# CS4450

## Computer Networks:
## Architecture and Protocols

## Lecture 9
## Spanning Tree Protocol
## Internet Protocol

**Spring 2018**
**Rachit Agarwal**

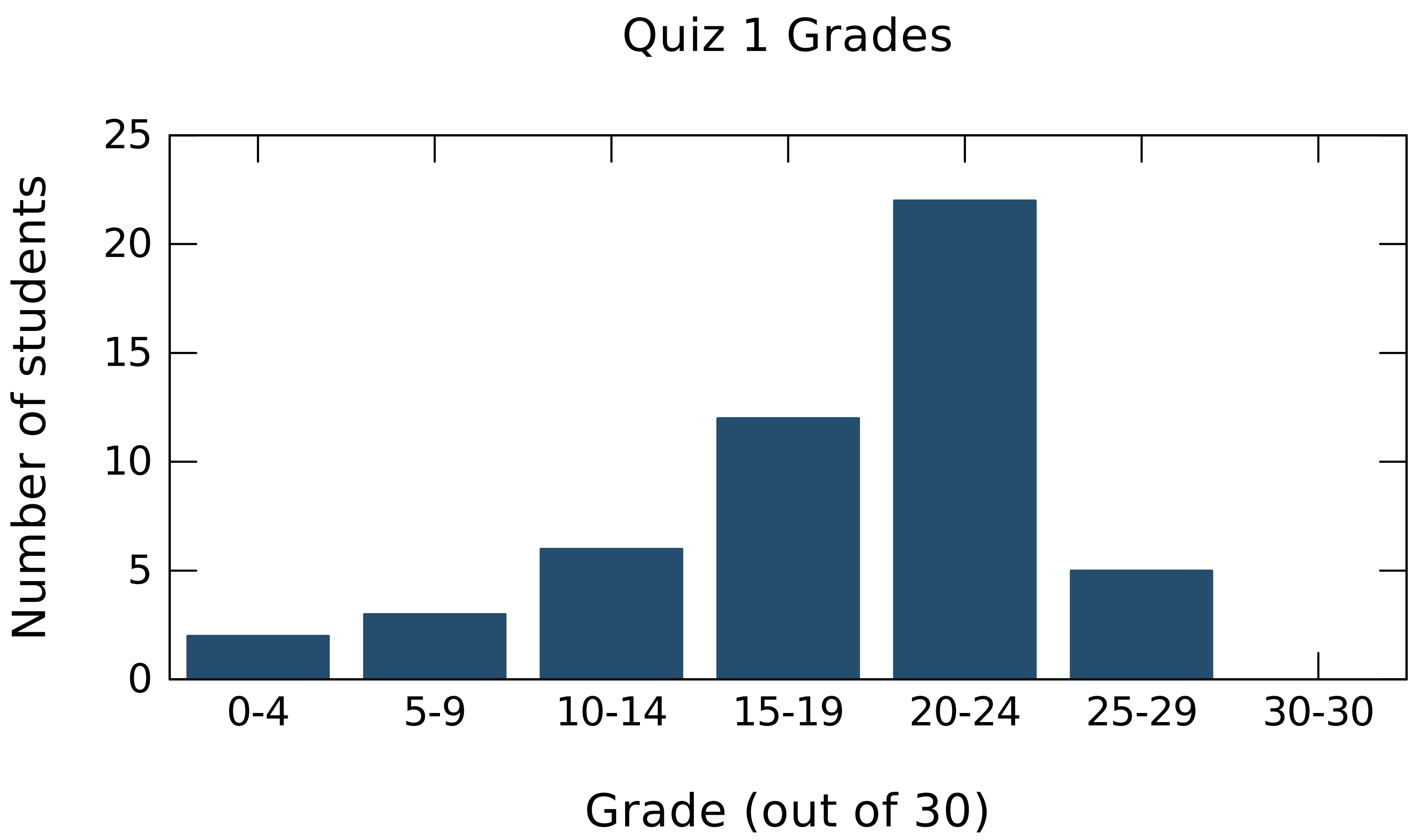
# Life Lessons

- **Life is full of important people and events**
    - **YOU,** my PhD students, colleagues, deadlines, family, friends, me …
- **Sharing life across people is like sharing networks between users**
    - Delays mostly due to just transmission and propagation;
        - My meetings, sleep (rare, but happens)
    - When #incoming-packets > link load, queueing delay is inevitable;
        - If #emails > what I can handle, queueing delay (current status)
    - Sometimes failures happen — requires retransmitting packets
- **Last week was one of those for me**
    - Queueing delay at my inbox (too many emails to handle)
    - **I am reducing the queue sizes …**
    - **Help me!**

# Announcements

- Please give your TAs more work to do
  - **I am happy to receive emails**
  - **Please cc the two TAs on emails:** Justin (jmm825@), Burcu (bc633@)
- Problem Set 2 is out (and on the webpage now)
- Quiz 2 solutions will be out soon (on Piazza)
  - Already graded! Available after class
- We will release the code for socket programming soon
- Thanks for notifying me **before** the class about absence
  - Please cc the TAs in future

# Quiz 1 distribution




| | |
|---|---|
| Mean | 17.22 |
| Median | 20 |
| Std. deviation | 6.214827562583942 |

# Goals for Today's Lecture

- **Wrap up Switched Ethernet (and link layer)**

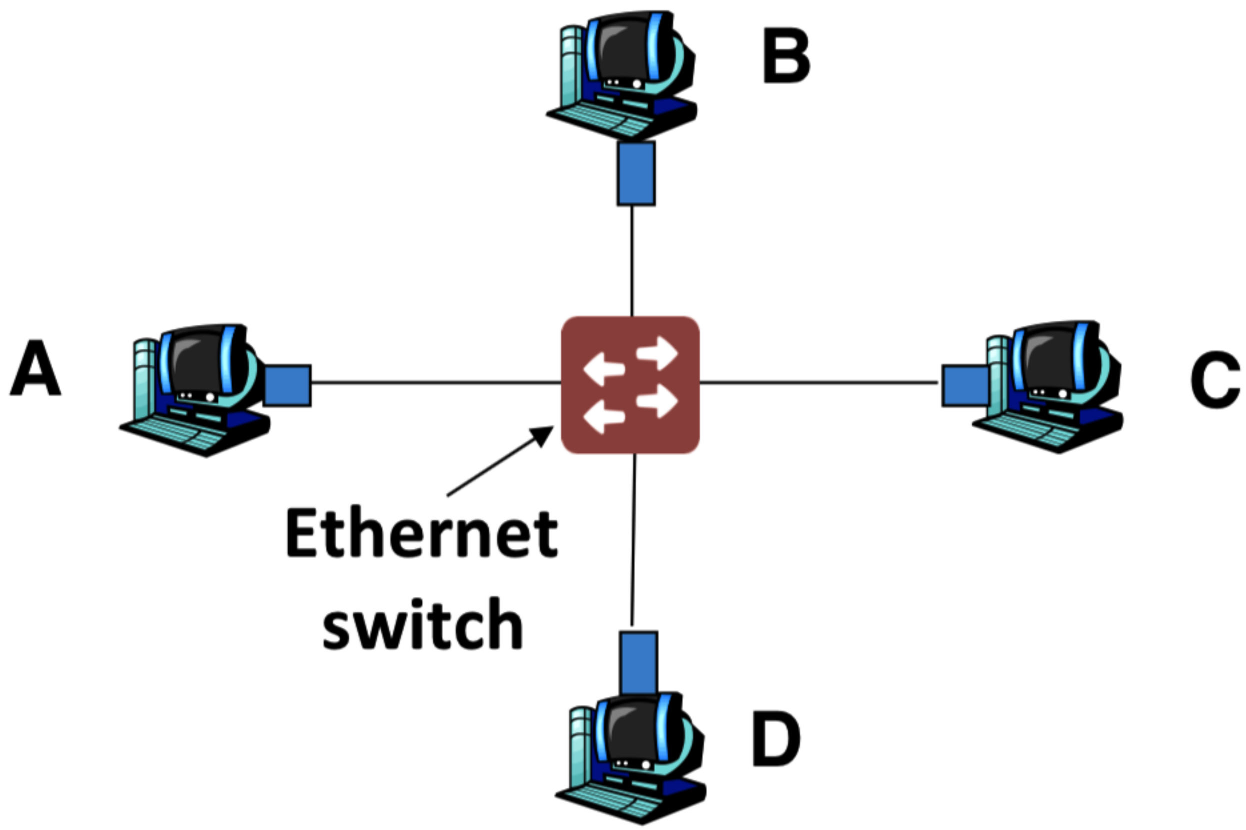
- Start on IP (the Internet Protocol)
  - Packet Header as a network "interface"

# Recap: Link Layer

- **Originally a broadcast channel**
  - MAC addresses (really, names)
  - CSMA/CD
    - Remember: **Exponential back-off** (more in problem set 2)
  - Why does Ethernet use **frames**?
  - How Link Layer builds on top of Physical Layer (that uses bits)
  - Bounds on network length and/or minimum frame size
    - Due to propagation delays

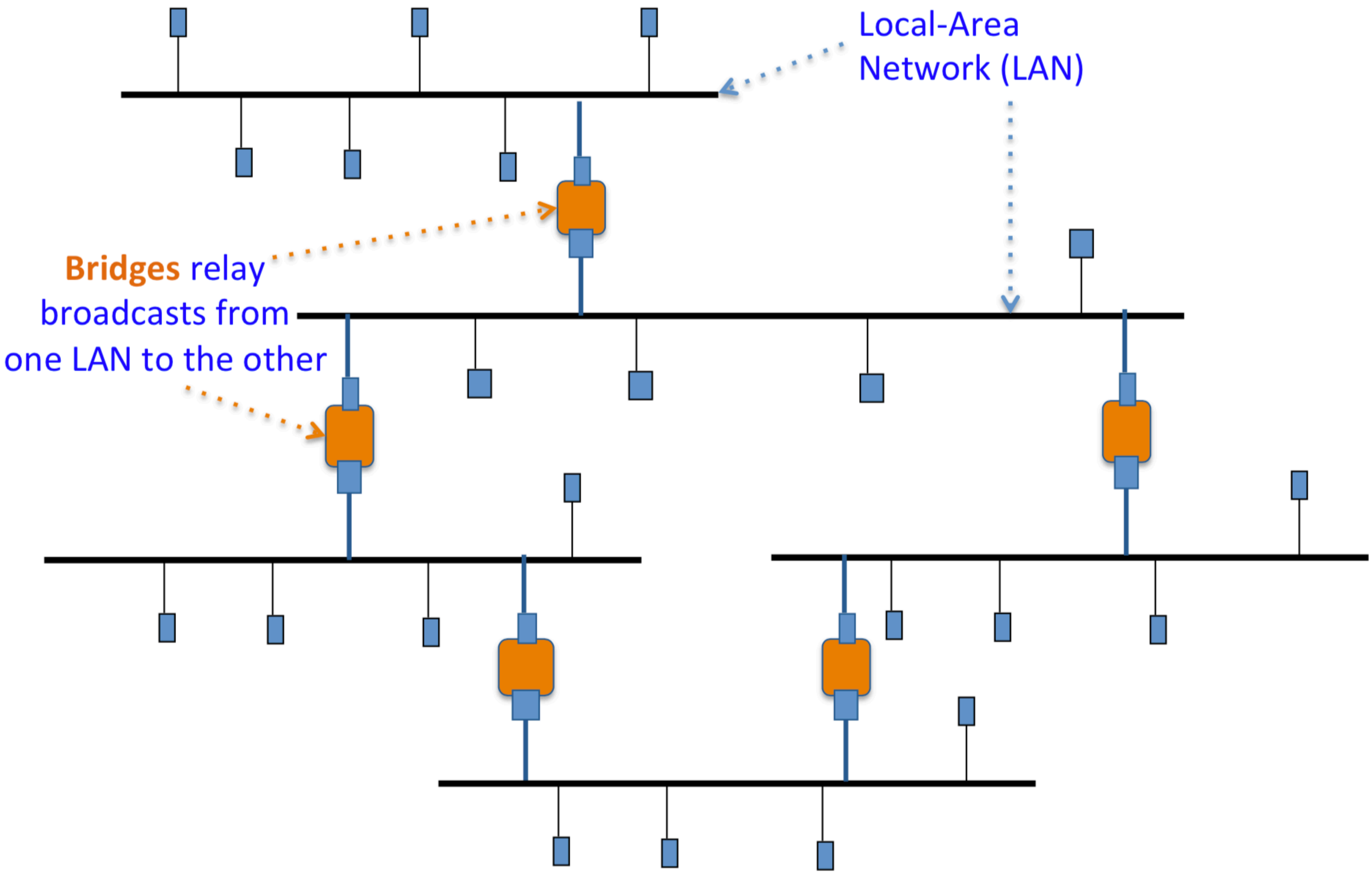
- **More recently: switched Ethernet**
  - **Broadcast storm!**

# Switched Ethernet

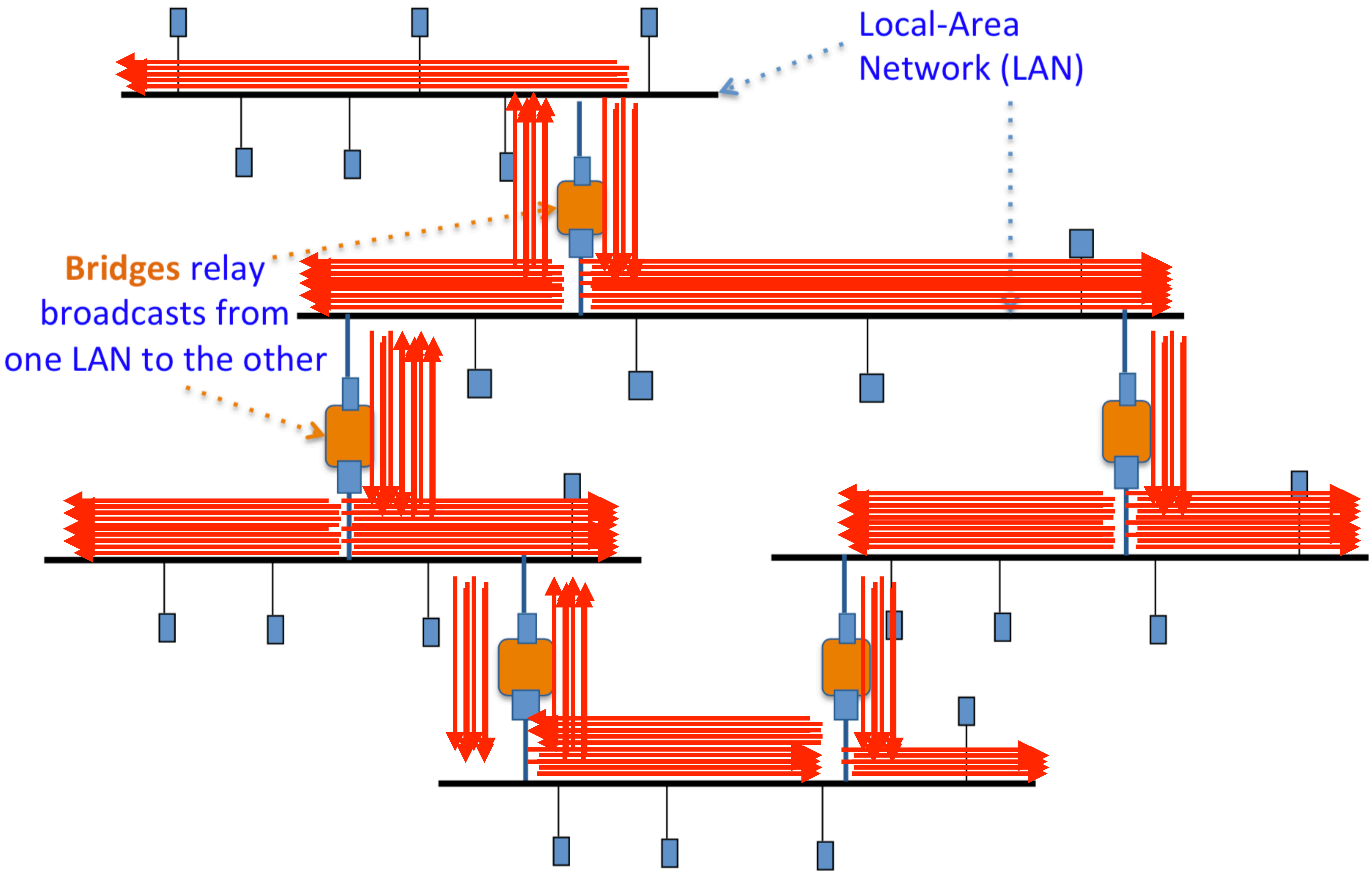



- Enables concurrent communication
  - Host A can talk to C, while B talks to D
  - No collisions -> no need for CSMA, CD
  - No constraints on link lengths or frame size

# Routing in “Extended LANs”



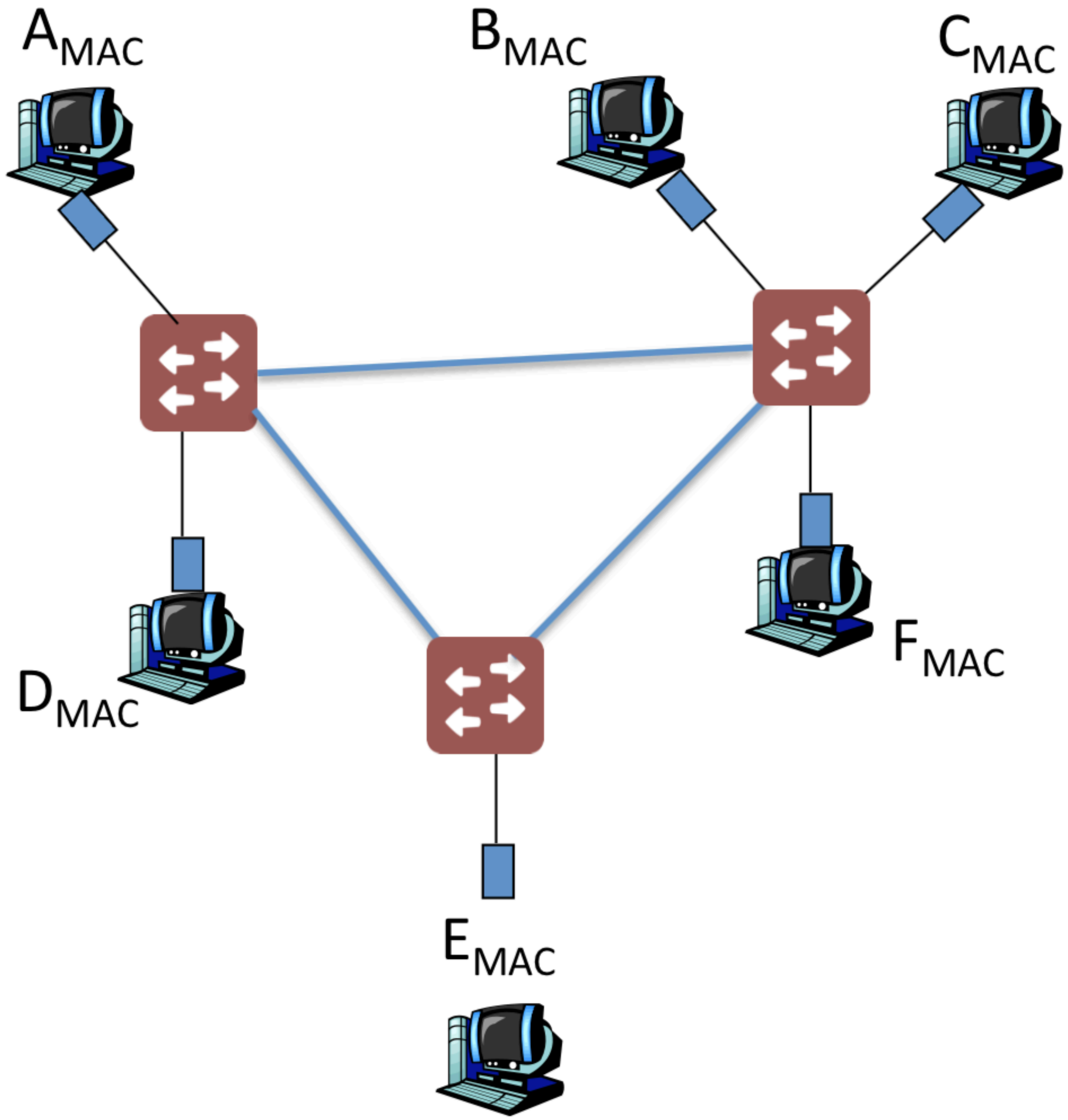
# Naïvely Routing in "Extended LANs": Broadcast storm



# How to avoid the Broadcast Storm Problem?

**Get rid of the loops!**

# Lets get back to the graph representation!



# Easiest Way to Avoid Loops

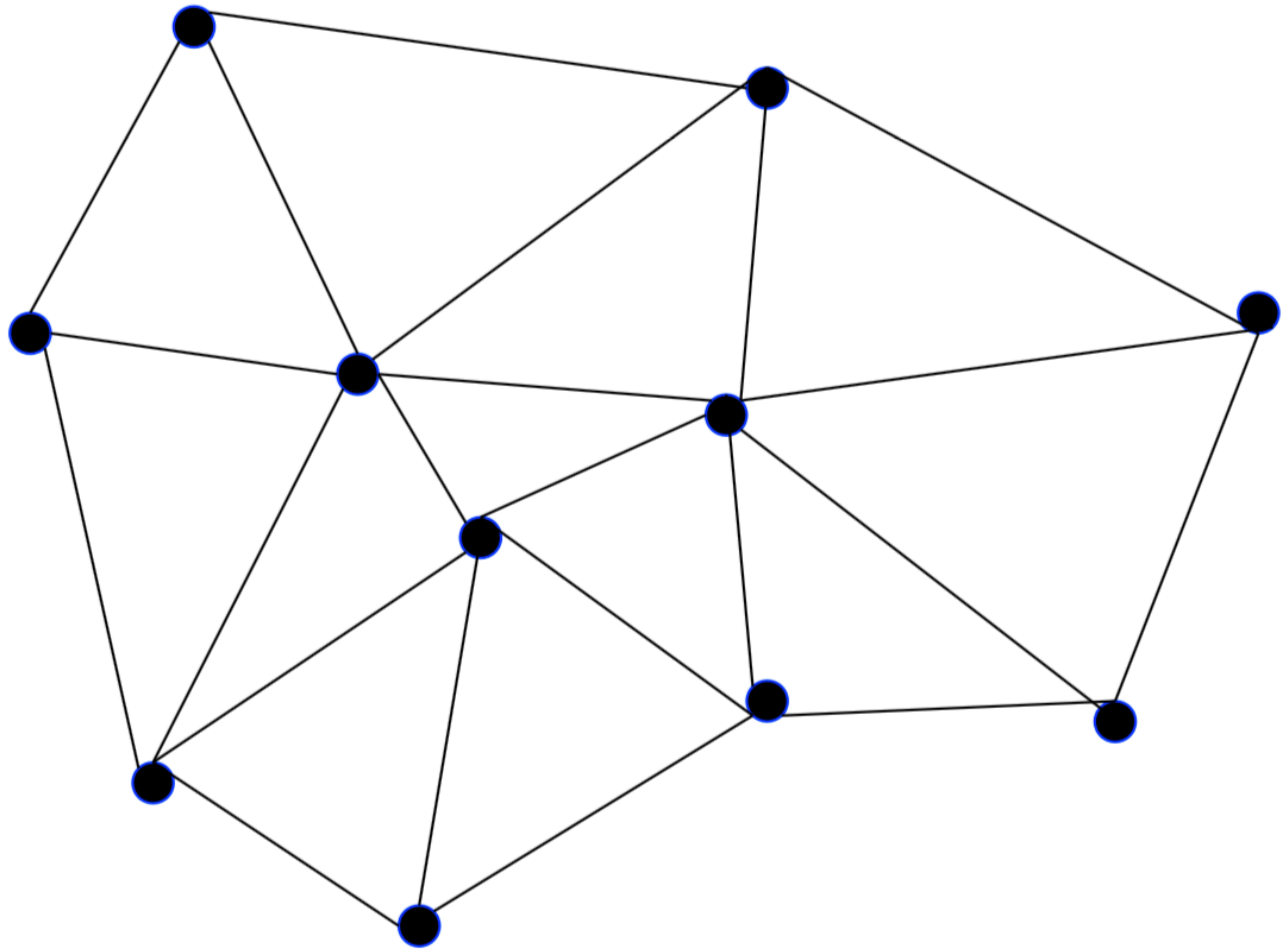
- Use a network topology (graph) where loop is impossible!

- Take arbitrary topology (graph)

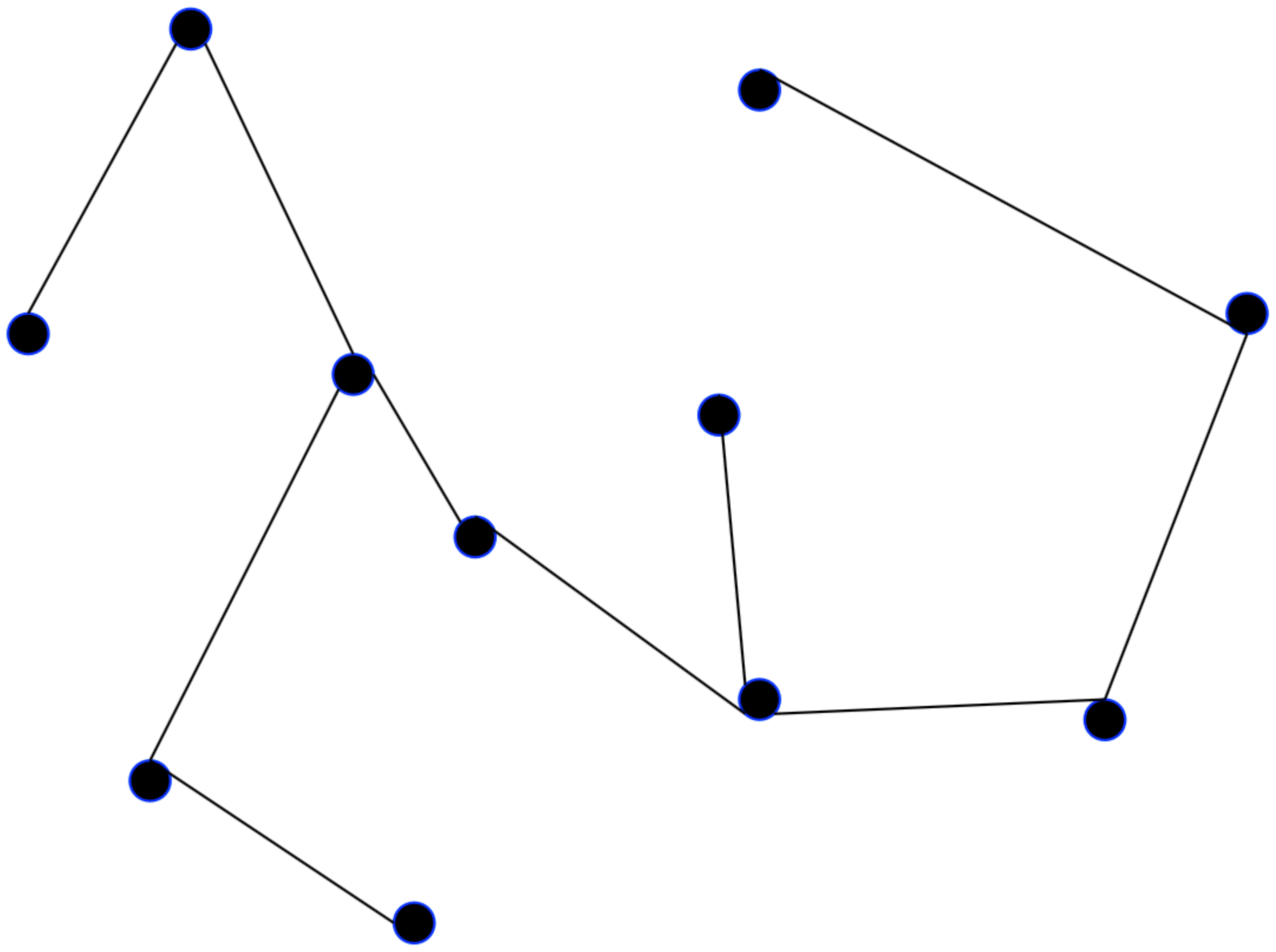
- **Build spanning tree**
  - **Subgraph that includes all vertices but contains no cycles**
  - Links not in the spanning tree are not used in forwarding frames

- Only one path to destinations on spanning trees
  - So don't have to worry about loops!

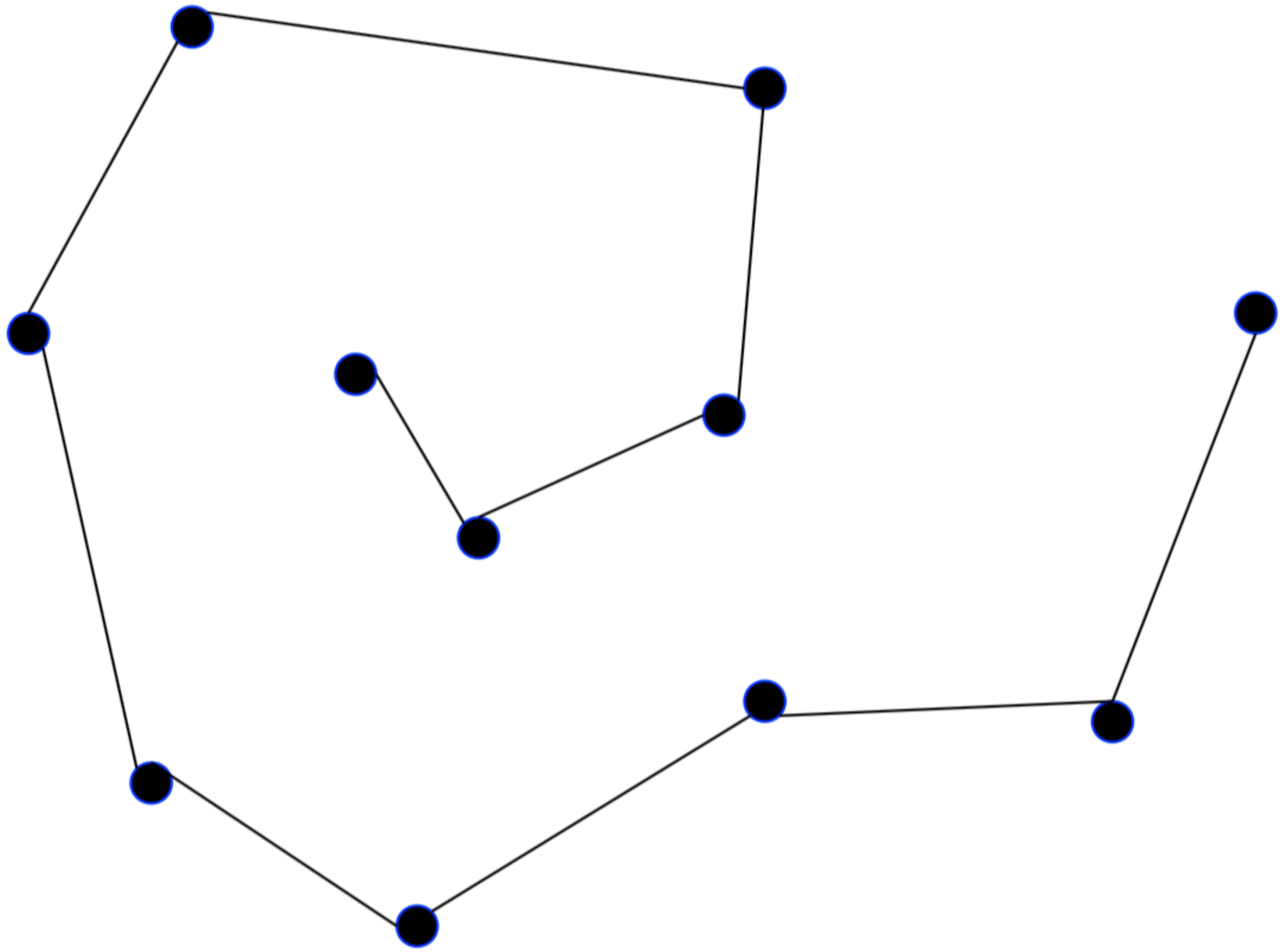
# Consider Graph



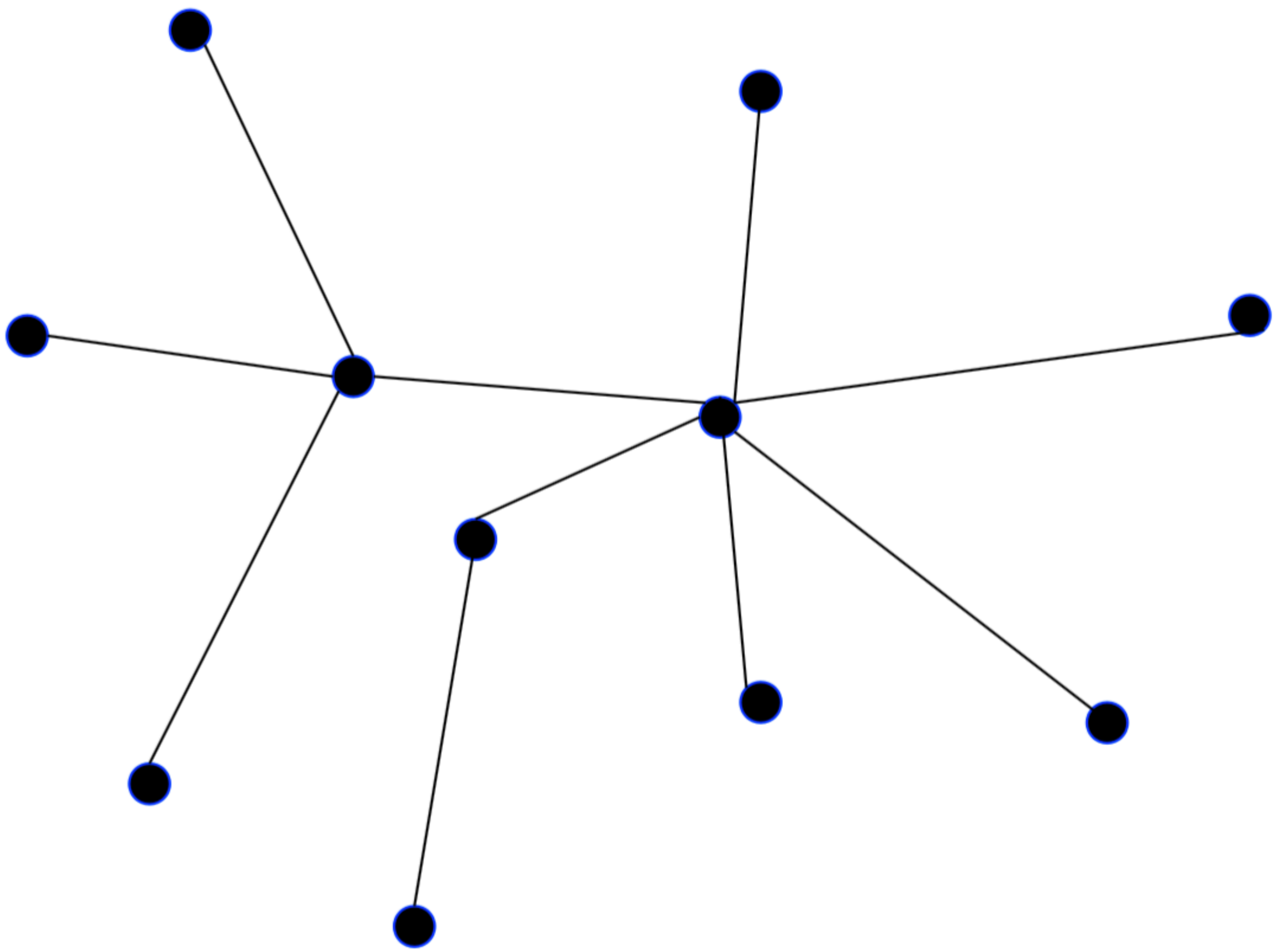
# A Spanning Tree



# Another Spanning Tree



# Yet Another Spanning Tree



# Spanning Tree Protocol

- Protocol by which bridges construct a spanning tree
- Nice properties
    - Zero configuration (by operators or users)
    - Self healing
- Still used today
- Constraints for backwards compatibility
    - No changes to end-hosts
    - Maintain plug-n-play aspect
- Earlier Ethernet achieved plug-n-play by leveraging a broadcast medium
    - Can we do the same for a switched topology?

# Algorithm has Two Aspects…

- Pick a root:
    - Destination to which the shortest paths go
    - Pick the one with the smallest identifier (MAC address)

- Compute the shortest paths to the root
    - No shortest path can have a cycle
    - Only keep the links on the shortest path
    - Break ties in some way
        - so we only keep one shortest path from each node

- Ethernet’s spanning tree construction does both with a single algorithm

# Breaking Ties

- When there are multiple shortest paths to the root,
  - Choose the path that uses the neighbor switch with the lower ID

- **One could use any tie breaking system**
  - This is just an easy one to remember and implement

# Constructing a Spanning Tree

- Messages (Y,d,X)
    - From node X
    - Proposing Y as the root
    - And advertising a distance d to Y

- Switches elect the node with smallest identifier (MAC address) as root
    - Y in messages

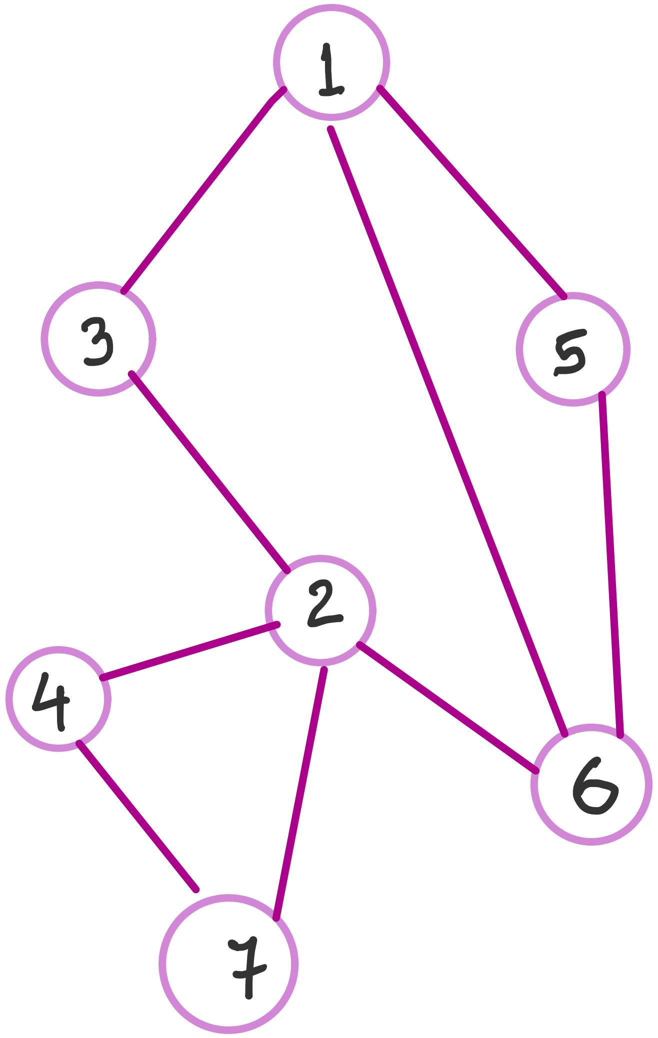
- Each switch determines if a link is on its shortest path to the root
    - If not, excludes it from the tree
    - d to Y in the message is used to determine this

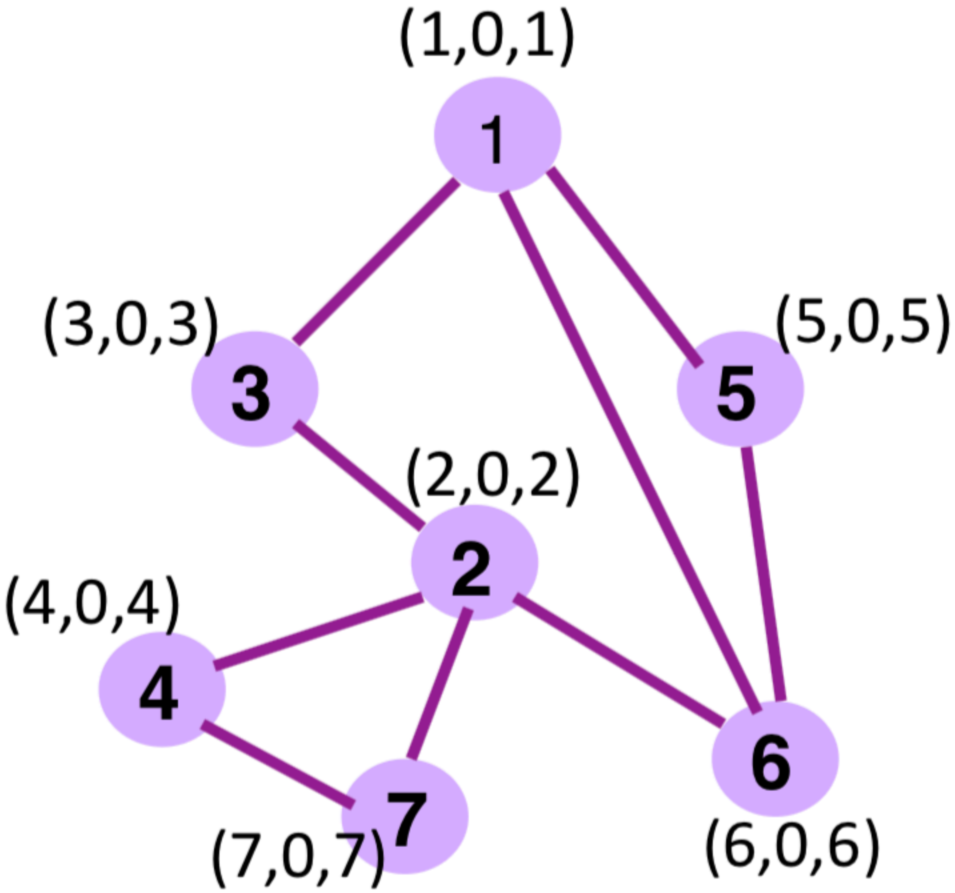
# Steps in Spanning Tree Protocol

- Messages (Y,d,X)
  - For root Y; From node X; advertising a distance d to Y
- Initially each switch proposes itself as the root
  - that is, switch X announces (X,0,X) to its neighbors
- Switches update their view
  - Upon receiving message (Y,d,Y) from Z, check Y's id
  - If Y's id < current root: set root = Y
- Switches compute their distance from the root
  - Add 1 to the shortest distance received from a neighbor
- If root or shortest distance to it changed, send neighbors updated message (Y,d+1,X)

# Group Exercise:

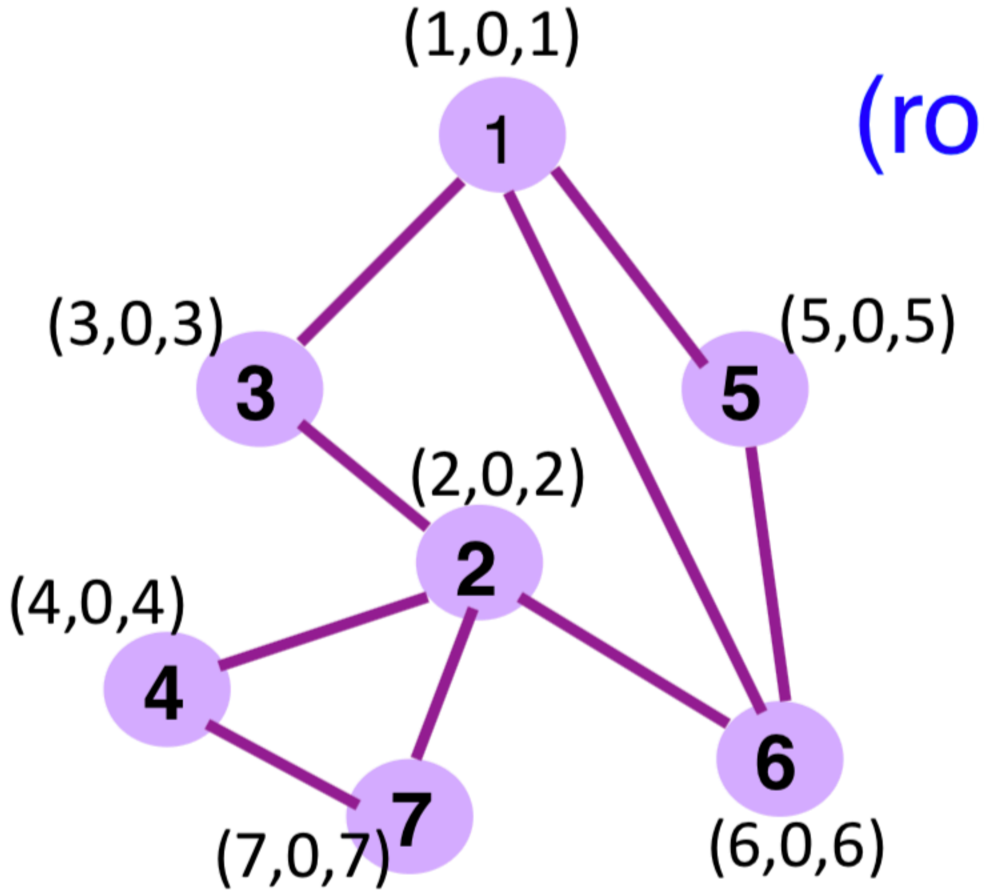
# Run the Spanning Tree Protocol on this example

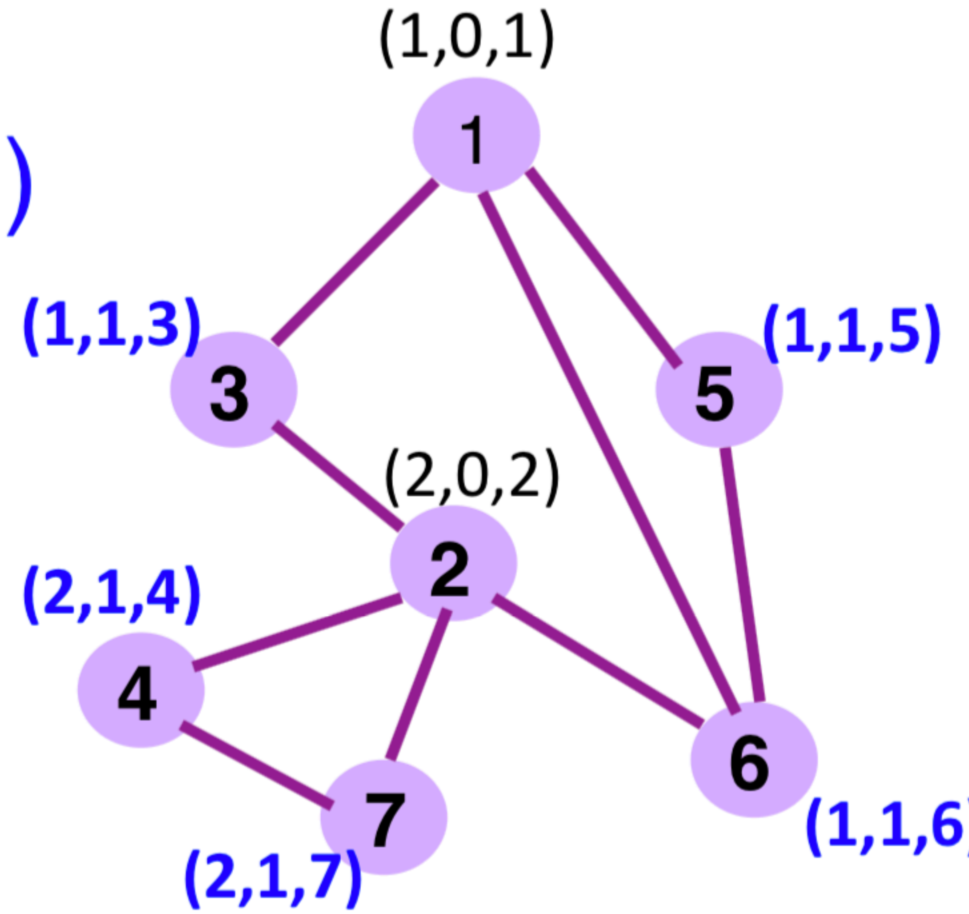



(1,0,1)
1
(3,0,3)
3
5
(5,0,5)
(2,0,2)
2
(4,0,4)
4
7
(7,0,7)
6
(6,0,6)

# Example

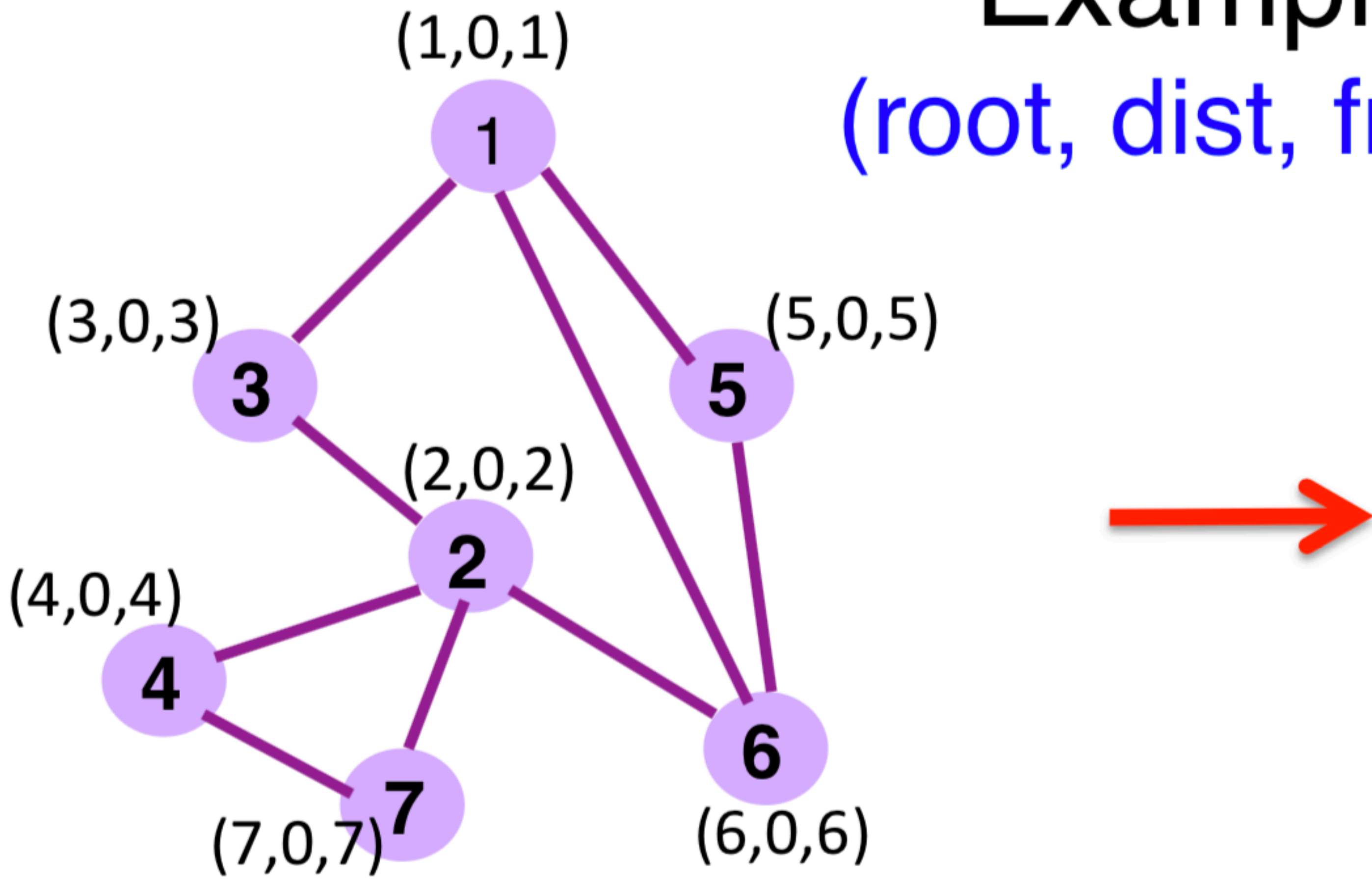
(root, dist, from)

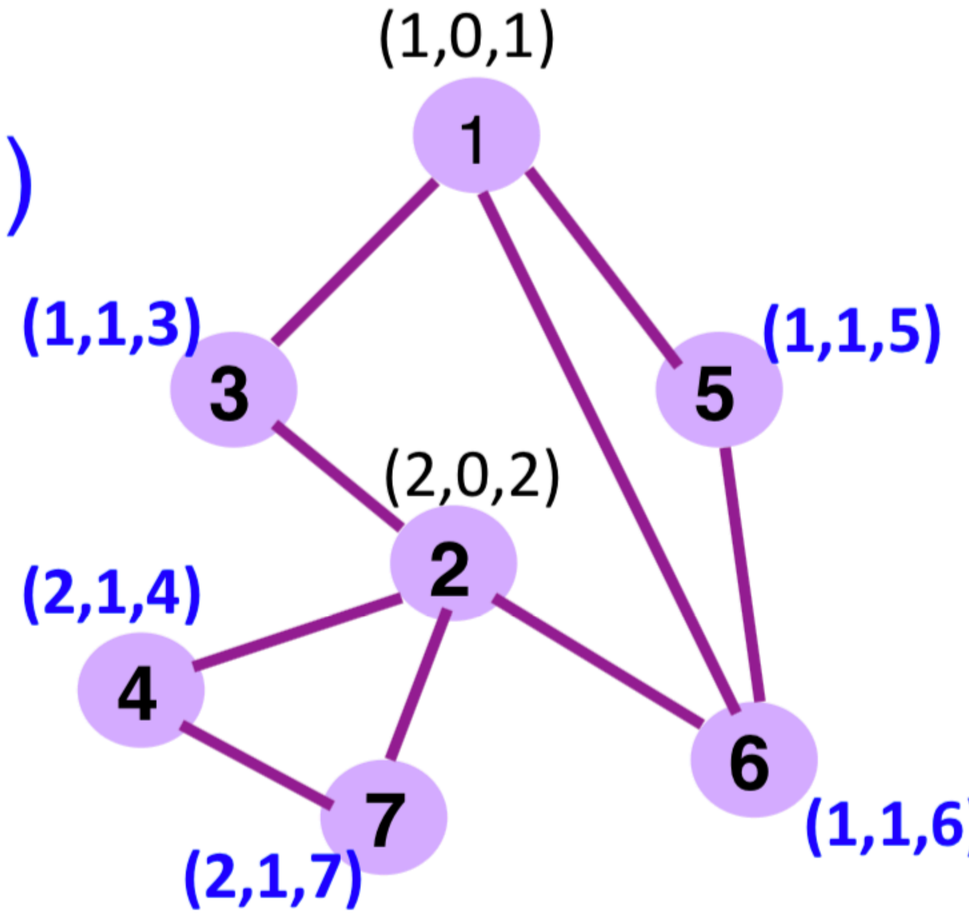


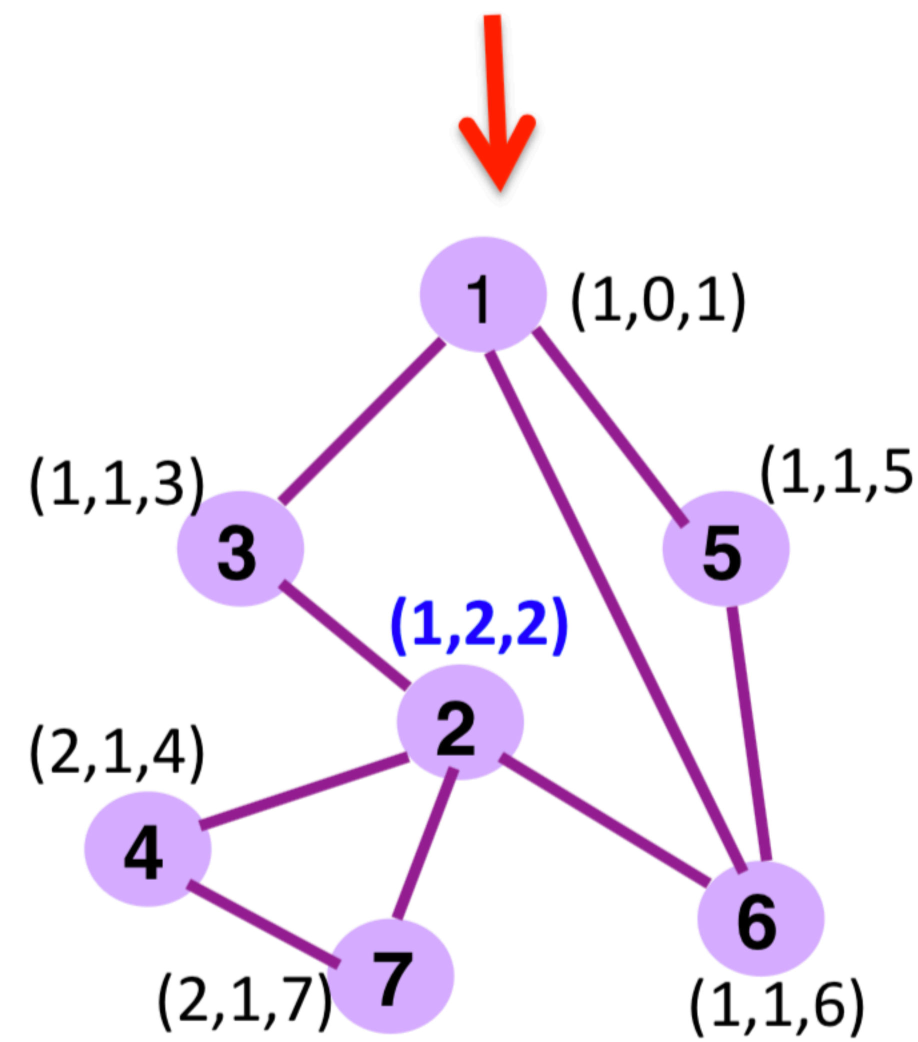



# Example

(root, dist, from)

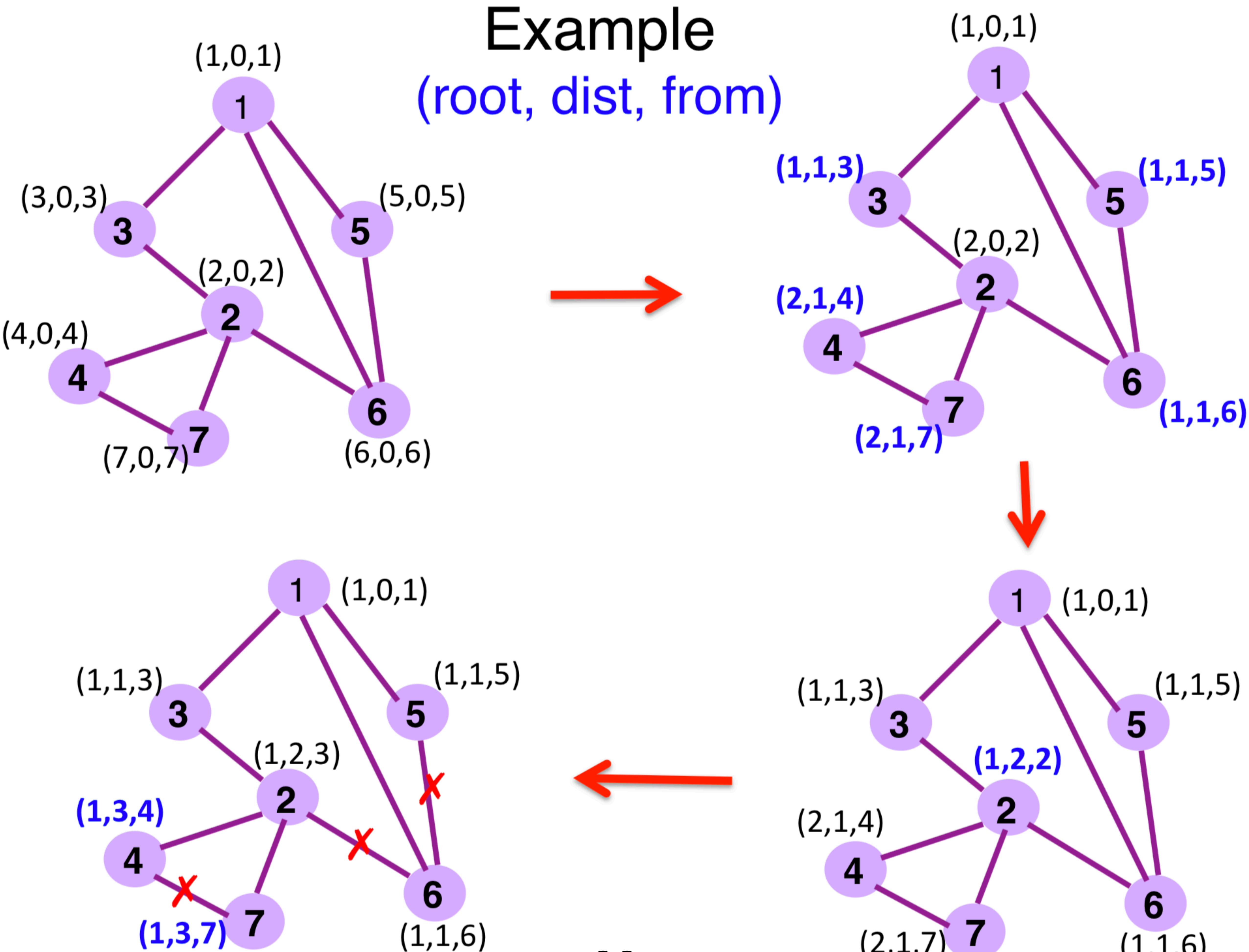


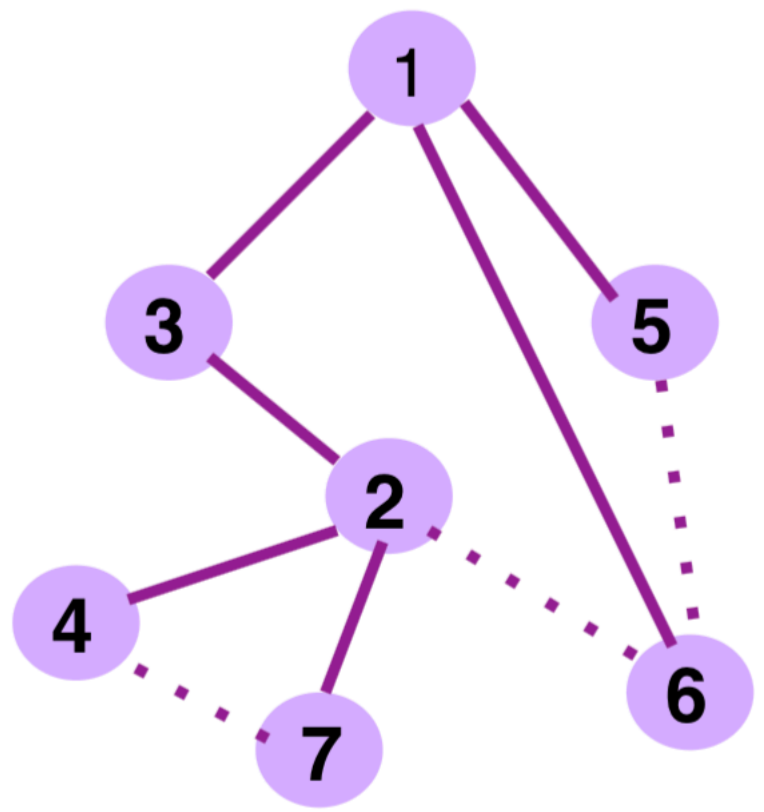
# Example

(root, dist, from)



# Links on Spanning Tree

- 3-1
- 5-1
- 6-1
- 2-3
- 4-2
- 7-2



# Robust Spanning Tree Algorithm

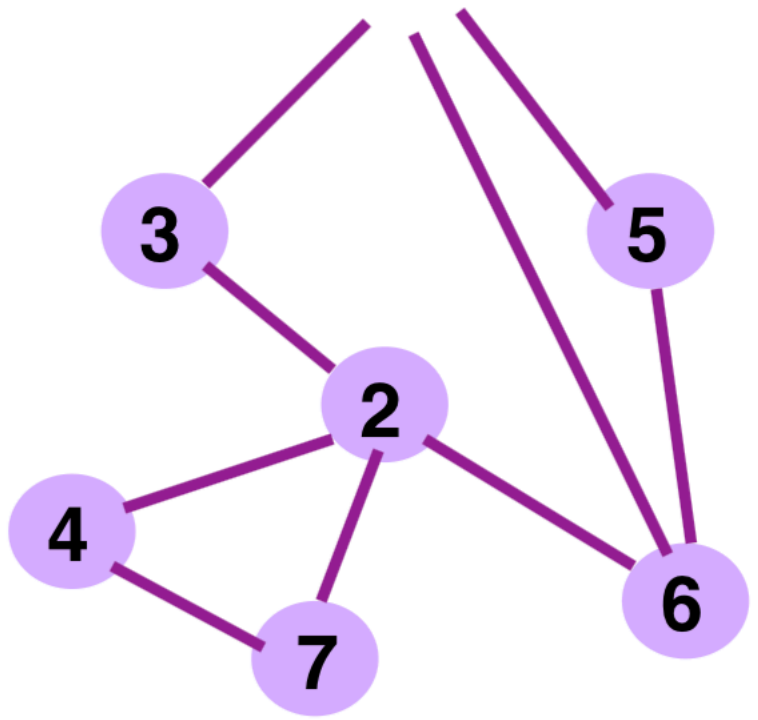
- Algorithm must react to failures
    - Failure of the root node
    - Failure of switches and links

- Root node sends periodic announcement messages
    - Other switches continue forwarding messages

- Detecting failures through timeout (soft state)
    - If no word from root, time out and claim to be the root!

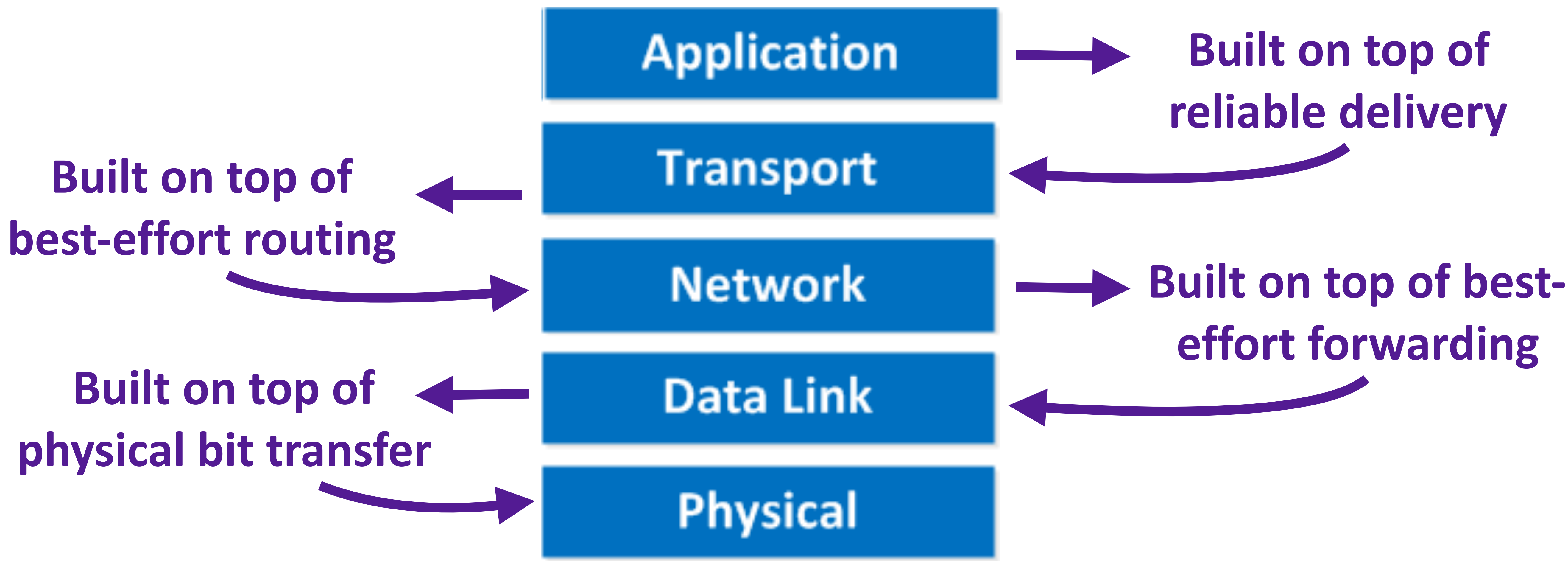
# Self-resilient upon link/node failures (suppose node 1 fails)

- 2 is new root
- 3-2
- 6-2
- 4-2
- 7-2
- 5-6



## The end of Link Layer ….

## And the beginning of network layer :-D



# Network Layer

- THE functionality: **delivering the data**

- **THE protocol: Internet Protocol (IP)**
    - To achieve its functionality (delivering the data), IP protocol has **three** responsibilities

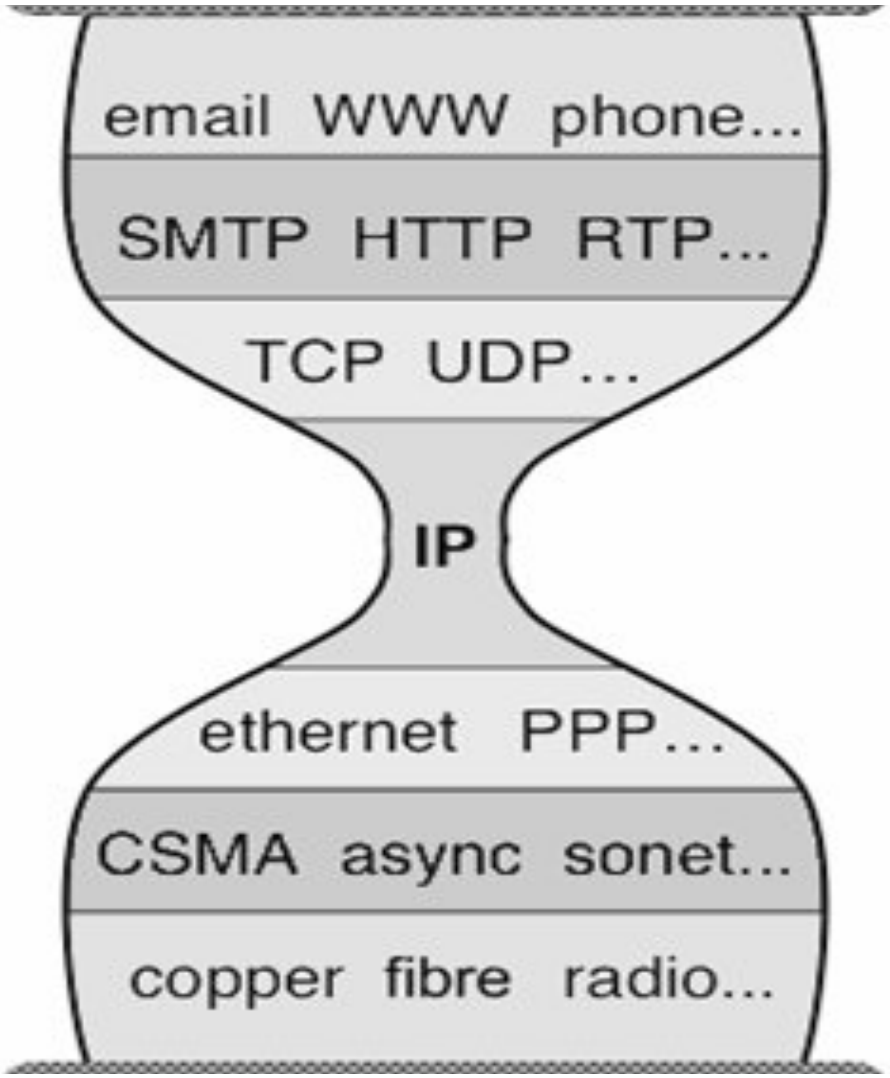
- **Addressing (next lecture)**
- **Encapsulating data into packets (actually datagrams; next lecture)**
- **Routing (using a variety of protocols; several lectures)**

# Internet Protocol

- THE functionality: **delivering the data**

- **THE protocol: Internet Protocol (IP)**
  - To achieve its functionality (delivering the data), IP protocol has **three** responsibilities

- Unifying protocol

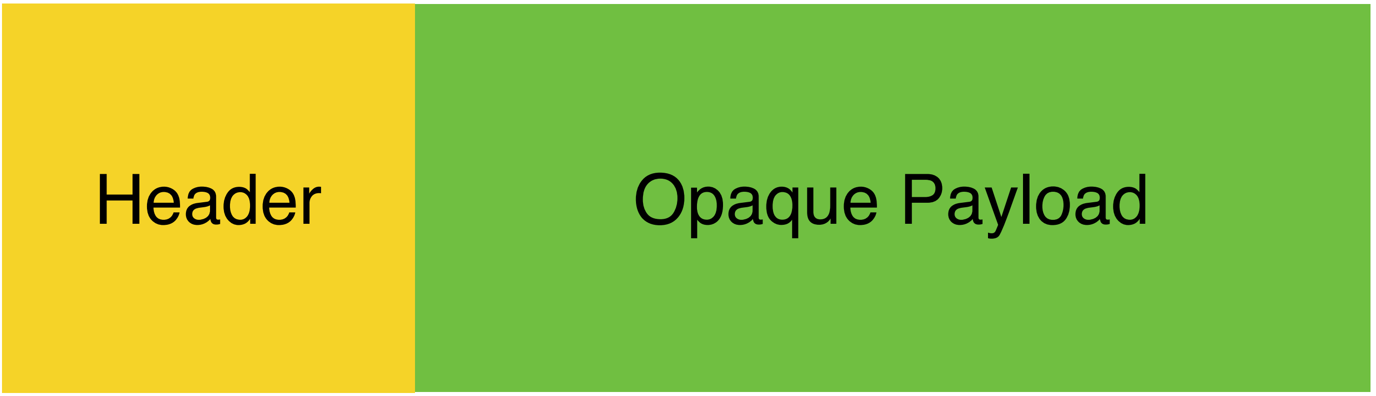


# What is “designing” a protocol?

- Specifying the syntax of its messages
    - Format
- Specifying their semantics
    - Meaning
    - Responses

# What is Designing IP?

- Syntax: format of packet
  - Nontrivial part: packet “header”
  - Rest is opaque payload (**why opaque?**)




- Semantics: meaning of header fields
  - Required processing

# Packet Header as Interface

- Think of packet header as interface
  - Only way of passing information from packet to switch
- Designing interfaces:
  - What task are you trying to perform?
  - What information do you need to accomplish it?
- Header reflects information needed for basic tasks

# What Tasks Do We Need to Do?

- Read packet correctly
- Get the packet to the destination
- Get responses to the packet back to source
- Carry data
- Tell host what to do with packet once arrived
- Specify any special network handling of the packet
- Deal with problems that arise along the path

# Reading Packet Correctly

- Where does the header end?
- Where the the packet end?
- What version of IP?
    - Why is this so important?

# Getting to the Destination

- Provide destination address
- Should this be location or identifier (name)?
    - And what's the difference?
- If a host moves should its address change?
    - If not, how can you build scalable Internet?
    - If so, then what good is an address for identification?

# Getting Response Back to Source

- Source address
- Necessary for routers to respond to source
  - When would they need to respond back?
    - Failures!
  - Do they really need to respond back?
    - How would the source know if the packet has reached the destination?

# Carry Data

- Payload!

Questions?

# List of Tasks

- Read packet correctly
- Get the packet to the destination
- Get responses to the packet back to source
- Carry data
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# Telling Destination How to Process Packet

- Indicate which protocols should handle packet
- What layers should this protocol be in?
- What are some options for this today?
- How does the source know what to enter here?

# Special Handling

- Type of service, priority, etc.
- Options: discuss later

# Dealing With Problems

- Is packet caught in loop?
    - TTL
- Header corrupted:
    - Detect with Checksum
    - What about payload checksum?
- Packet too large?
    - Deal with fragmentation
    - Split packet apart
    - Keep track of how to put together

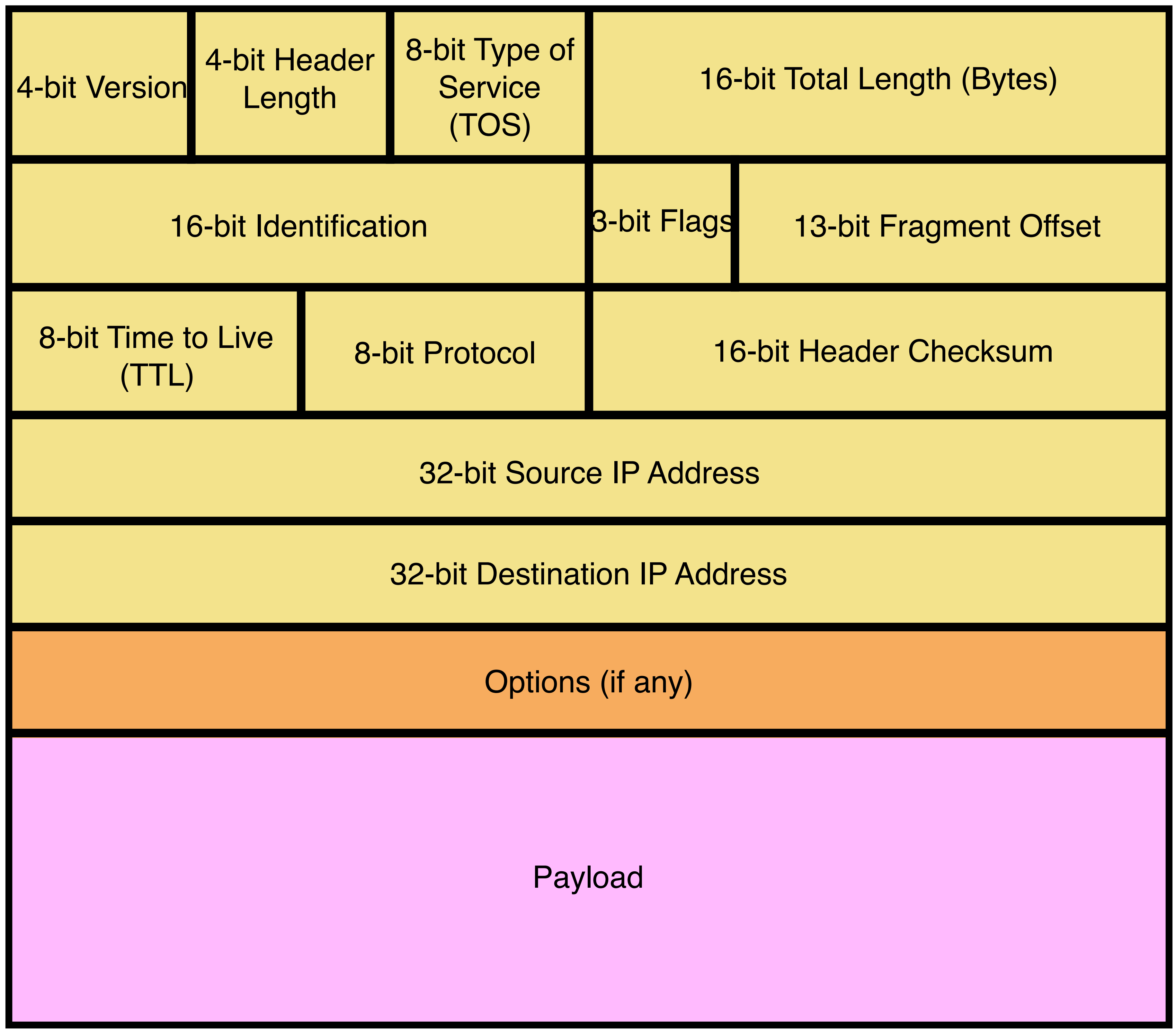
# Are We Missing Anything?

- Read packet correctly
- Get the packet to the destination
- Get responses to the packet back to source
- Carry data
- Tell host what to do with packet once arrived
- Specify any special network handling of the packet
- Deal with problems that arise along the path

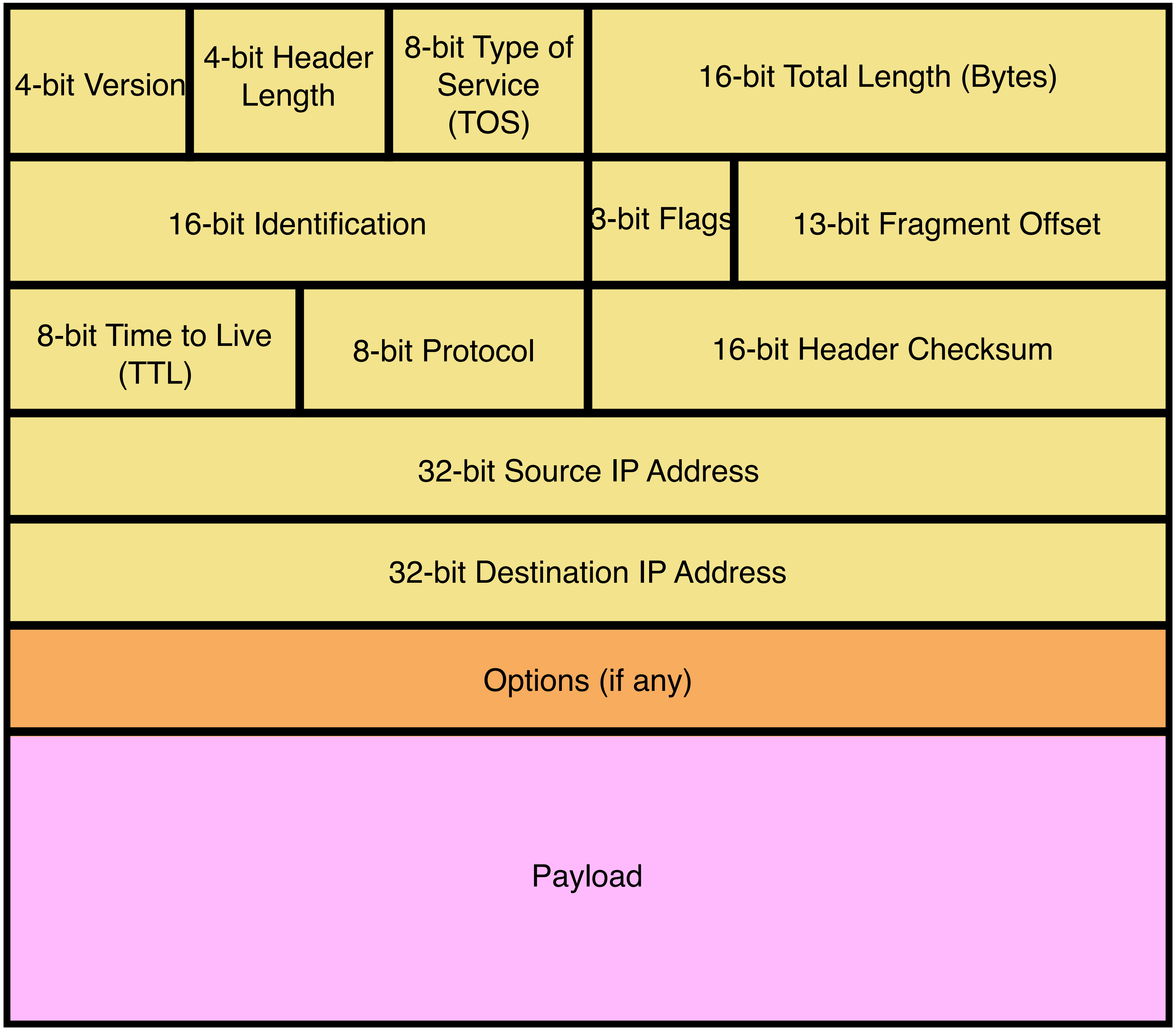
# From Semantics to Syntax

- The past few slides discussed the kinds of information the header must provide
- Will now show the syntax (layout) of IPv4 header, and discuss the semantics in more detail

# IP Packet Structure



# 20 Bytes of Standard Header, then Options



# Next Set of Slides

- Mapping between tasks and header fields
- Each of these fields is devoted to a task
- Let’s find out which ones and why…

# Go Through Tasks One-by-One

- Read packet correctly
- Get the packet to the destination
- Get responses to the packet back to source
- Carry data
- Tell host what to do with packet once arrived
- Specify any special network handling of the packet
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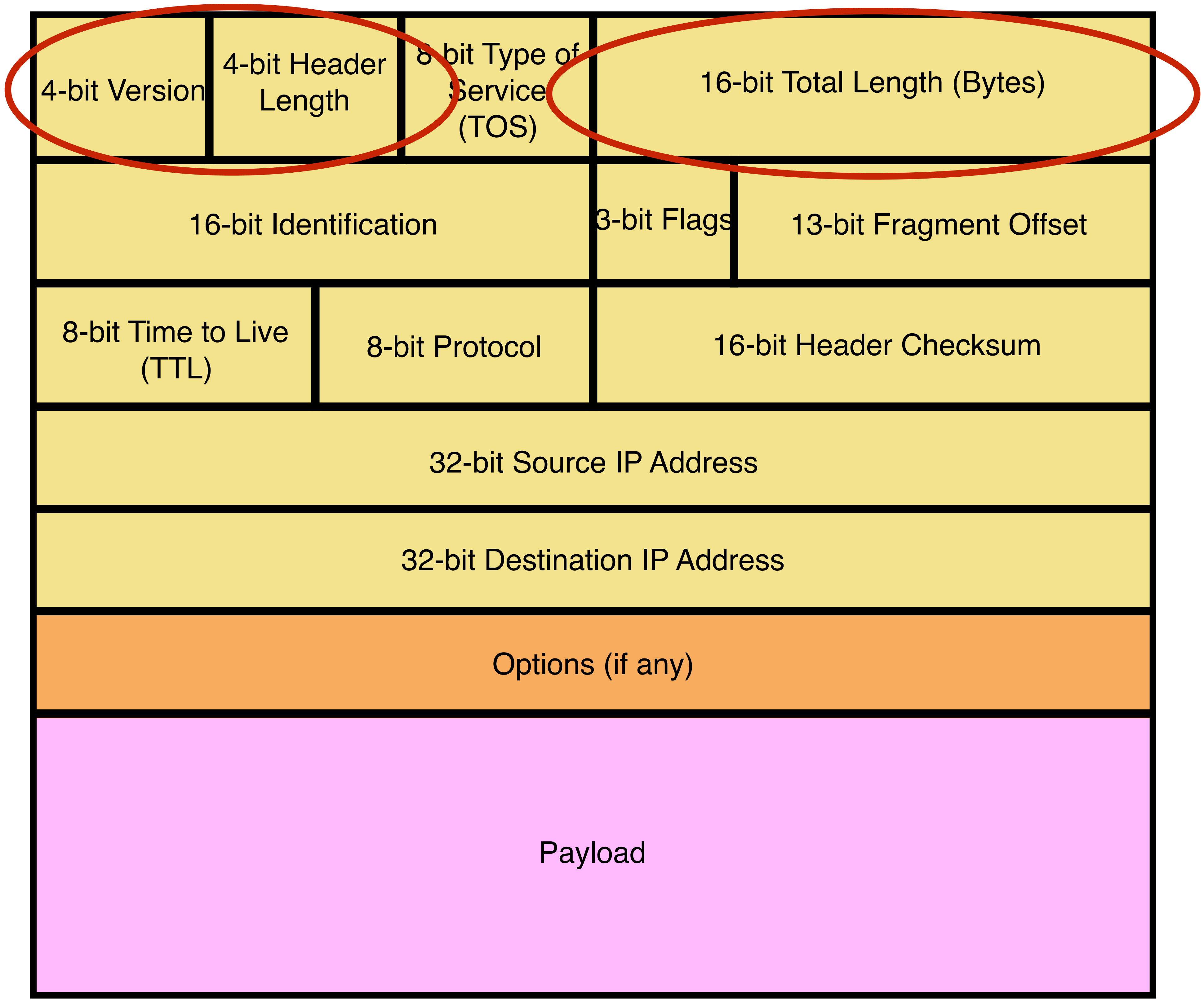
# Read Packet Correctly

- **Version number** (4 bits)
  - Indicates the version of the IP protocol
  - Necessary to know what other fields to expect
  - Typically "4" (for IPv4), and sometimes "6" (for IPv6)
- **Header length** (4 bits)
  - Number of 32-bit words in the header
  - Typically "5" (for a 20-byte IPv4 header)
  - Can be more when IP options are used
- **Total length** (16 bits)
  - Number of bytes in the packet
  - Maximum size is 65,535 bytes (2^16 -1)
  - … though underlying links may impose smaller limits

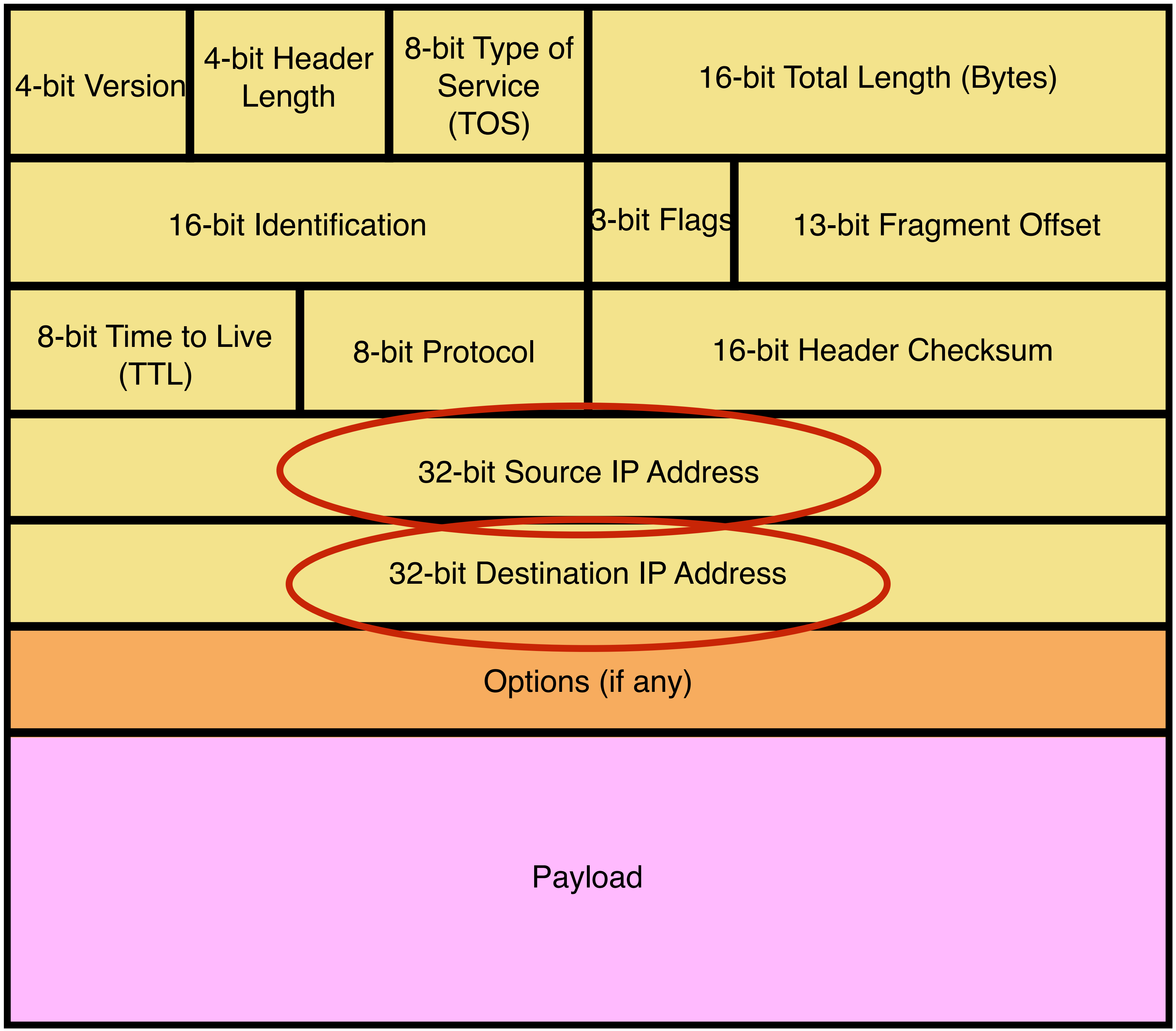
# Fields for Reading Packet Correctly



# Getting Packet to Destination and Back

- **Two IP addresses**
  - Source IP address (32 bits)
  - Destination IP address (32 bits)
- **Destination Address**
  - Unique locator for the receiving host
  - Allows each node to make forwarding decisions
- **Source Address**
  - Unique locator for the sending host
  - Recipient can decide whether to accept packet
  - Enables recipient to send a reply back to the source

# Fields for Reading Packet Correctly



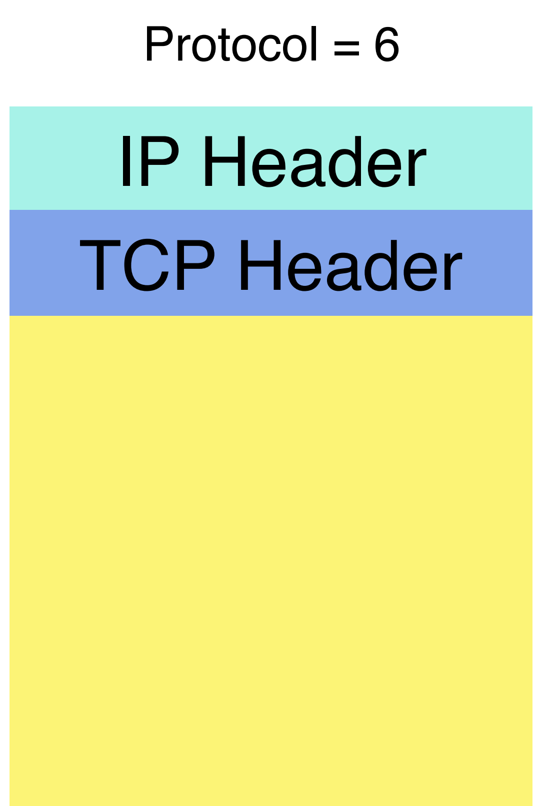
Questions?

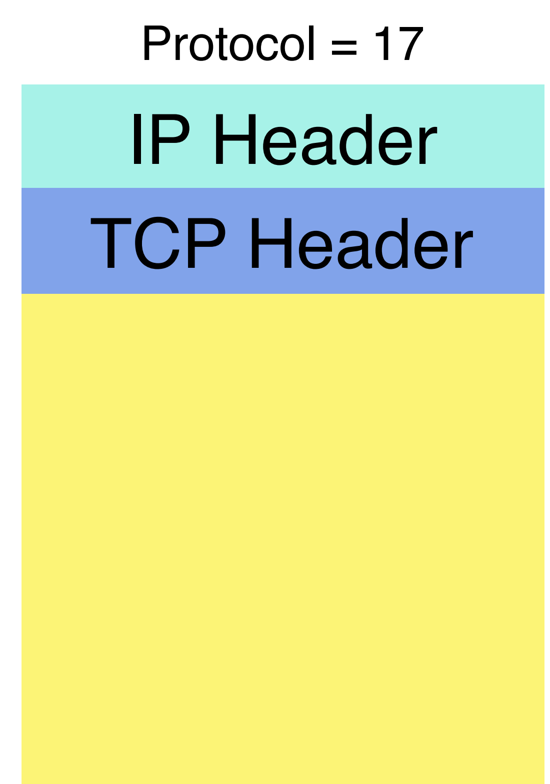
# List of Tasks

- Read packet correctly
- Get the packet to the destination
- Get responses to the packet back to source
- Carry data
- **Tell host what to do with packet once arrived**
- Specify any special network handling of the packet
- Deal with problems that arise along the path

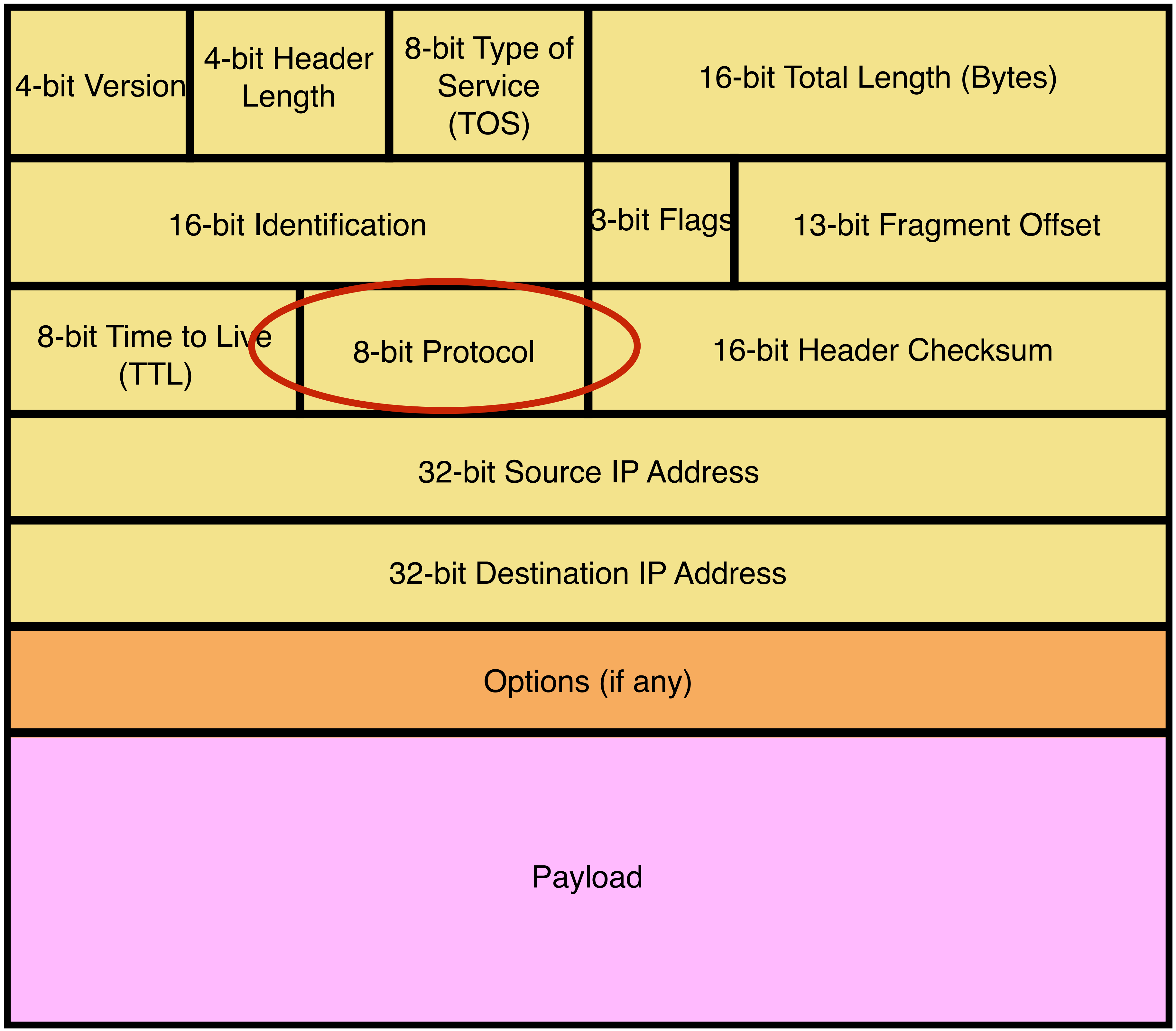
# Telling Host How to Handle Packet

- **Protocol (8 bits)**
  - Identifies the higher level protocol
  - Important for demultiplexing at receiving host
- **Most common examples**
  - E.g., “6” for the Transmission Control Protocol (TCP)
  - E.g., “17” for the User Datagram Protocol



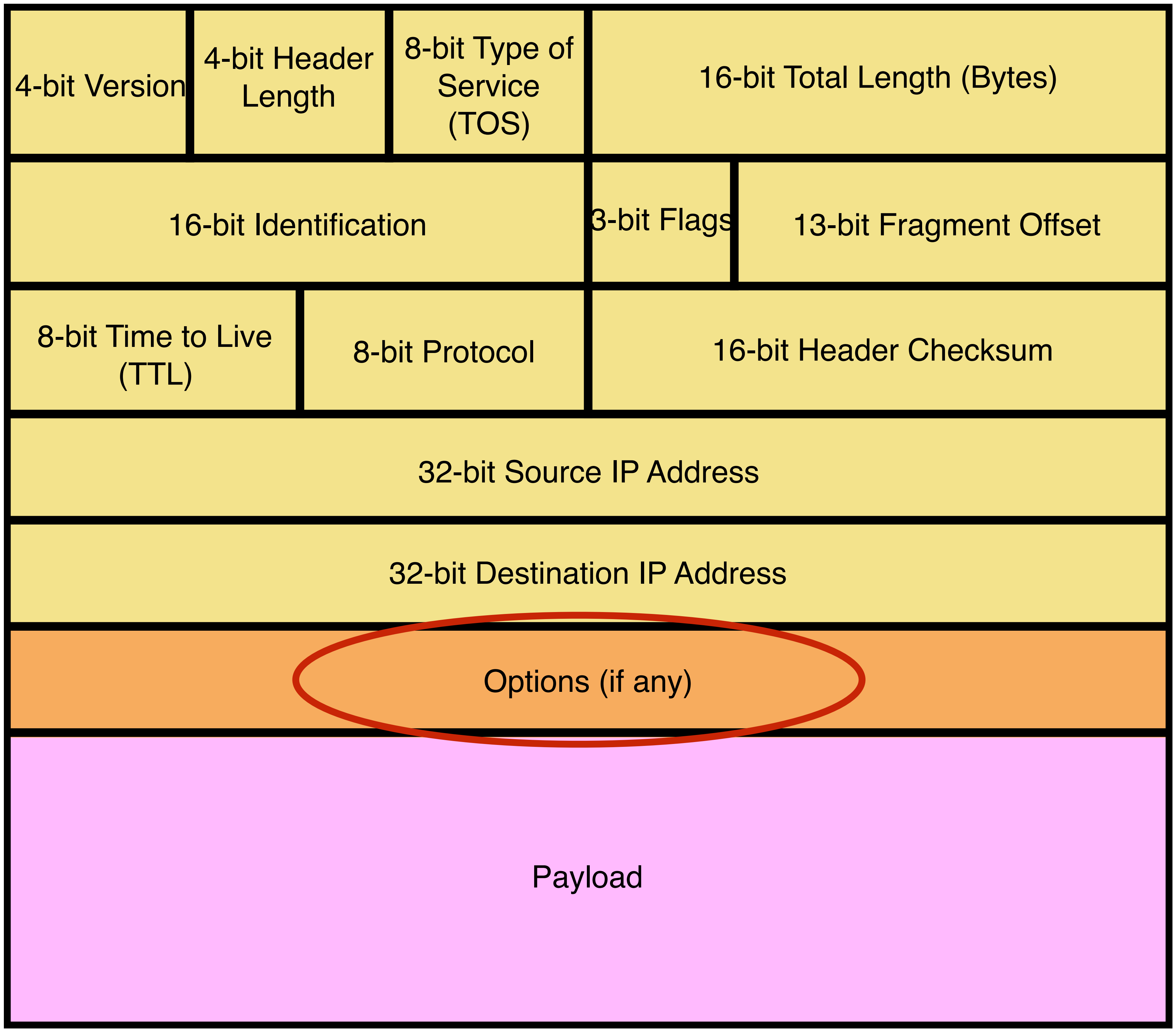
# Fields for Reading Packet Correctly



# Special Handling

- **Type-of-Service (8-bits)**
    - Allow packets to be treated differently based on needs
    - E.g., low delay for audio, high bandwidth for bulk transfer
    - Has been redefined several times, no general use
- **Options**
    - Ability to specify other functionality
    - Extensible format (later)

# Fields for Reading Packet Correctly



# Option Field Layout

| Field | Size (bits) | Description |
|---|---|---|
| Copied | 1 | Set if field copied to all fragments |
| Class | 2 | 0 = control, 2 = debugging/ measurement |
| Number | 5 | Specified option |
| Length | 8 | Size of entire option |
| Data | Variable | Option-specific data |

# Examples of Options

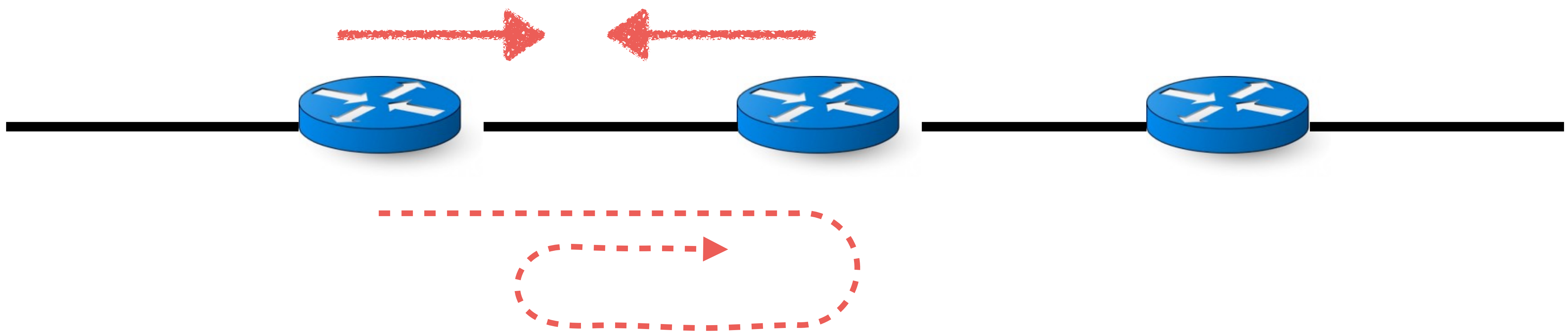
- Record Route
- Strict Source Route
- Loose Source Route
- Timestamp
- Traceroute
- Router Alert
- …

# Potential Problems

- Header Corrupted: **Checksum**
- Loop: **TTL**
- Packet too large: **Fragmentation**

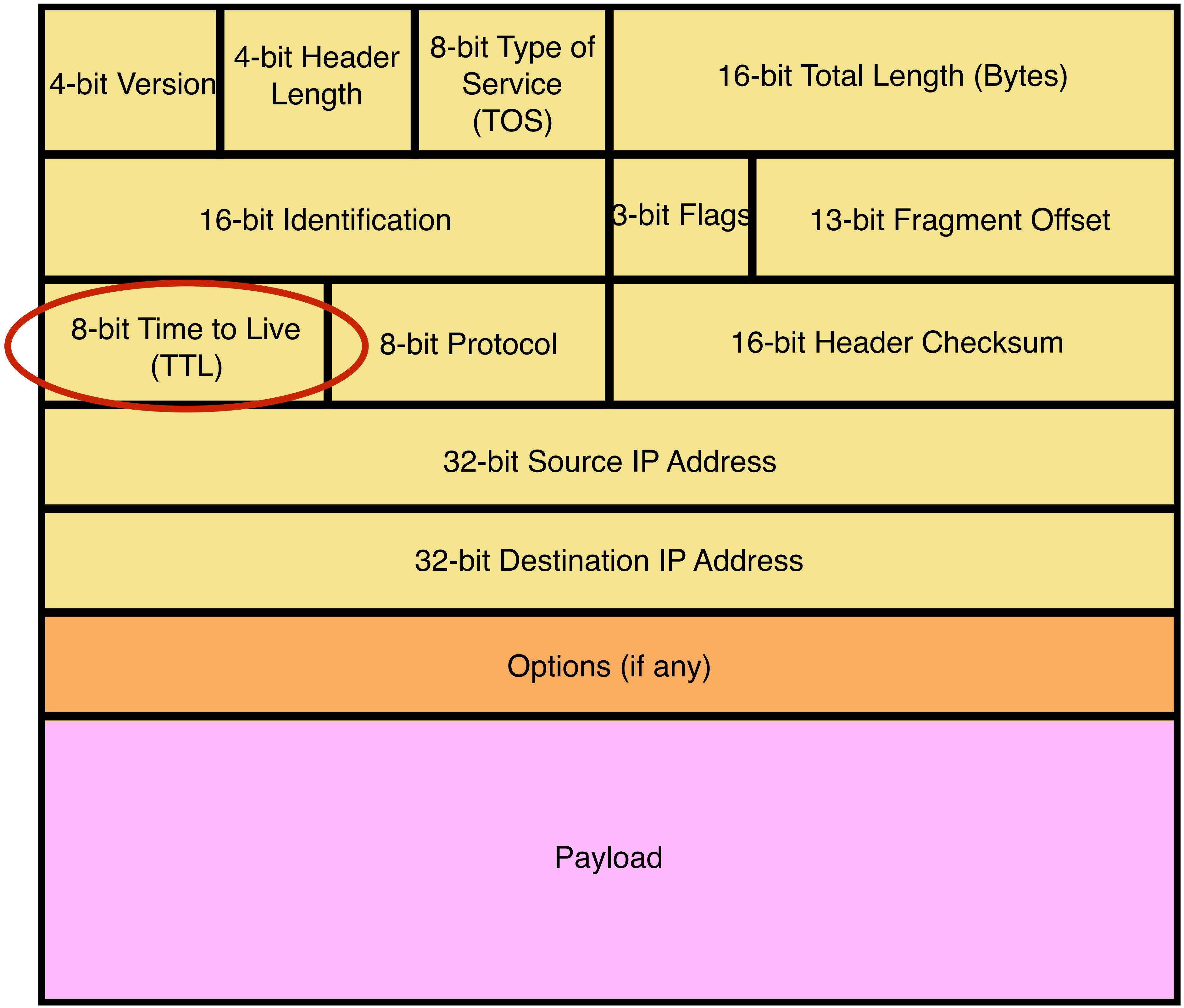
# Preventing Loops

- Forwarding loops cause packets to cycle forever
    - As these accumulate, eventually consume all capacity



- Time-to-live (TTL) Field (8-bits)
    - Decremented at each hop, packet discarded if reaches 0
    - … and “time exceeded” message is sent to the source
        - Using “ICMP” control message; basis for traceroute

# TTL Field


4-bit Version
4-bit Header Length
8-bit Type of Service (TOS)
16-bit Total Length (Bytes)
16-bit Identification
3-bit Flags
13-bit Fragment Offset
8-bit Time to Live (TTL)
8-bit Protocol
16-bit Header Checksum
32-bit Source IP Address
32-bit Destination IP Address
Options (if any)
Payload

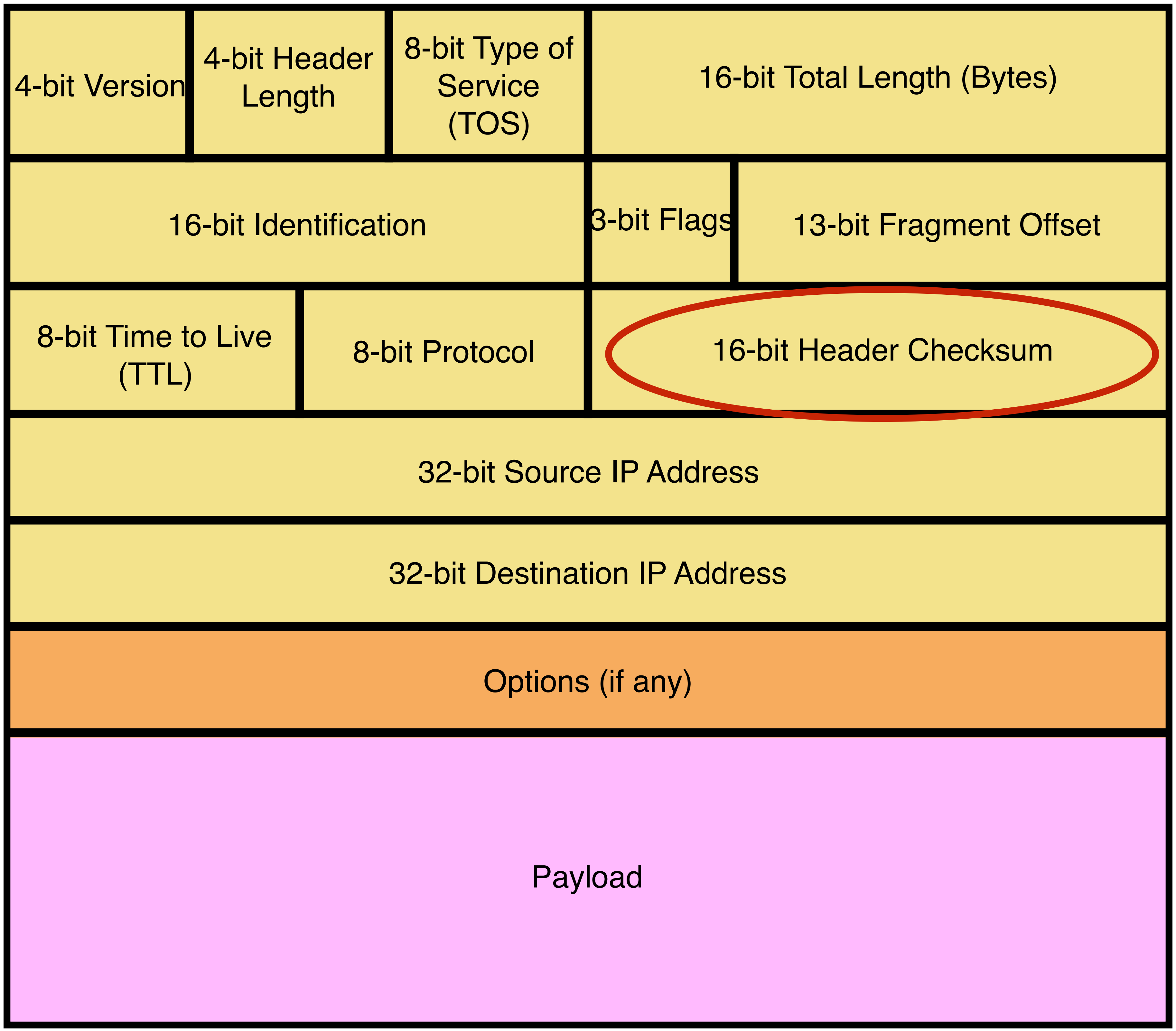
# Header Corruption

- Checksum (16 bits)
    - Particular form of checksum over packet header

- If not correct, router discards packets
    - So it doesn’t act in bogus information

- Checksum recalculated at every router
    - Why?
    - Why include TTL?
    - Why only header?

# Checksum Field



**Thats it for today**