Introduction

- Networks are everywhere
  - Local Area Networks (LANs)
    - Office buildings
  - Metropolitan Area Networks (MANs)
    - Businesses Connecting LANs
  - Wide Area Networks (WANs)
    - Regional and Nationwide Networks
  - Internetworks
    - Interconnected Networks

How do we design networks?

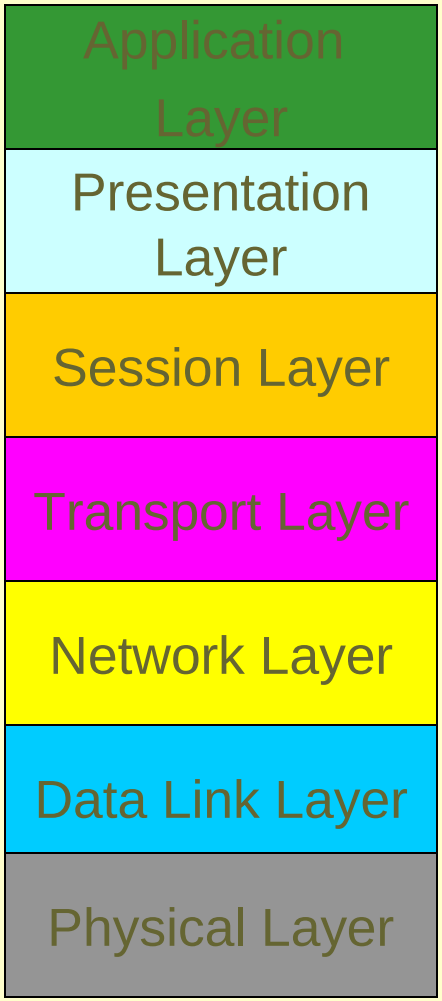
Like any other large program, network implementations are broken down into modules.

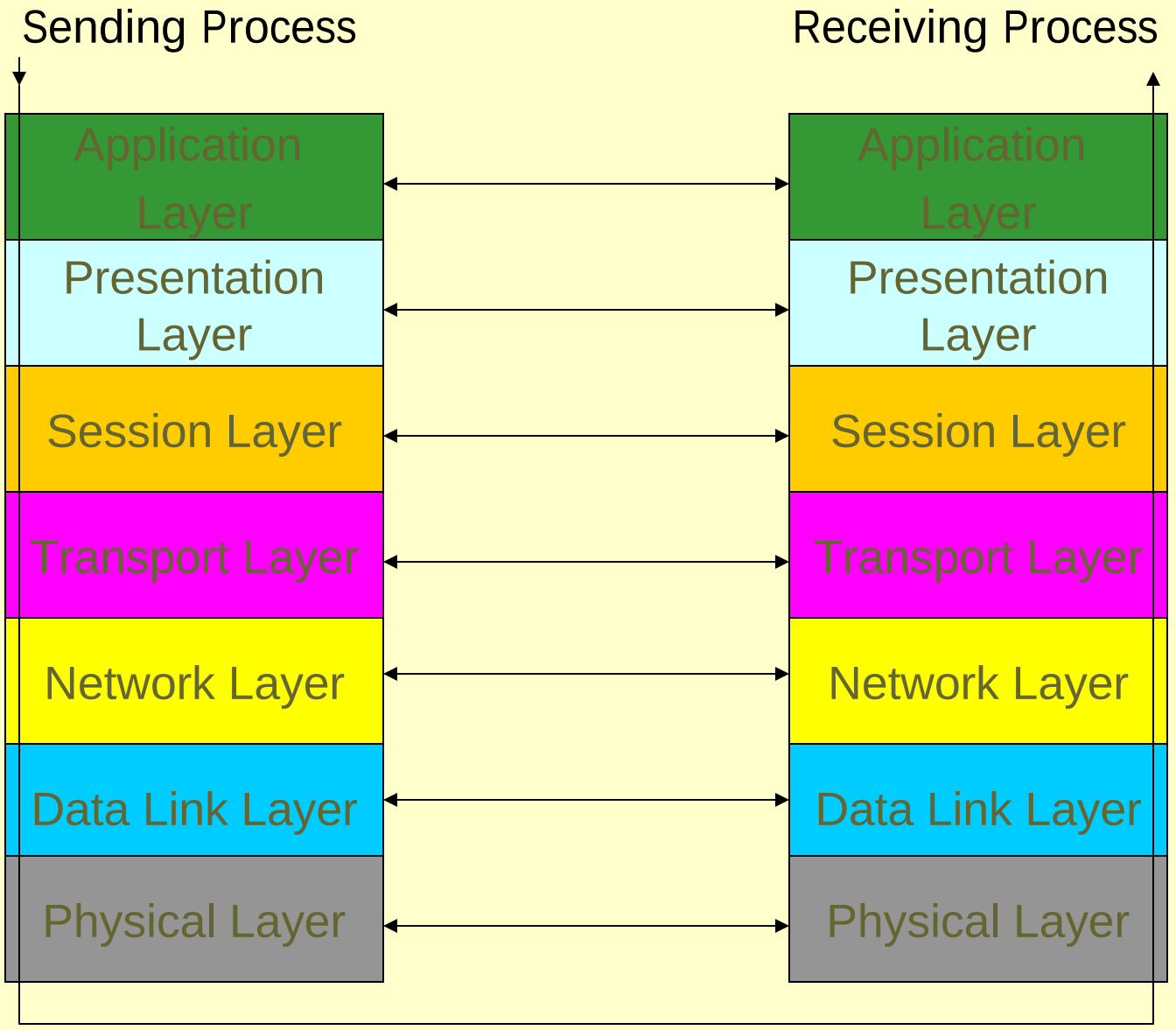
Unlike other large programs, networks utilize every module with every transmission in a hierarchical fashion.

ISO OSI Reference Model

- International Standards Organization
- Open Systems Interconnection (OSI)
- The ISO OSI contains 7 layers

OSI Reference Model





- **Adapted from p34, Tanenbaum**

OSI Reference Model Terminology

- Services - What the layer does
  - like public member functions in OOP
- Interface - Parameters and results
  - like the parameter lists and return values in OOP
- Protocols - the communication between peer levels
  - like the hidden implementation of class in OOP.

Physical Layer

- Transmission of “raw” bits
- Hardware level concerns
  - voltages, pins
  - mechanical, electrical, and procedural interfaces
- Communicates between a pair of nodes
- Provided by modems and other point-to-point transmission hardware

Data Link Layer

- Imposes a structure on the bit stream
  - data *frames* (100's or 1000's of bytes long)
- Acknowledge receipt of frames
- Handle damaged, lost, or duplicate frames
- Flow regulation
  - Don't overflow buffers

The Network Layer

- Routing “packets”
- Congestion Control
- Accounting
- Heterogeneous network interconnects

The Transport Layer

- Provides multiplexing/demultiplexing between network traffic and individual processes.
- Establishes/deletes network connections
- End-to-end flow control.
- Not needed on routers (unless router is also a host).
- Often provides a reliable bit stream.
- Transport layer protocols handle “messages.”

The Session Layer

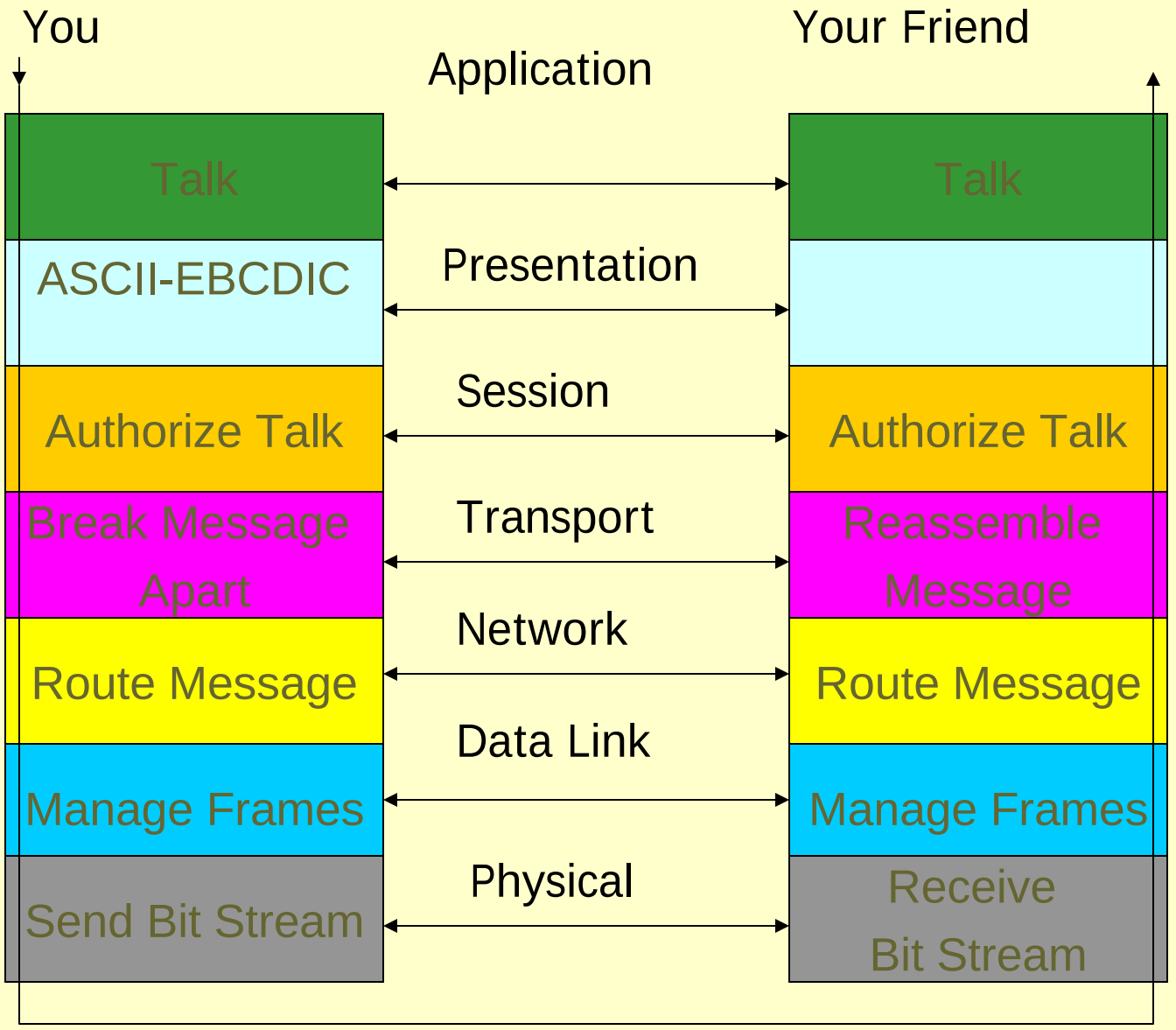
- Information about where to obtain service
- Access Rights/permissions
  - establish “sessions” (login or ftp)
- Traffic Control (half/full duplex connections)
- The Session Layer is generally under utilized

Presentation Layer

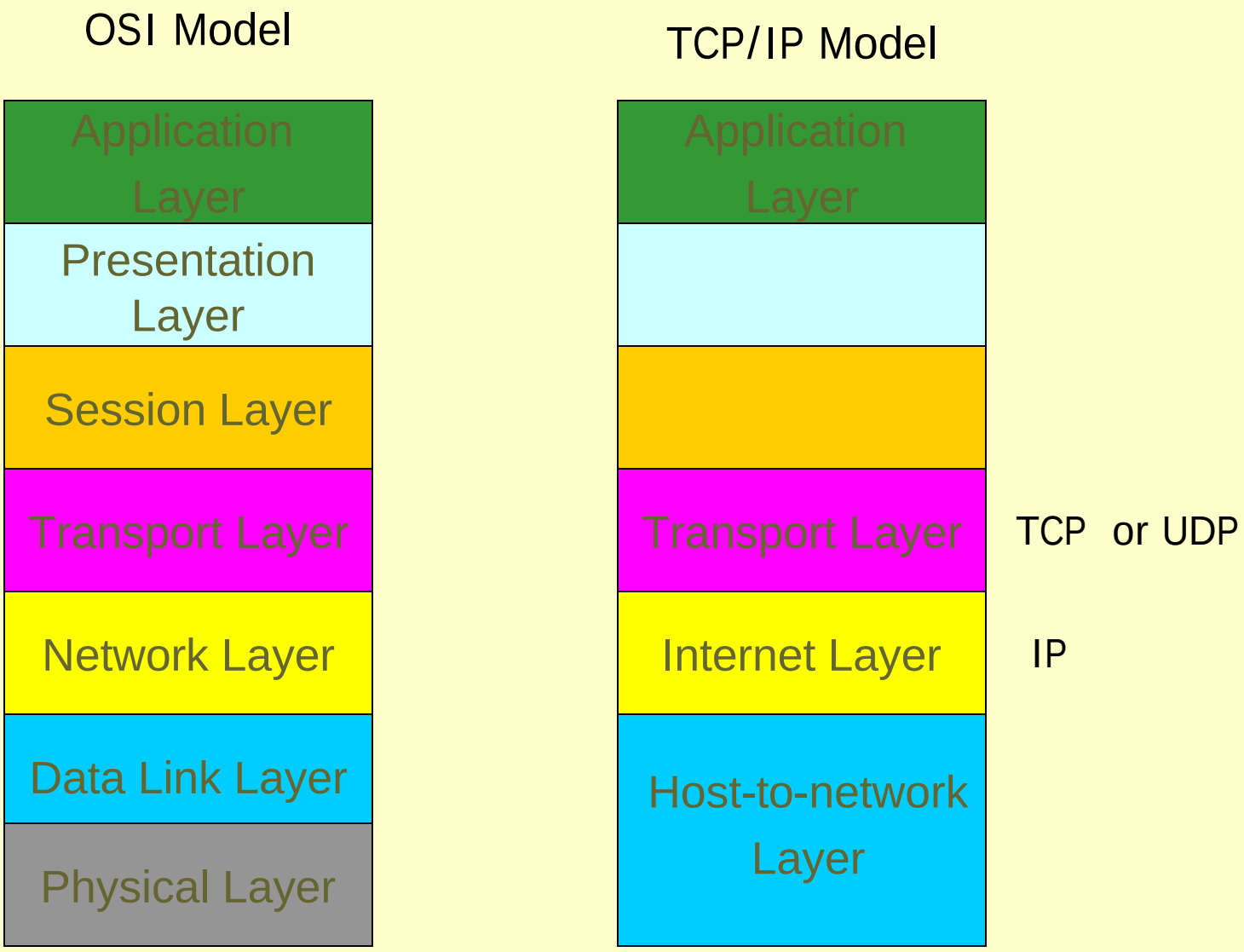
- General Purpose Application Utilities
- Utilities that operate on data
  - Data word sizes
  - Encryption
  - Data Compression
  - Code conversions
    - e.g., ASCII <-> EBCDIC

Application Layer

- Application specific code
  - ftp
  - telnet
  - http
- Anything not implemented elsewhere in the protocol stack.


You
Your Friend
Application
Talk
Talk
ASCII-EBCDIC
Presentation
Authorize Talk
Session
Authorize Talk
Break Message Apart
Transport
Reassemble Message
Route Message
Network
Route Message
Manage Frames
Data Link
Manage Frames
Send Bit Stream
Physical
Receive Bit Stream

TCP/IP Reference Model



The Network Layer

Network Layer

- Route packets from source to destination
  - first layer that knows about communications beyond a single connection
  - must know the topology of the network
- Interface between transport layer and to data link layer

Goals of the Network Layer*

- The services should be independent of the subnet
- The transport layer should be shielded from the number, type and topology of the subnets present
- The network addresses made available to the transport layer should use a uniform numbering plan, even across LANs and WANs

*Andrew S. Tanenbaum

Connection-oriented vs Connectionless Routing

- Connectionless
  - Subnet is unreliable
  - Primitives
    - Send Packet
    - Receive Packet
  - Hosts reorder packets
  - Each packet must provide full destination address
  - Each independently routed packet is a datagram
  - IP is a connectionless protocol

Connection-oriented vs Connectionless Routing

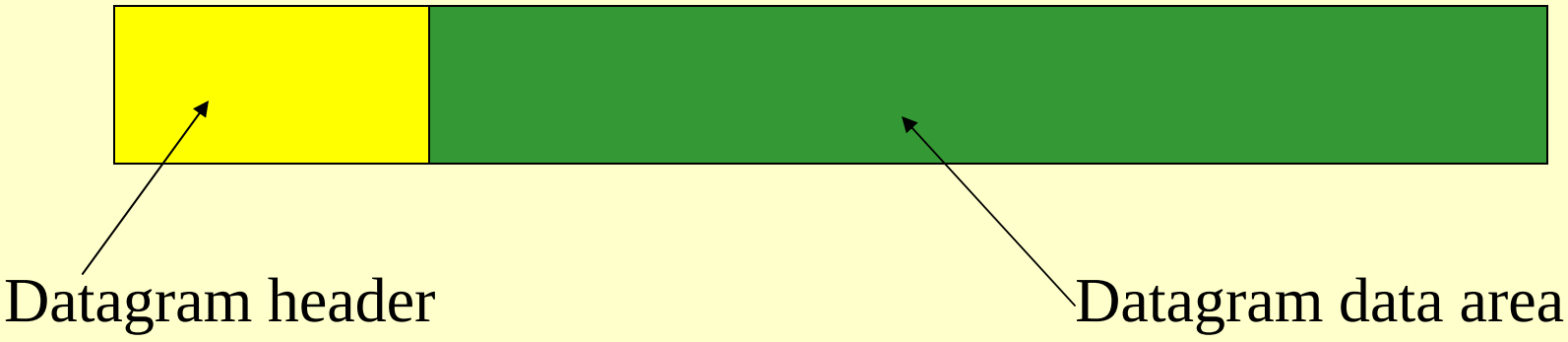
- Connection-oriented
  - All communication begins with the establishment of a connection. This connection is called a virtual circuit.
  - Identifiers are assigned to each connection
  - Packets arrive in order
  - Each packet must connection identifier
  - ATM is a connection-oriented protocol

Internet Protocol (IP)

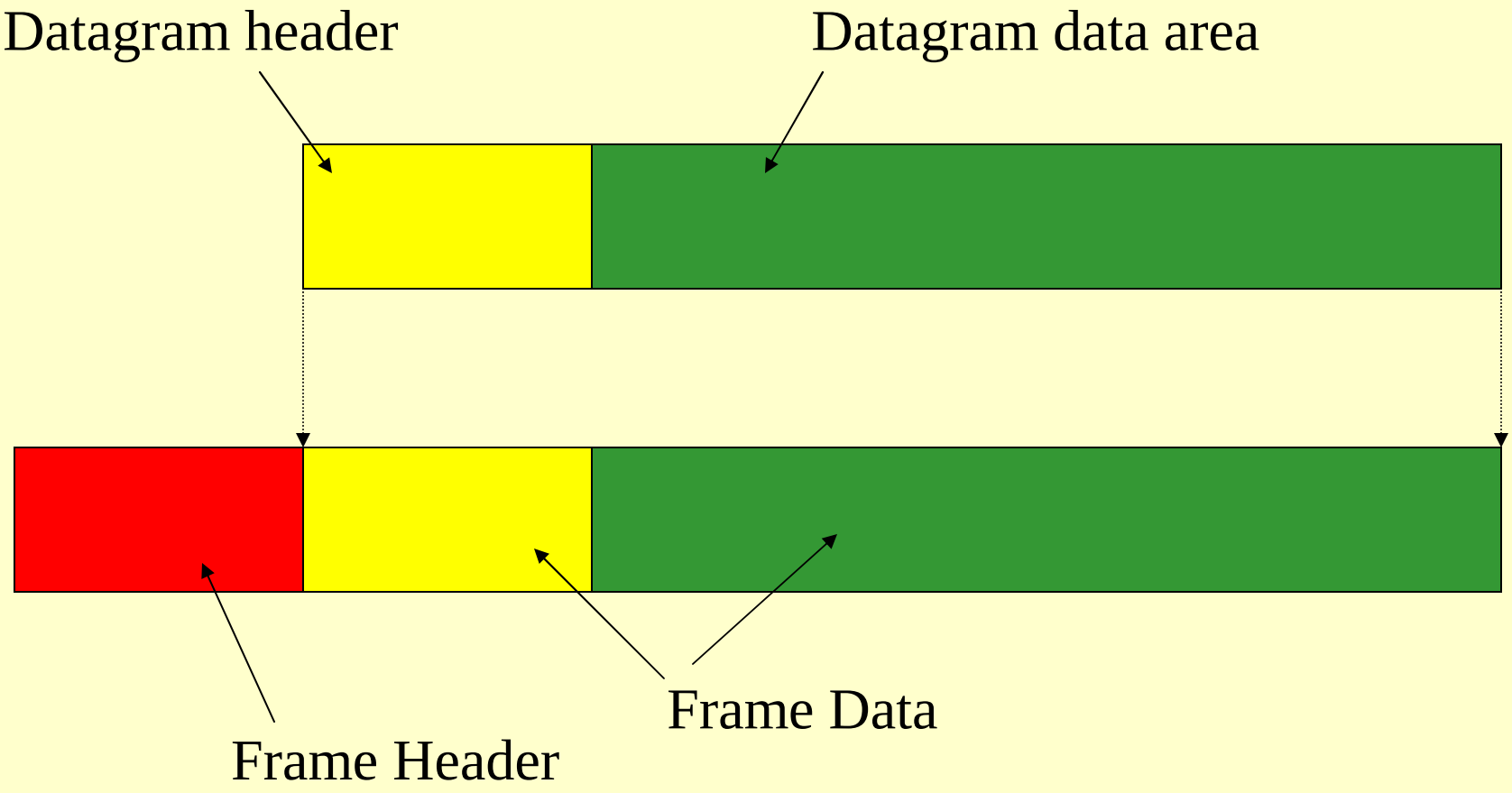
- IP is the network layer of the TCP/IP reference model

IP Packets (datagrams)

- Network layer peers communicate via IP packets
- Ip Packets consist of a header and a data area



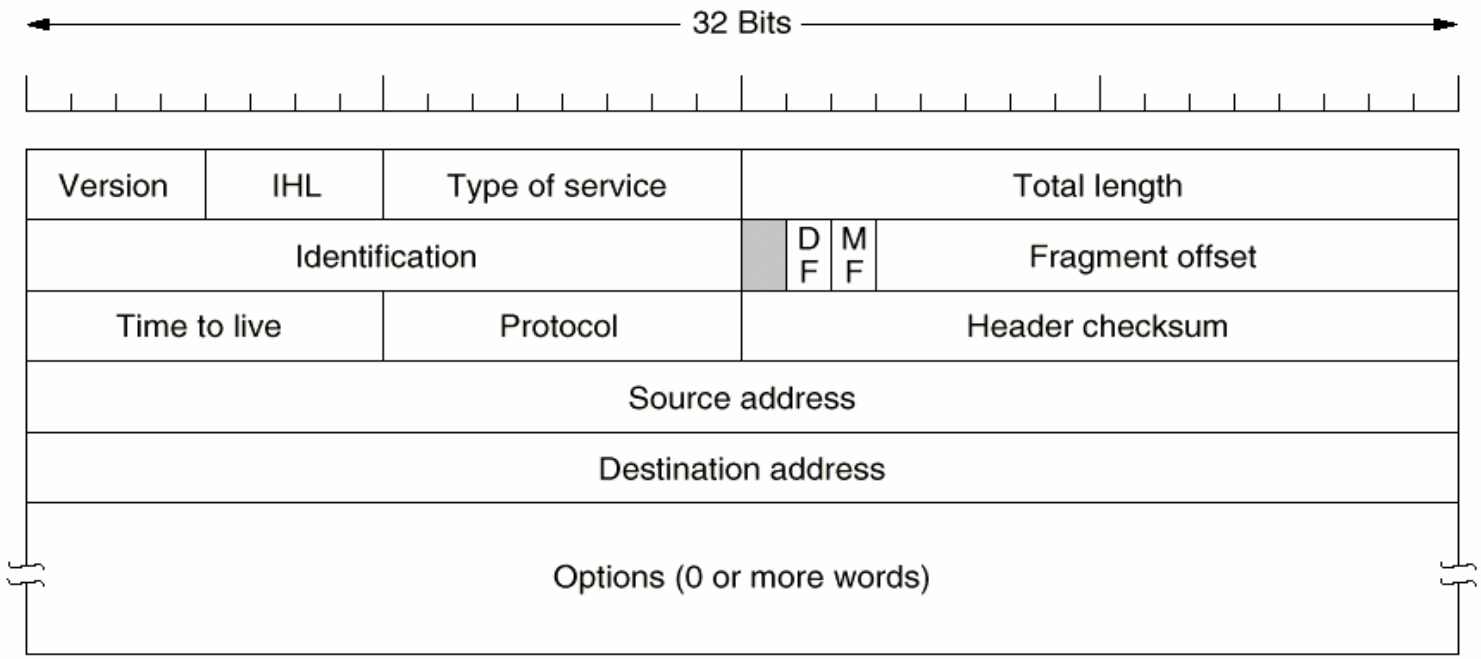
IP Datagrams are Encapsulated into Data Link Frames by the Data Link Layer



Maximum Transfer Units (MTU)

- Maximum frame size available
  - Ethernet (approximately 1500 bytes)
  - Minimum MTU is 576
- What happens if we can't fit an entire datagram into a single frame?
  - Fragment the datagram so that it can be sent in multiple frames.
  - Fragmentation and reconstruction occur at the network level.
  - Reconstruction occurs at the final destination only.

IPv4 Packet Header



IP Header Fields

- IHL - Length of header in 32-bit words
  - normally 5
- Type of Service
  - Precedence (bits 0-2)
    - 8 levels of precedence
    - D- low delay (bit 3)
    - T- high throughput (bit 4)
    - R- high reliability (bit 5)
- Total Length is in 8-bit bytes

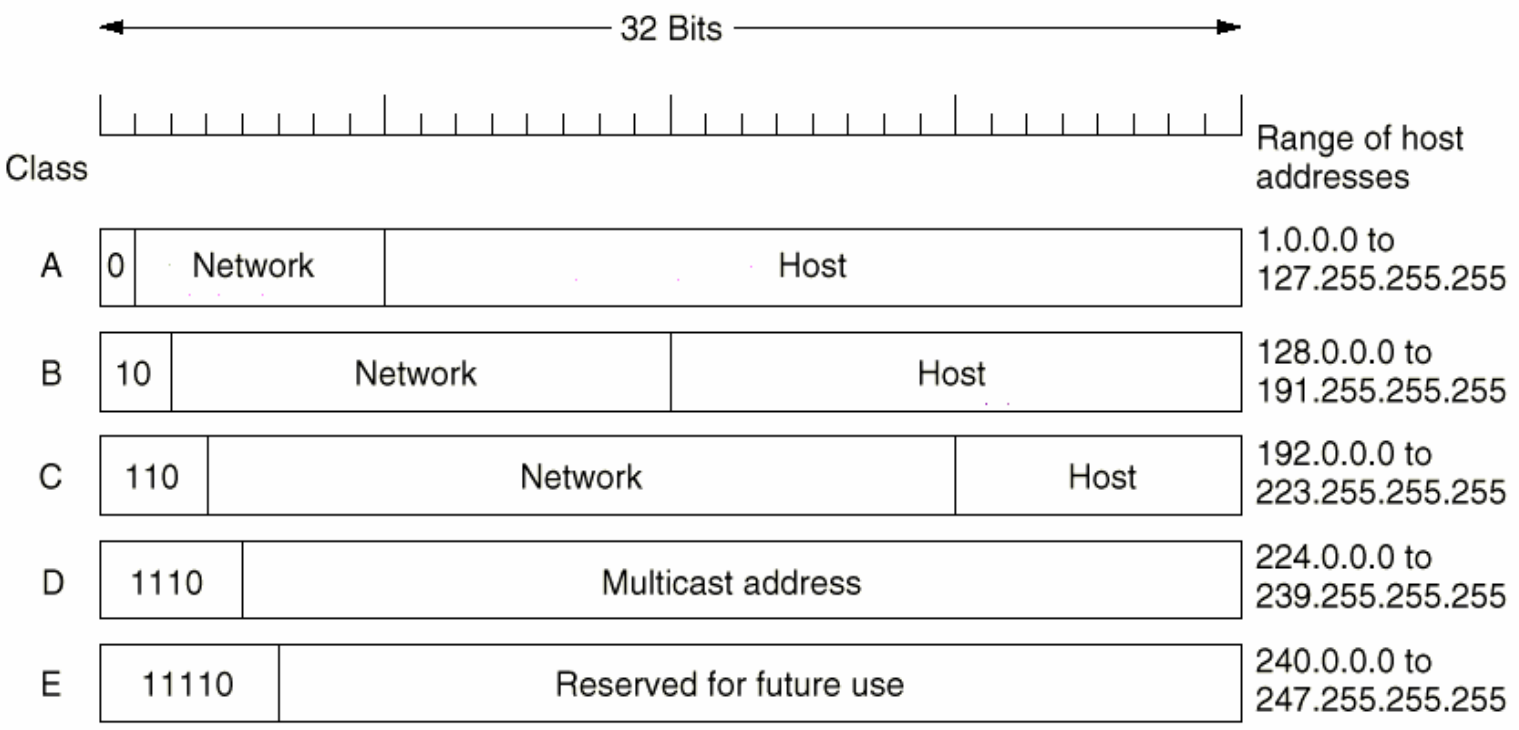
IP Header Fields

- Identification (16-bits)
  - Which datagram does this fragment belong to?
- DF
  - Don’t Fragment (576 or less must be supported)
- MF
  - More Fragments
    - All but the last fragment has this bit set
- Fragment Offset
  - Where in the datagram does this fragment go?
  - Units are 8 bytes.

IP Header Fields

- Time to Live (8-bits)
  - Counter that is decremented each time the datagram traverses a router. Datagram is deleted when Time to Live is zero.
- Protocol (8-bits)
  - Transport protocol in use (e.g., TCP or UDP)
- Header Checksum
  - Basic error detection mechanism
  - Recomputed at each hop (Time to Live changes)
- Source and Destination IP address (32-bits each)

Classes of IP Addresses



Network/Host Address Breakdown

- Class A Networks
  - (N.H.H.H) (value of first byte is between 1 and 127)
  - 126 networks with 16 million hosts each
- Class B Networks
  - (N.N.H.H) (value of first byte is between 128 and 191)
  - 16,382 networks with 64K hosts each
- Class C Networks
  - (N.N.N.H) (value of first byte is between 192 and 223)
  - 2 million networks with 254 hosts each

Special Ip Addresses

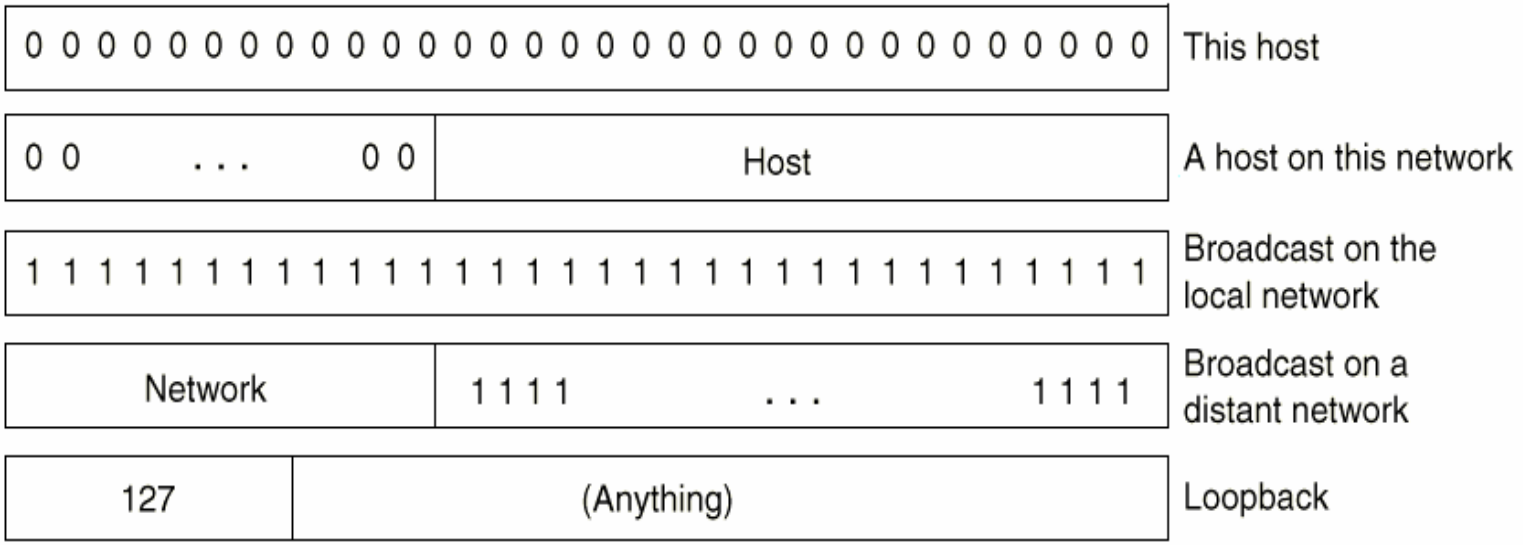
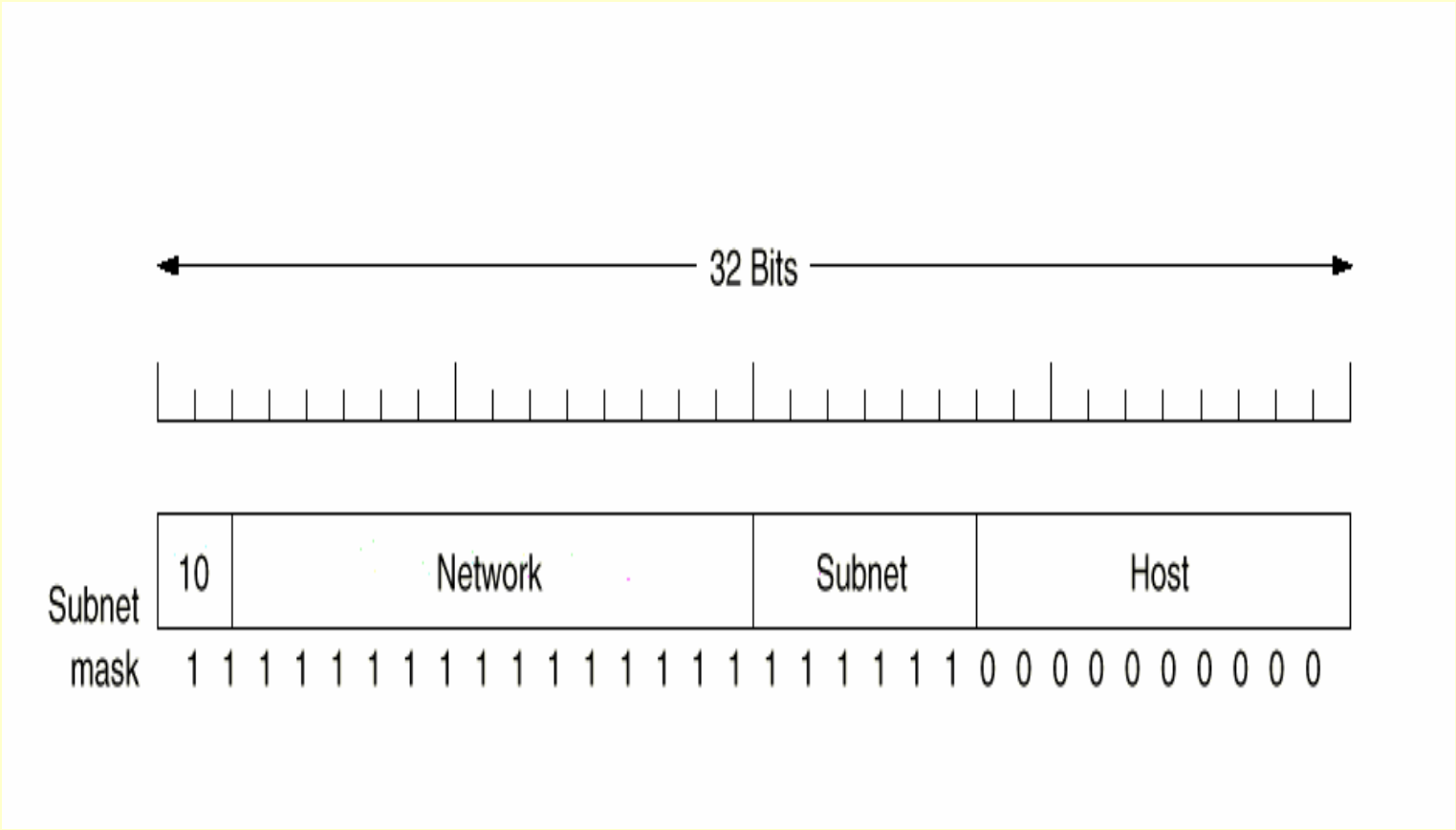


Fig. 5-48. Special IP addresses.

Subnets

- Problem:
  - We are rapidly running out of IP addresses
  - Many networks do not have the maximum number of hosts that can be supported
- Temporary Solution:
  - Create subnet. Subnet works with smaller numbers of hosts.
- Changes the distribution of network and host addresses
  - Uses some of the bits originally allocated for the host address for the network address

Sample subnet for class “B” network



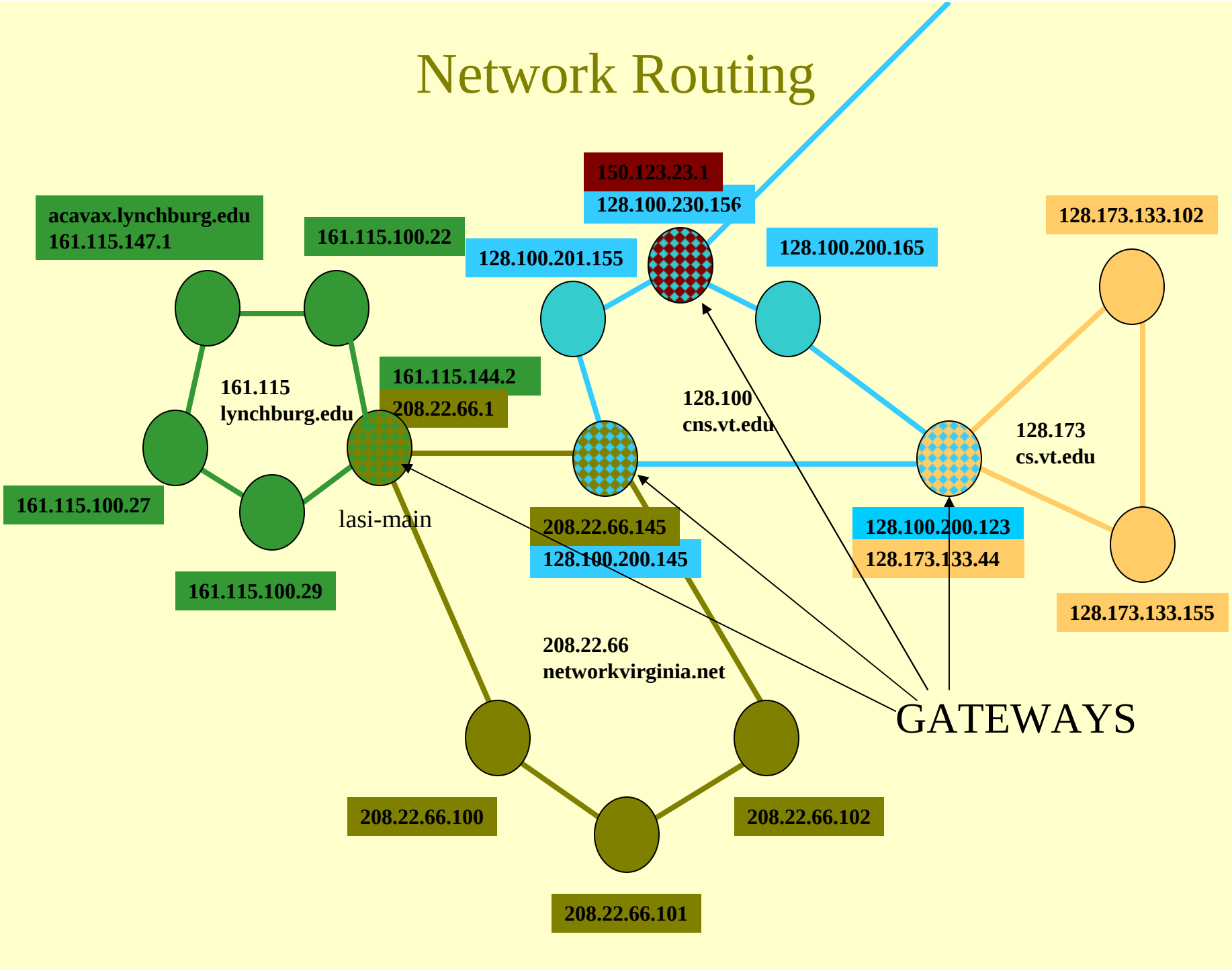
Types of Routing

- Direct Routing
  - Both machines are on the same network
  - Machines communicate directly, e.g., on the same Ethernet
- Indirect Routing
  - Machines are on different physical networks
  - There is no direct connection
  - Datagrams travel from source to destination via one or more gateways or routers.
- Hosts can determine which method to use by comparing their network address with the network address of the datagram.

Gateways and Routers

- A gateway is a host that belongs to more than one network
- A gateway has more than one IP address, one for each network that includes it.
- Gateways can also work as hosts, but more frequently gateways provide routing as their principal function.
- The terms router and gateway are often used interchangeably, but the term router is more often used to describe custom hardware dedicated to routing.

Network Routing



Routing on a LAN

- Datagrams can be routed directly to a destination host that is connected to the same LAN
- Ethernet cards all have a unique 6-byte address (e.g., 08-f3-32-a3-b5-23)
- The hosts maintain a table of IP to Ethernet address translations
- This table is maintained automatically using ARP

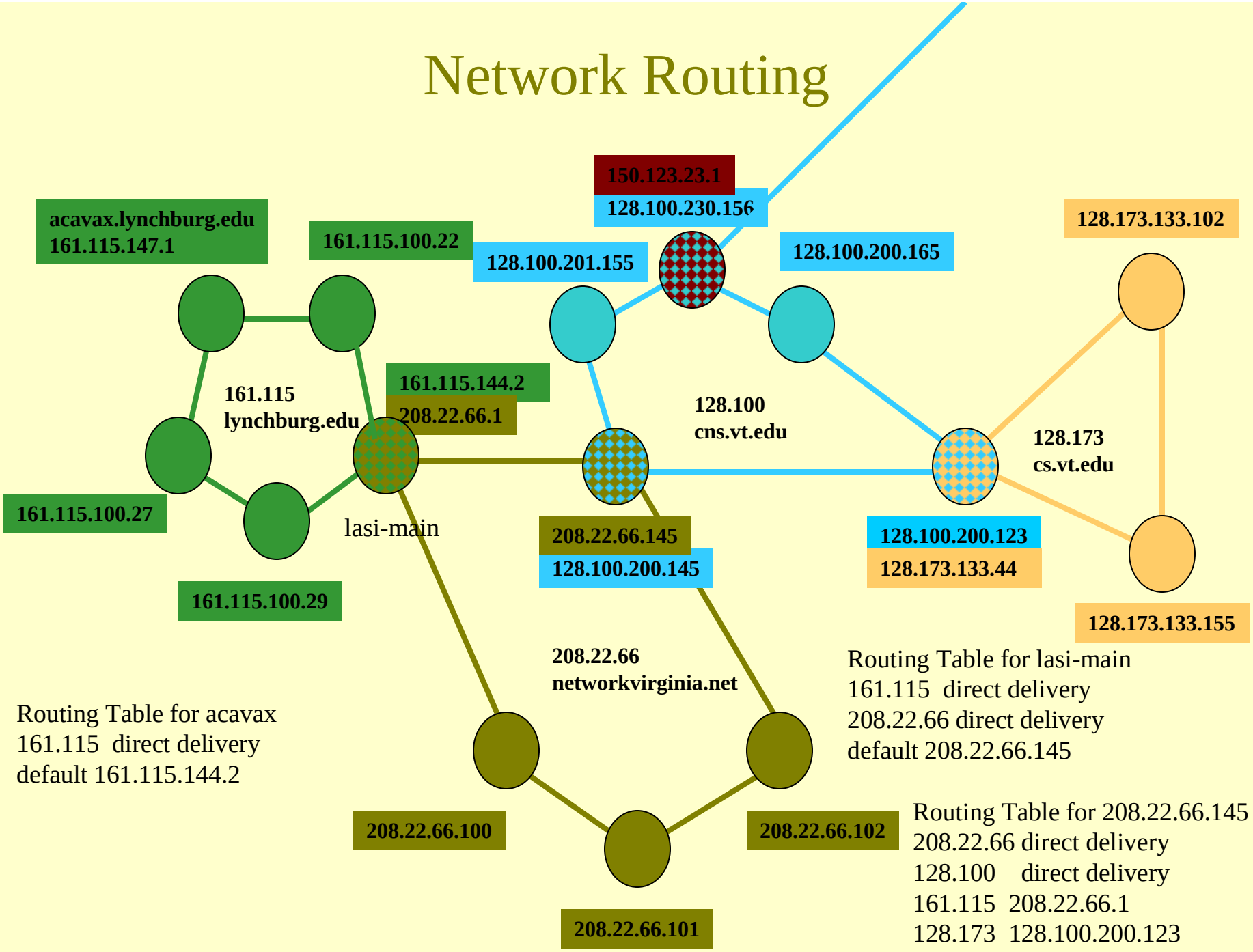
Address Resolution Protocol (ARP)

- The source broadcasts the destination address to the local network (along with the local source's address) requesting the Ethernet address of the corresponding host
- The destination host responds by sending its Ethernet address to the source host
- The destination host sends the data to the destination and records the IP/Ethernet address pair in a cache for future use.
- Cache entries time-out and must be reacquired

Basics of Internet Routing

- Look at the destination IP address
- Extract the network address
- If network is directly connected, send the datagram directly. Use ARP to resolve the physical address if necessary.
- If network is indirectly connected, lookup the address of the network in a routing table.

Network Routing



Routing Table for acavax
161.115 direct delivery
default 161.115.144.2

Routing Table for lasi-main
161.115 direct delivery
208.22.66 direct delivery
default 208.22.66.145

Routing Table for 208.22.66.145
208.22.66 direct delivery
128.100 direct delivery
161.115 208.22.66.1
128.173 128.100.200.123
default 128.100.230.156

How are routing problems handled?

- Internet Control Message Protocol (ICMP)
  - Provide error reporting (not correction)
  - Sends message to the source host only
  - Provide basic flow control
    - Destinations can send ICMP messages when they are overloaded
  - Makes route change requests
  - Reports to the source when time to live expires