentation Layer: data reformatting
  - Character set translation
- Neither exist in the TCP/IP suite
  - Application is responsible for these functions

Layer 7: Application Layer

- The actual work you want to do
- Protocols specific to each application
- Examples?

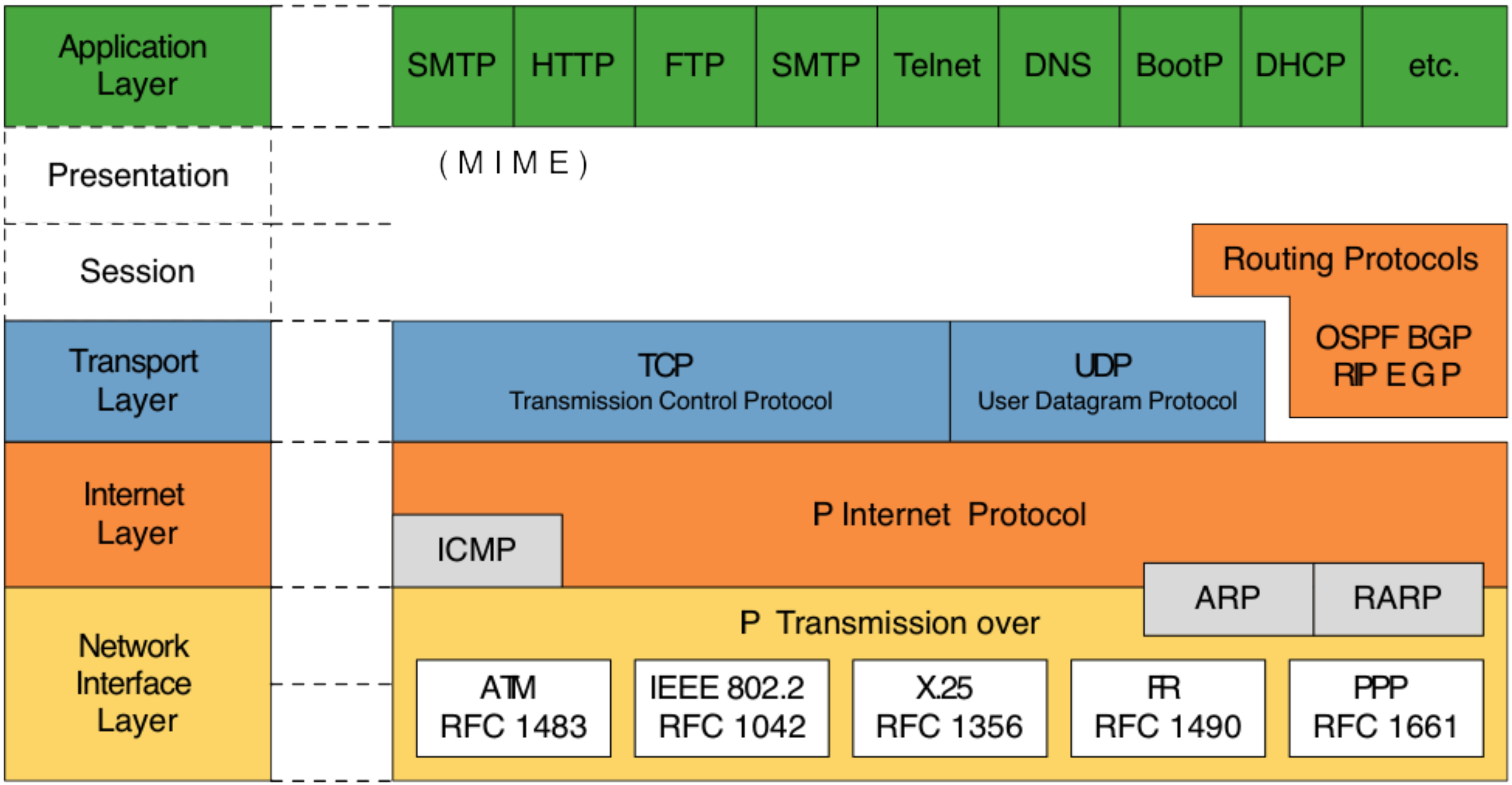
OSI Model


DATA
User
Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer
DATA

Other Layer Models

- The OSI Model is most used... but
- The DoD Model also applicable... and
- The Hourglass Model is realistic & appropriate

DoD Four-Layer Model



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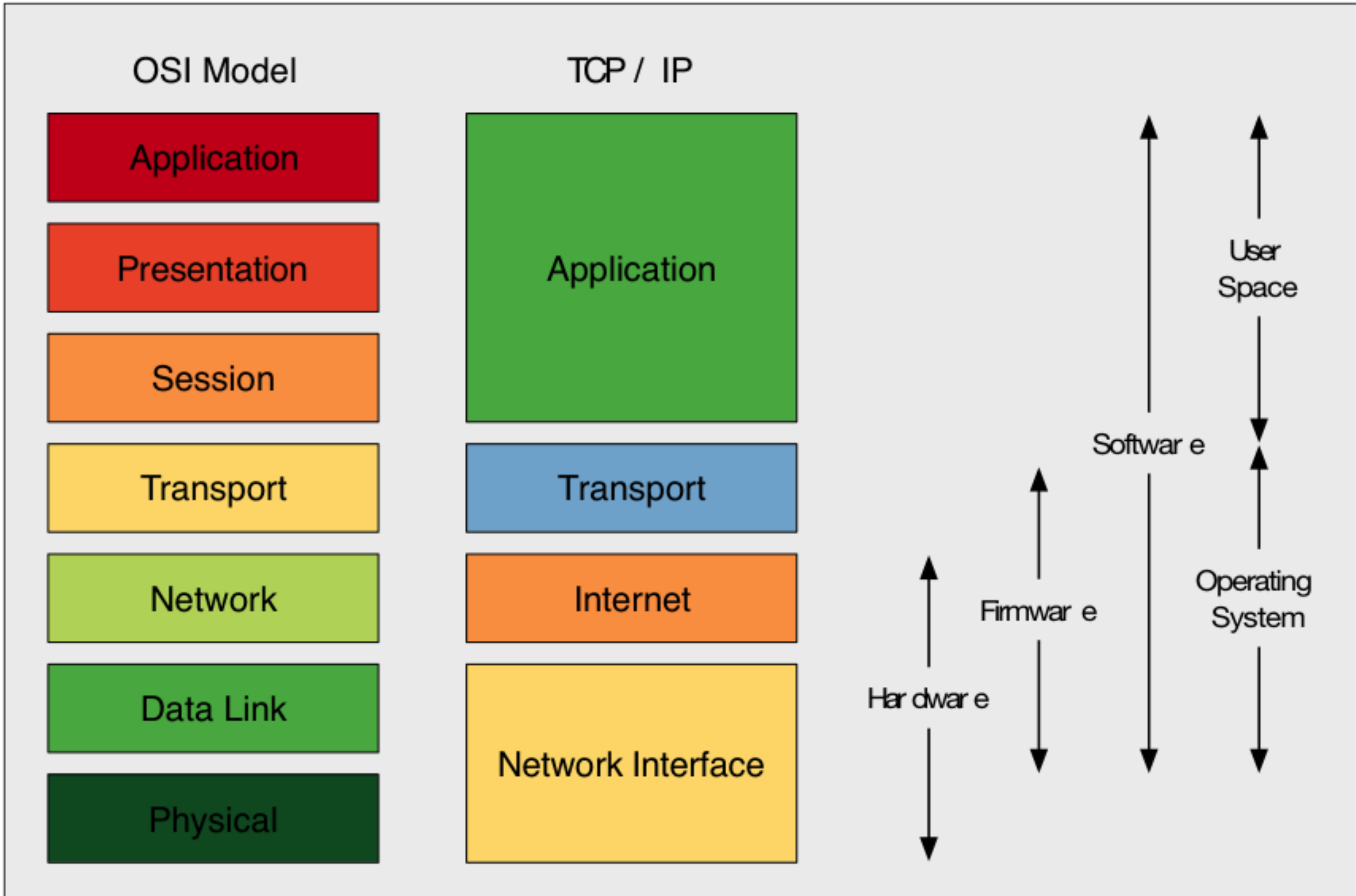
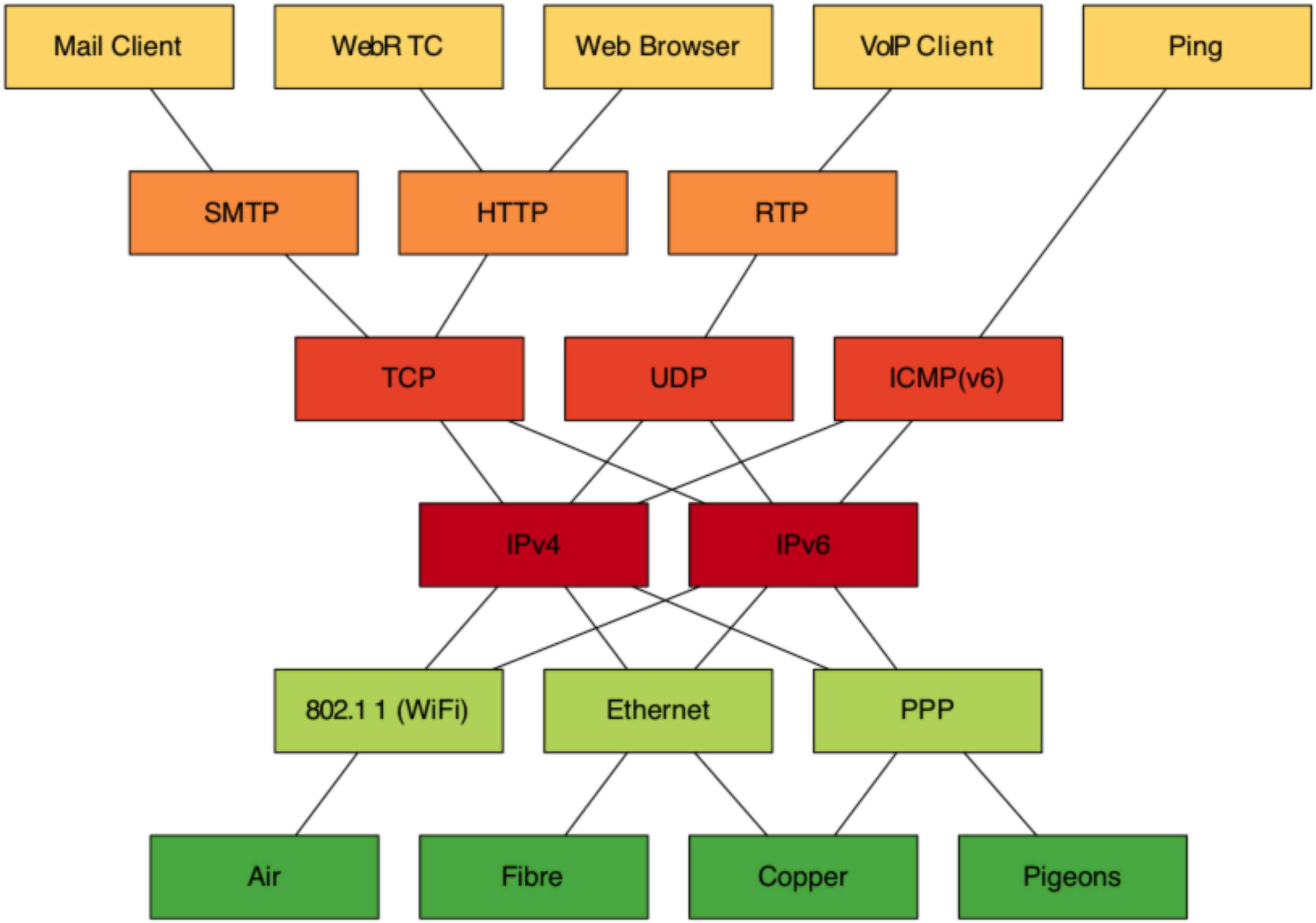
OSI vs DoD Layer Models



TCP/IP “Hourglass” Model



Layers Summary

- Networks designed & described with layers
  - OSI Model: 7 Layers
  - DoD: 3-5 Layer Model
  - Hourglass Model: 6 Layers
- Each layer encapsulates the layer below
- Receiving hosts reverse the process

IP Addresses for IPv4

- 32 bit addresses
- Calculating in decimal, bin and hex
- Hierarchical division in IP Addresses
- Network Masks
- Allocating Addresses
- Special IP addresses
- Subnetting / Supernetting

What's an IPv4 Address?

- 32 bit number
  - 4 octet number
- Can be represented in several ways:

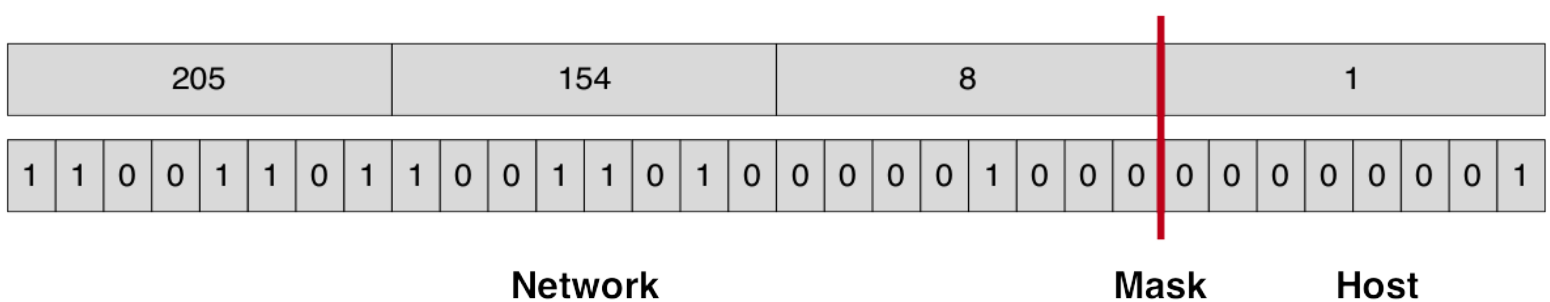
133	27	162	125
85	1B	A2	7D
1 0 0 0 0 1 0 1	0 0 0 1 1 0 1 1	1 0 1 0 0 0 1 0	0 1 1 1 1 1 0 1

Calculating dec, hex, bin

- ipcalc is your friend!
- Try this: ipcalc 133.27.162.125
- The Linux command line is your friend!
- Try this:
  - echo 'ibase=10;obase=16;27' | bc
  - echo 'ibase=10;obase=2;27' | bc
  - echo 'ibase=16;obase=A;1B' | bc

Hierarchical Division in IP Addresses

- Network Part (Prefix): Describes which network
- Host Part (Host Address): Describes which host
- Boundary can be anywhere!
  - Used to be a multiple of 8, but not required today

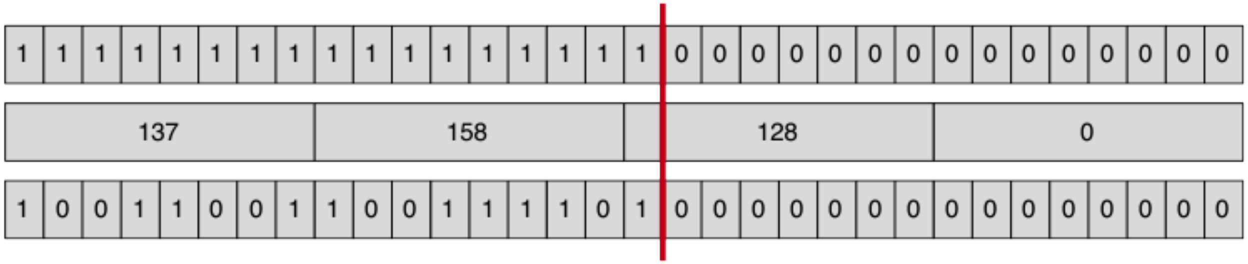


Network Masks

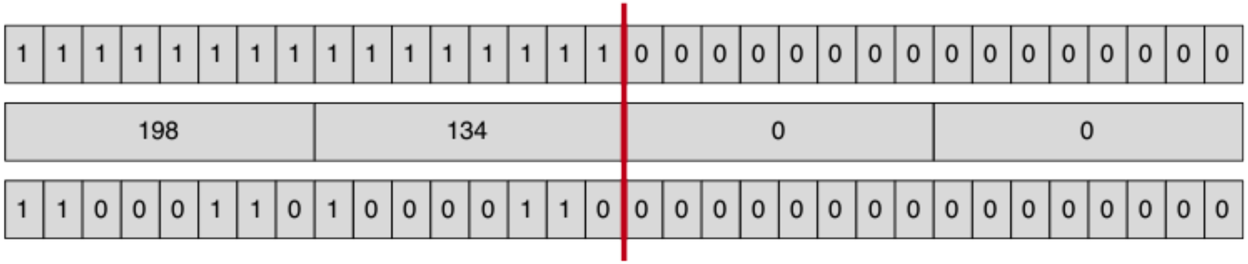
- Help define which bits are used for the Network
- And which bits are used for the hosts
- Different Representations Exist:
  - Decimal dot notation
  - Binary notation
  - Number of network bits
- Binary AND of 32 bit IP address with 32 bit netmask = network part of address

Sample Netmasks

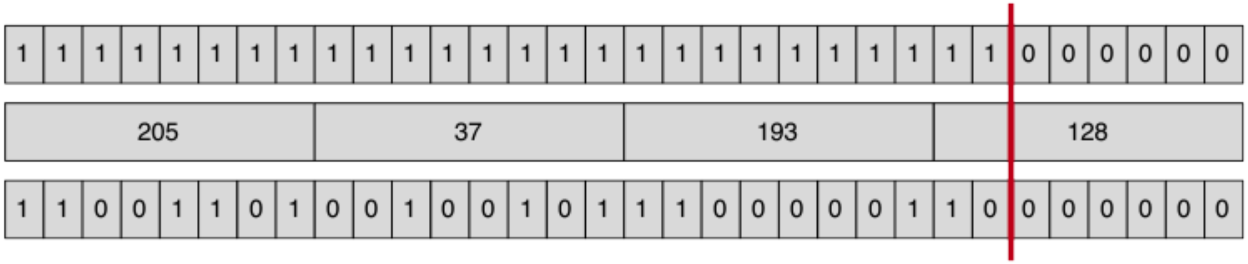
137.158.128.0/17 (netmask 255.255.128.0)



198.134.0.0/16 (netmask 255.255.0.0)



205.37.193.128/26 (netmask 255.255.255.192)



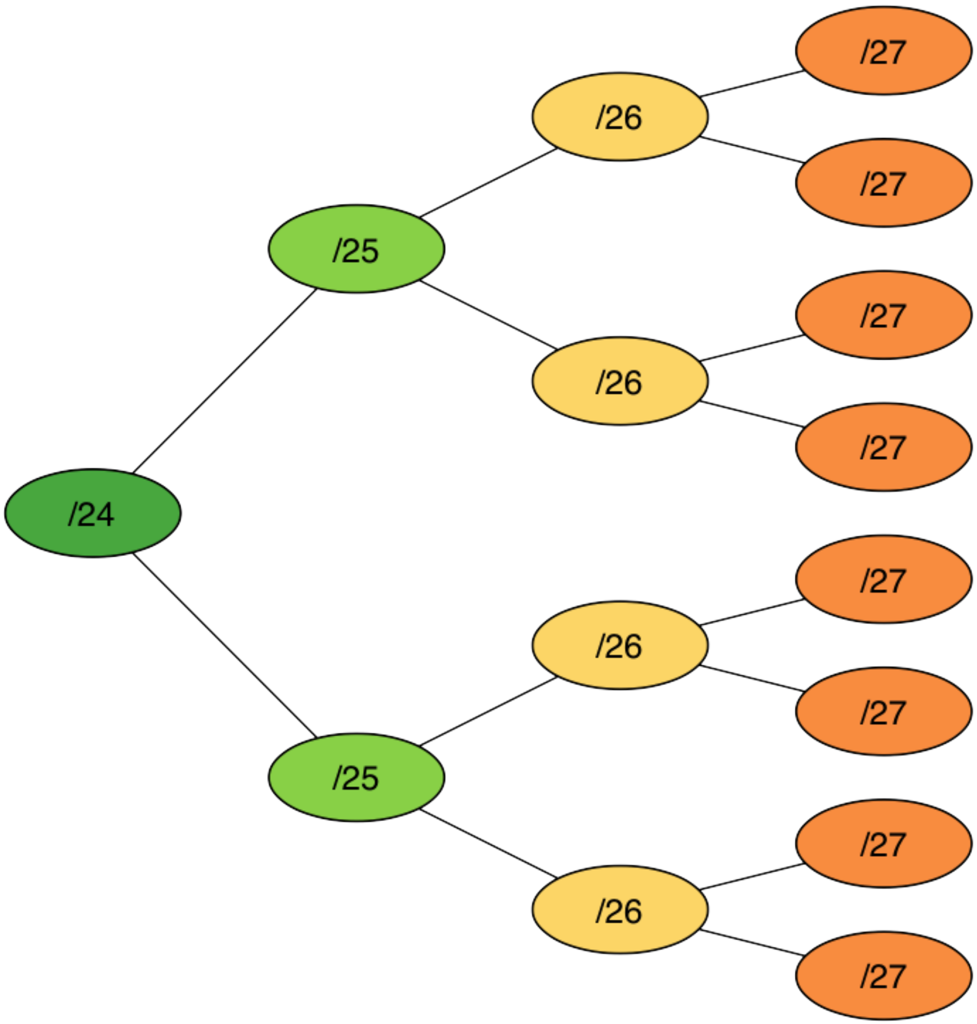
Allocating IP addresses

- The subnet mask defines the network size
- A mask of /24 or 255.255.255.0
  - 32-24 = 8 host bits
  - 2^8 – 2 = 254 possible hosts
- A mask of /27 or 255.255.255.224
  - 32 – 27 = 5 host bits
  - 2^5 – 2 = 30 possible hosts

Special IP Addresses

- Network Address: All 0s in the host part
  - e.g. 193.0.0.0/24
  - e.g. 138.37.128.0/17
- Broadcast Address: All 1s in the host part
  - e.g. 137.156.255.255
  - e.g. 134.132.100.255
- Loopback Address
  - 127.0.0.0/8
- Special Addresses: 0.0.0.0
  - e.g. DHCP

Networks: Subnetting



Add one bit to the netmask

& the network divides in two

This is subnetting

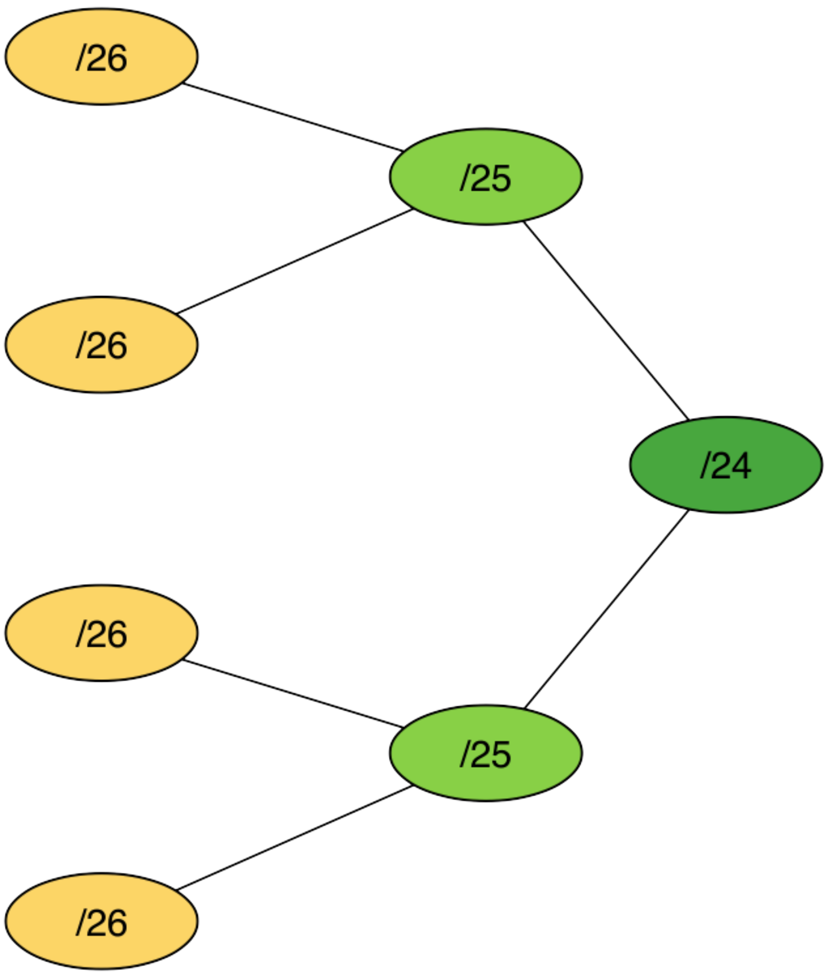
Example: 192.168.10.0/25

Subnets to:

192.168.10.0/26

192.168.10.64/26

Networks: Supernetting



Subtract one bit from netmask

& the network joins together

This is supernetting

192.168.10.0/26

192.168.10.64/26

join together to form:

192.168.10.0/25

IP Numbers

- Public address space available from your NIC
  - AFRINIC, APNIC, ARIN, LACNIC, RIPE NCC
- Private address space available to anyone
  - RFC 1918 Ranges for private networks
    - 10/8, 172.16/12, 192.168/16
  - RFC 6598 for large scale NAT
    - 100.64.0.0/10

Routing

- Every host on the Internet needs a way to get packets to other hosts outside its own subnet
- Hosts that can move packets between subnets are called routers
- Packets can pass through many routers before reaching their destination

The Route Table

- All hosts (including routers) have a route table
- Route tables show which networks are connected
- They specify how to forward packets to other networks
- “ip -B route” on Linux to see v4 & v6 routes
- “netstat -rn -46” on Linux see v4 & v6 routes
- “netstat -rn” on BSD/Mac to see v4 & v6 routes

IPv4 routing table entries

```
Kernel IP routing table
Destination     Gateway         Genmask         Flags   MSS Window  irtt Iface
0.0.0.0         192.168.2.1     0.0.0.0         UG        0 0          0 eth0
192.168.2.0     0.0.0.0         255.255.255.0   U         0 0          0 eth0
root@librenms:~#
```

- Destination is a network address
- Gateway is a router that can forward packets
- Iface is the network interface the route will use

The default route

```
Kernel IP routing table
Destination     Gateway         Genmask         Flags   MSS Window  irtt Iface
0.0.0.0         192.168.2.1     0.0.0.0         UG        0 0          0 eth0
192.168.2.0     0.0.0.0         255.255.255.0   U         0 0          0 eth0
root@librenms:~#
```

- Note the first entry in this route table
- It matches every possible IP address
- This is the default route
- It must be a router capable of forwarding traffic

More Complex Routing

- A router's route table could look like this
- Note multiple interfaces & multiple networks
- There's also a gateway for other networks

Destination	Gateway	Genmask	Flags	Interface
192.168.0.0	0.0.0.0	255.255.255.0	U	eth0
192.168.1.0	0.0.0.0	255.255.255.0	U	eth1
192.168.2.0	0.0.0.0	255.255.254.0	U	eth2
192.168.4.0	0.0.0.0	255.255.252.0	U	eth3
0.0.0.0	192.168.1.1	0.0.0.0	UG	eth0

Summary

- Layers & Layer Models
- Encapsulation
- Frames, Datagrams, Segments, Packets
- TCP/IP Protocol Suite
- IP Addressing
- IP Routing