Network Layer Overview

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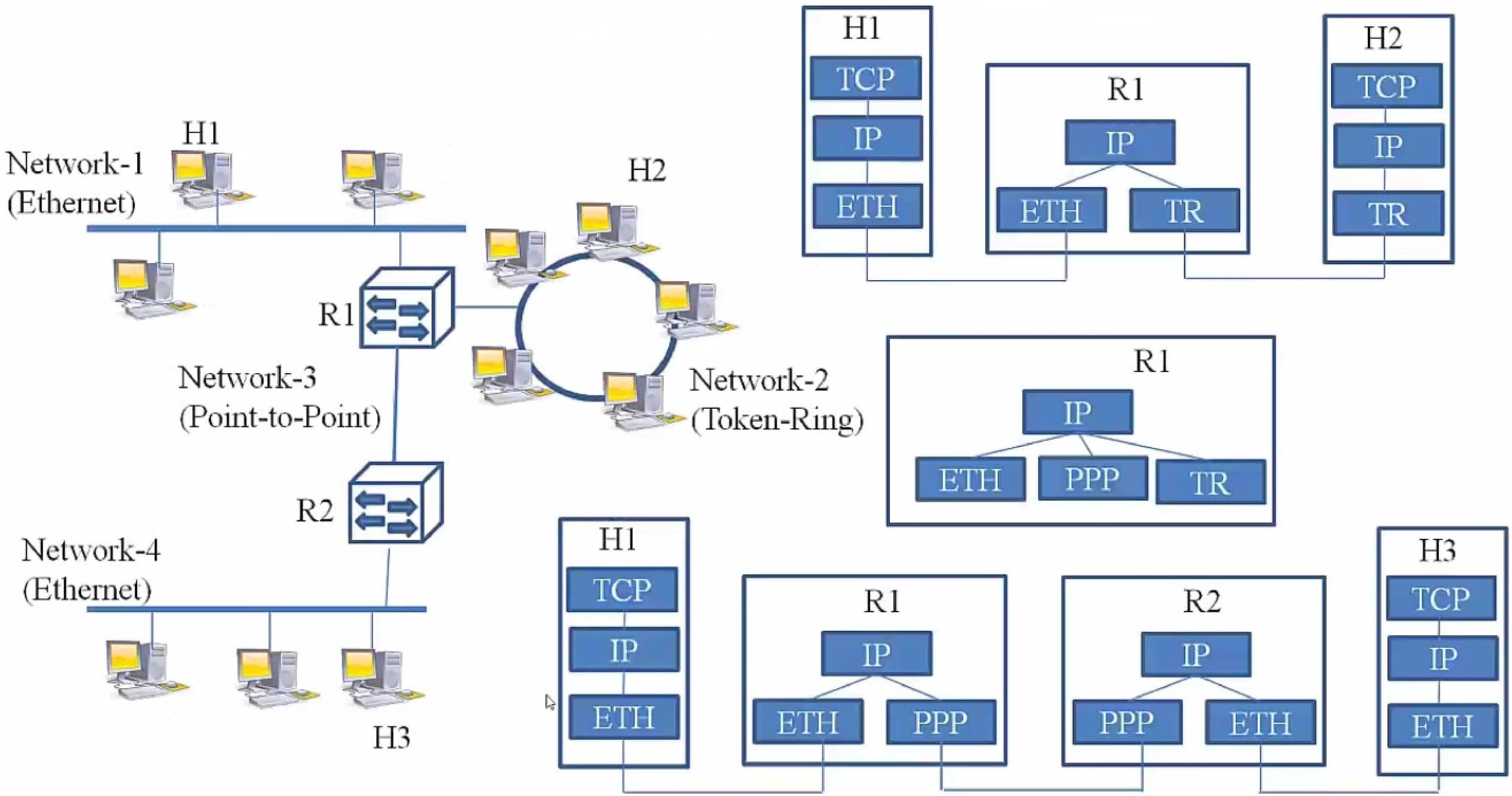
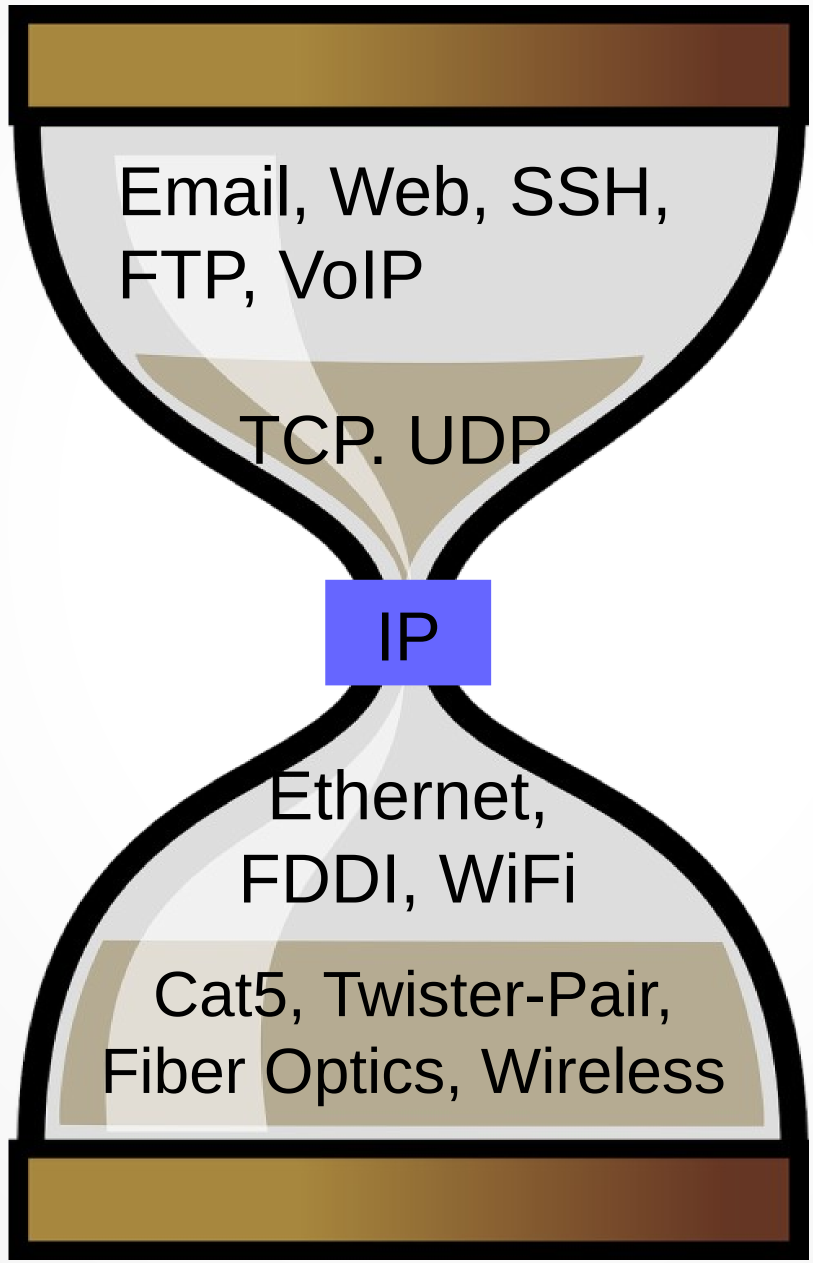
Heterogeneous Communication



Internet Architecture: Hour Glass



Network Layer

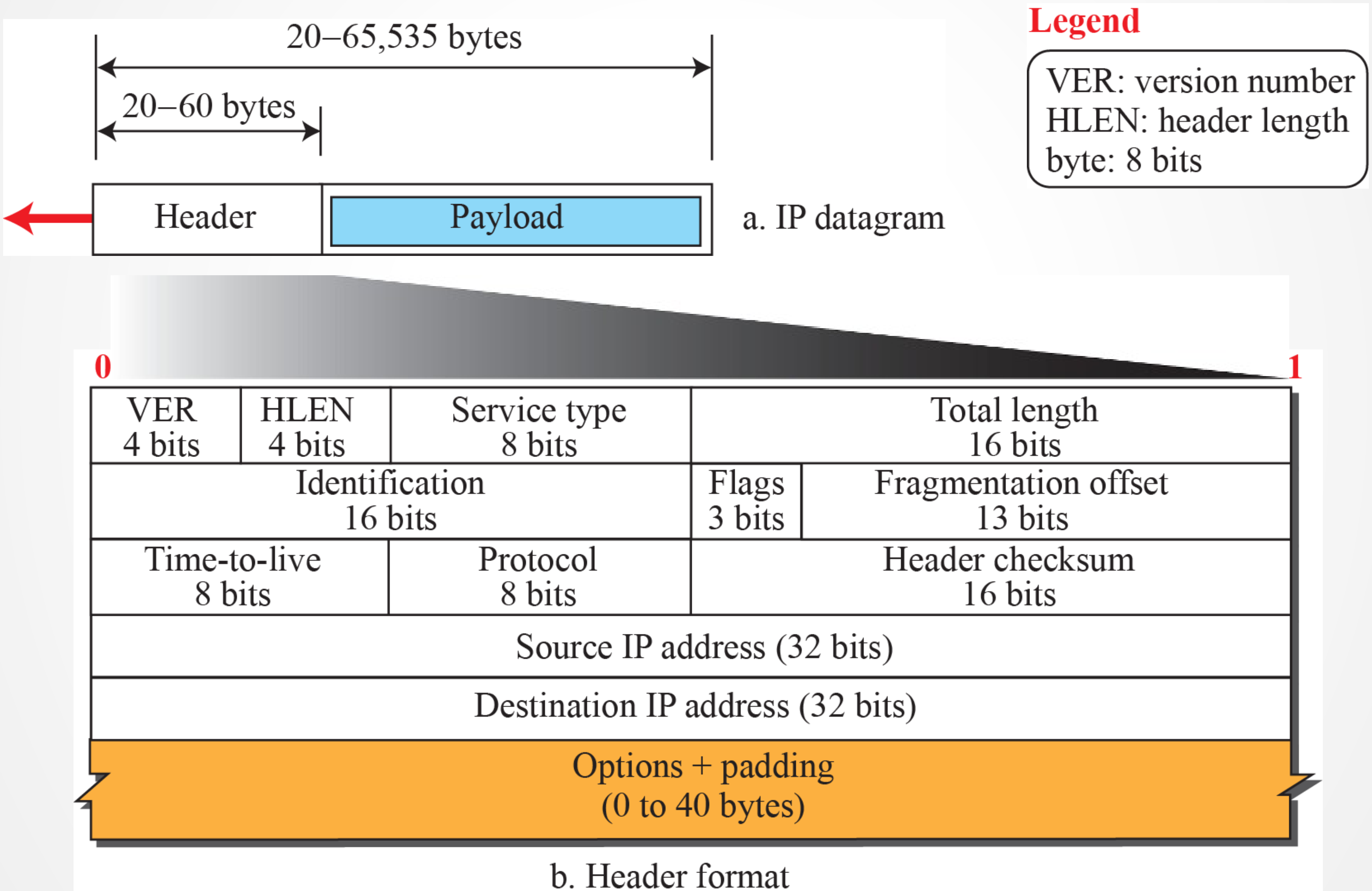
- Communication in Internet is heterogeneous i.e. different hosts uses different technology to communicate.
  - Heterogeneity: Addressing conventions, bandwidth, latency, loss rates, packet sizes

- Solution: Internet Protocol (IP)
  - Internet: Interconnect Networks
  - Invented by Robert Kahn and Vint Cerf

Internet Layer Services

- Services offered by Internet layer
  - host-to-host packet delivery.
  - routing of packets.
  - Fragmentation and reassembly of packets.
  - IP Addressing
  - Error Reporting
  - connectionless Best Effort Service.
    - Will make best effort to deliver the packet
      - Packets can get lost, corrupted, reordered, misdelivered, duplicated, delayed.
    - IP protocol’s greatest strength
      - Runs over anything

IP datagram Format



IP datagram Format

- Version: Specifies the version of the protocol
  - IPv4, IPv6
- Header Length: Specifies the header in 32-bit words
  - 5 words (without options)
- Type of Service: Permits packets to be treated differently
  - Research Focus
- Total Length: Specifies the length of the datagram (in bytes) including header
- Identification/Flags/ Fragment Offset:
  - Max size of IP packet is 65535 Bytes
  - Physical Networks may not support large packets
  - Need Fragmentation and reassembly

IP datagram Format

- Time to Live: Helps catch packets doing rounds
  - Not really time but hop count
  - Routers decrement the field by one before forwarding; if zero discard
  - Default value = 64
- Protocol: Demux key that identifies higher layer protocol
  - TCP: 6, UDP: 17
- Checksum (Internet): Detects errors in header
- Source/Destination IP address: 32-bit
  - Destination key to forwarding
  - Source for replying back
  - Global address space, independent of physical network address (MAC)
- Options: Rarely used
  - Record Time stamp
  - Record route taken
  - Specify source route

Fragmentation and Reassembly

- Goal: Interconnect heterogeneous networks
- Problem: Each technology has different Maximum Transmission Unit (MTU) size
  - MTU: Largest IP datagram that can be carried in a frame
  - E.g. Ethernet: 1500, FDDI: 4352, PPP: 296 (Negotiable), WiFi: 7981
- At host: Select MTU of link it is connected to
- At intermediate router: Forward datagram on a network with smaller MTU
  - Need to fragment the datagram
- Where to reassemble?
  - Next hop router? Increases overhead and datagram may again be fragmented
  - Destination is the best place

Fragmentation Fields

- Identification: Helps identify a datagram
  - All fragments carry same identification
- Flags: 3 bits
  - bit 0: Reserved, set to zero
  - bit 1: Don't Fragment (DF); Useful for path MTU discovery
  - bit 2: More Fragments (MF); Set to one to indicate more fragments to follow
- Fragmentation Offset: 13 bits long
  - Measures data/payload in units of eight-byte blocks
  - For a particular fragment, offset specifies start of data relative to the beginning of the original unfragmented IP datagram.
    - E.g first fragment would have an offset of zero

Example

- Original datagram: 1500B
  - TCP/UDP 20B
  - Data within is 1480B
- MTU: 296B 276
  - Max Data within is 276B
  - Offset has to be multiple of 8 → Data within 272B

8 bytes

Original Datagram

Length=1500	ID=x	Fragflag=0	Offset=0

$272 \times 5 = 1360$ $1480 - 1360 = 120$

Fragmented Datagrams

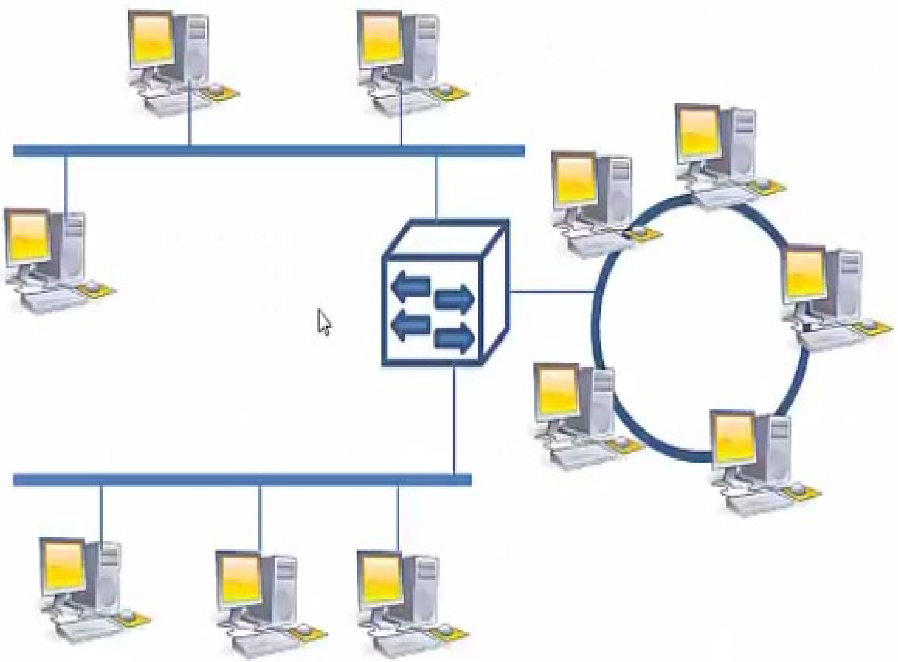
Length=292	ID=x	Fragflag=1	Offset=0
Length=292	ID=x	Fragflag=1	Offset=34
Length=292	ID=x	Fragflag=1	Offset=68
Length=292	ID=x	Fragflag=1	Offset=102
Length=292	ID=x	Fragflag=1	Offset=136
Length=140	ID=x	Fragflag=0	Offset=170

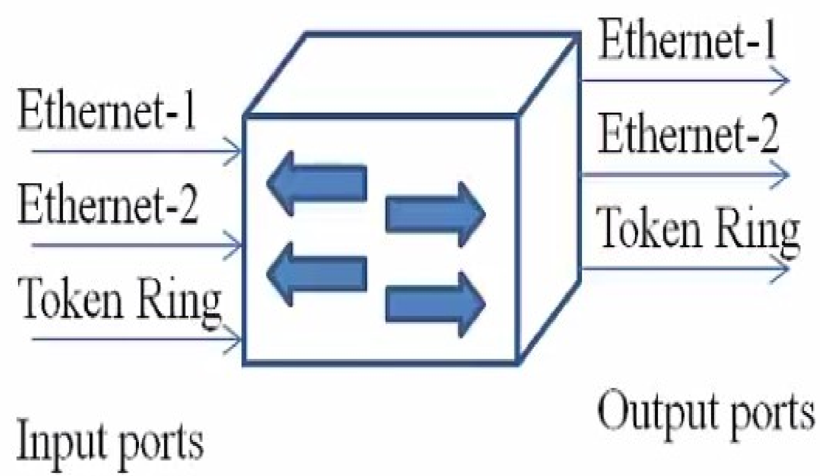
20

272/8

272 +20

Inside a Router

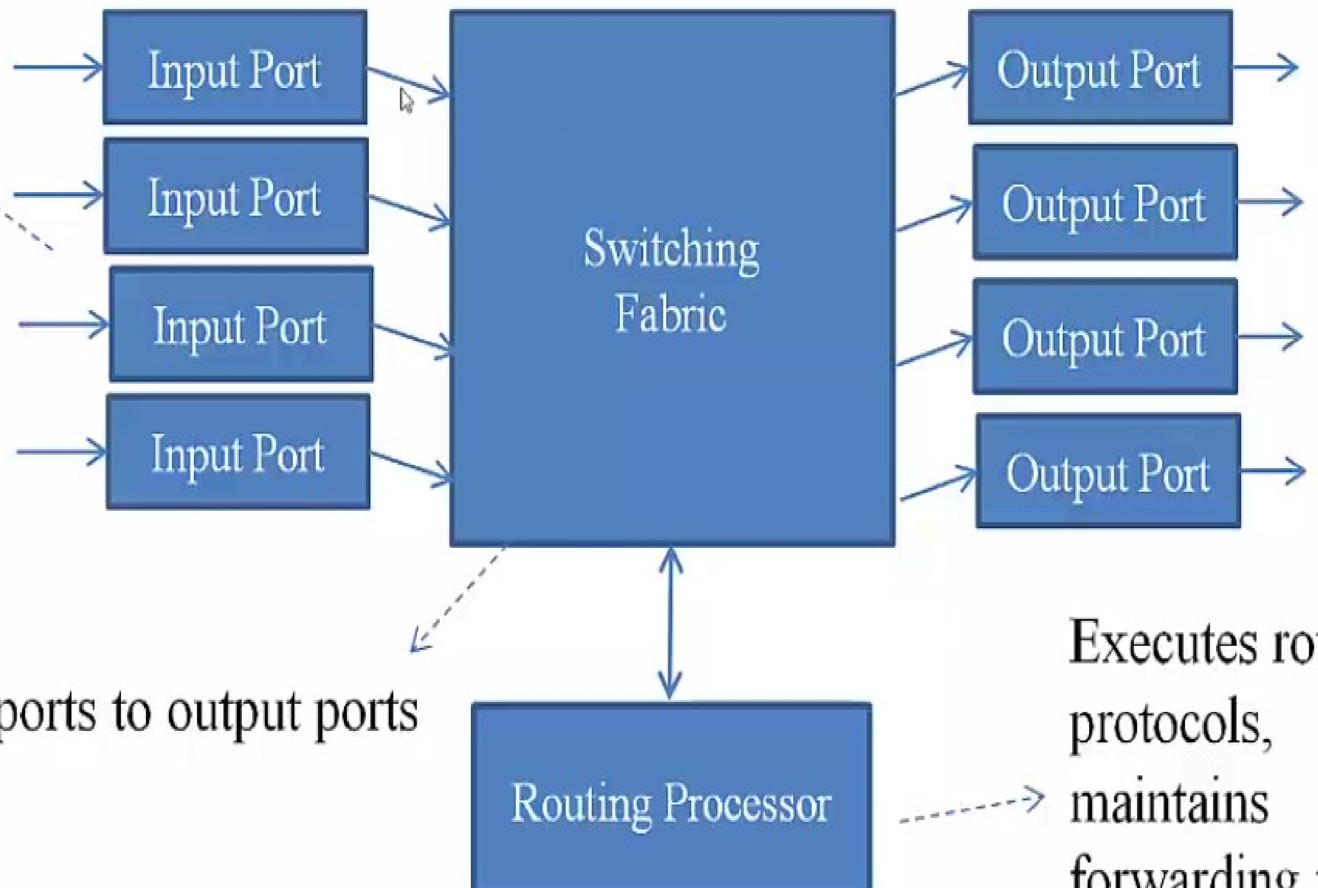




Terminates physical link;
Performs data-link-layer functions;
Can also perform look-up, forwarding, Queuing;
Routing protocol info passed to routing processor

Inside a Router

Stores incoming packets (queues) and transmits on outgoing link;
Performs data-link, phy layer functionality



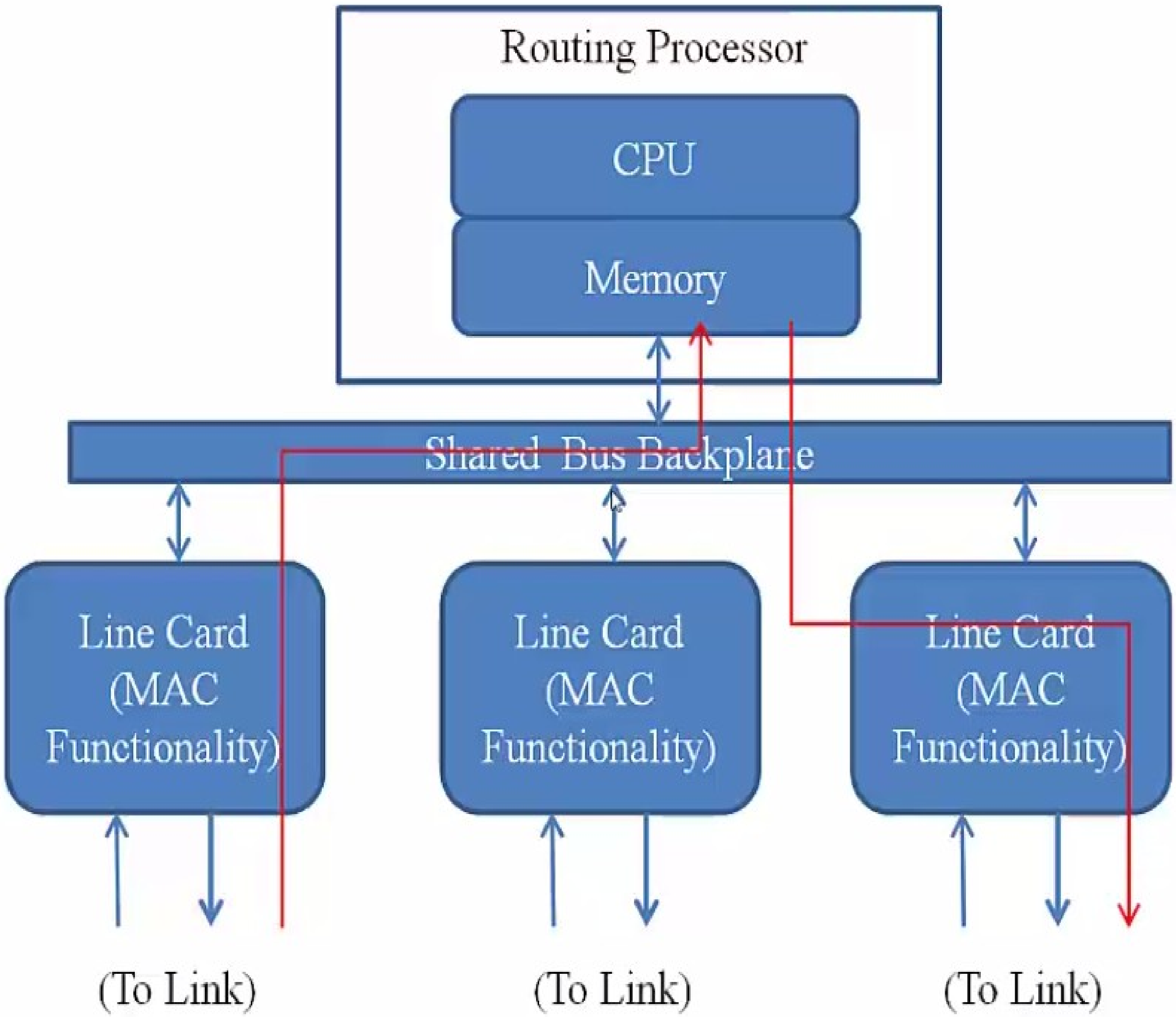
Connects input ports to output ports

Executes routing protocols, maintains forwarding tables

Router Functions

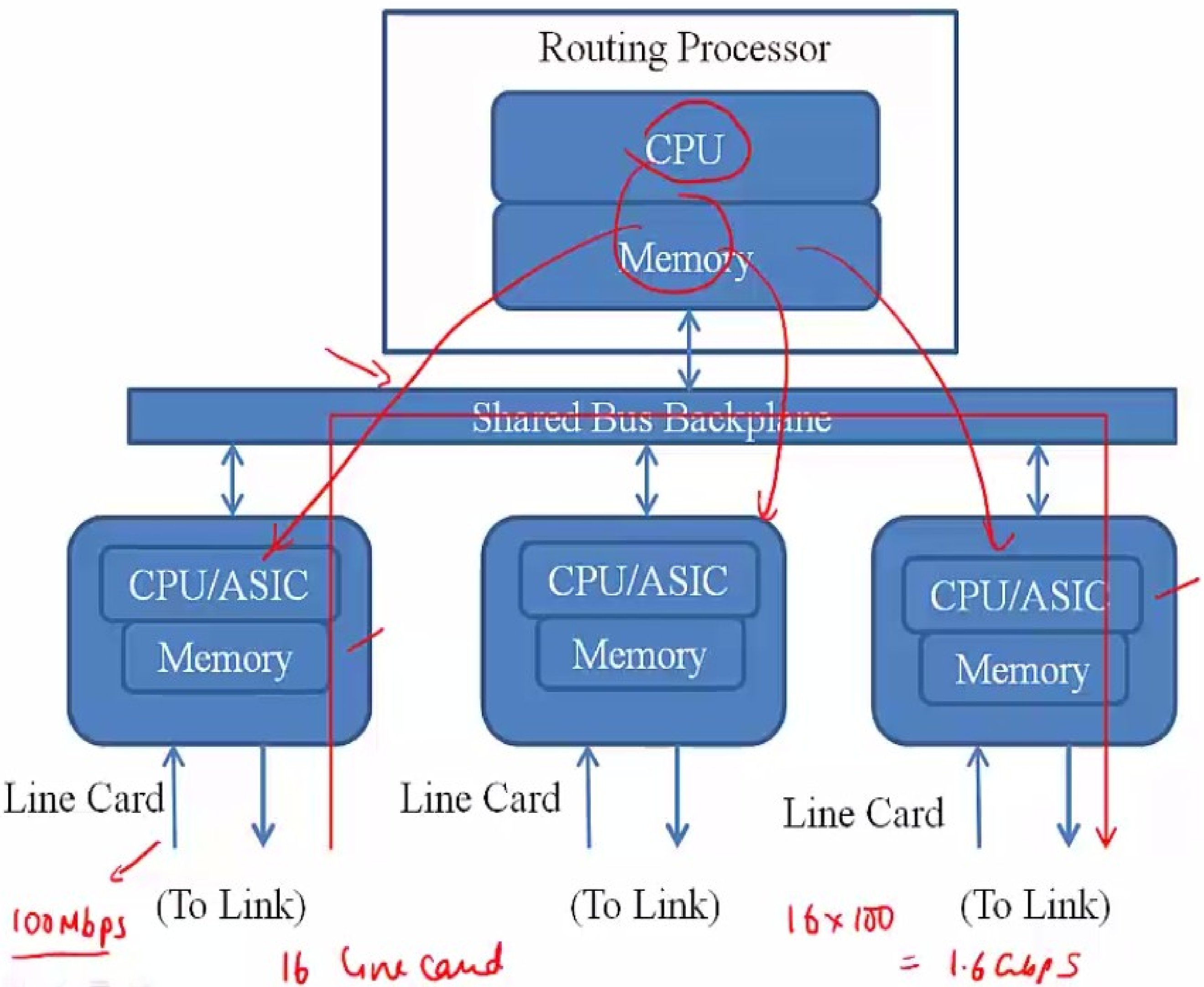
- Data-path functions: Operations performed on every datagram
  - forwarding, checksum calculation, FIFO scheduling etc
  - Often implemented in specialized hardware for high speed
- Control functions: Operations performed infrequently (packet exchange for routing protocols, system/network management)
  - Implemented in software

1st Generation Routers



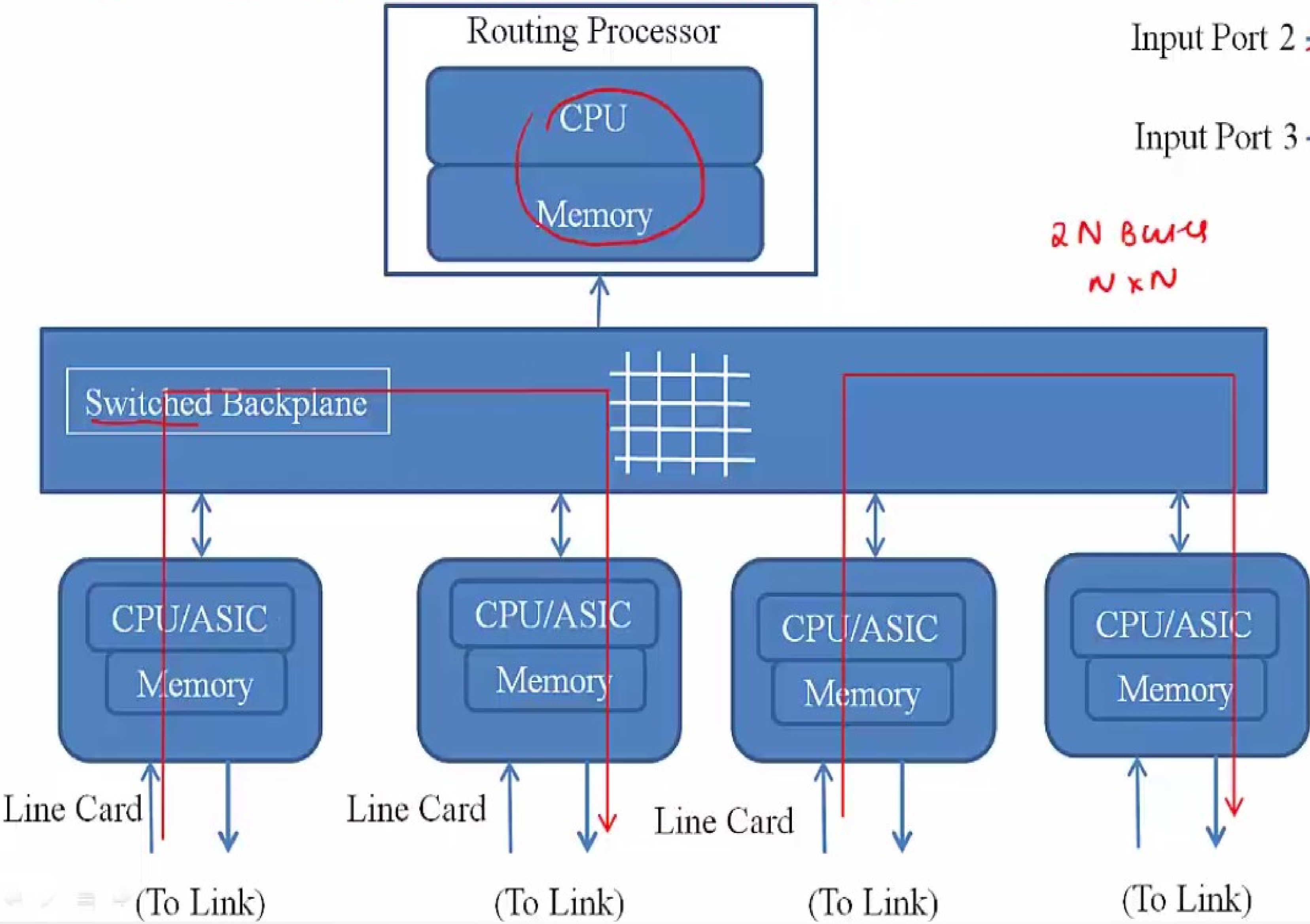
- In 1980's
- Every packet involves the Processor
  - Processor becomes bottleneck

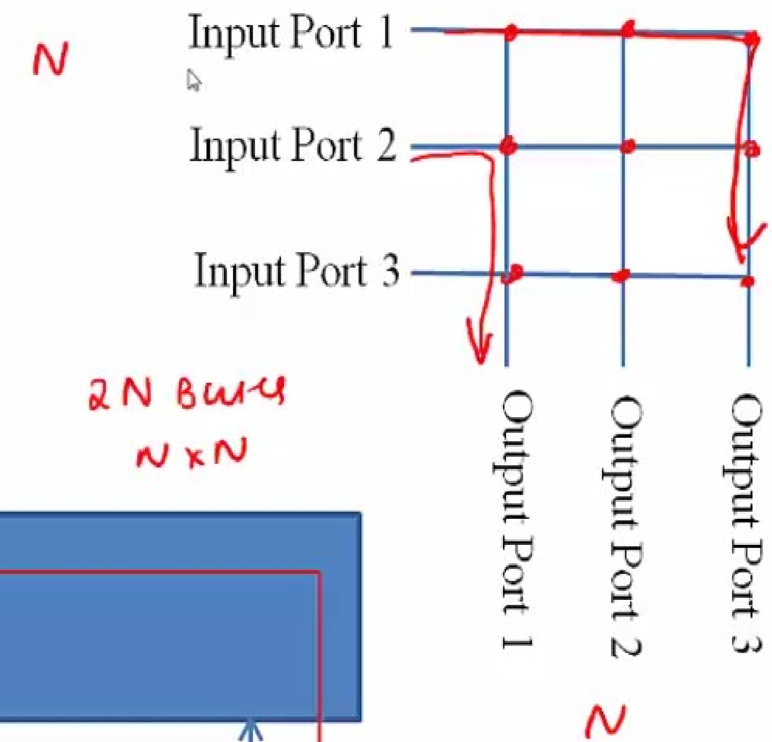
2nd Generation Routers



- Early1990's
- Parallelism: More hardware in each line card
- Packets travel bus only once
- Limitation: Bus becomes the bottleneck

3rd Generation Routers





Router Performance

- Minimize delay, losses → high forwarding speeds
- Look-up speed: determine output port
  - Forwarding table look-up at incoming port itself
- Look-up speed should exceed line-speed
  - E.g. 1Gbps link, packet size is 40 bytes → ~3 million packets per second → lookup speed has to be greater than 3 million lookups per second → each lookup should be under 8ns
- Switching fabric speed (S): Rate at which packets are moved from input to output
- N input and output ports with identical line speeds
- Input Port: No queue build-up if S > (N * line speed) → No loss
- Output Port: queues can build and losses can occur
  - If all N incoming packets on different input ports are directed to same output port