

# Lesson 4.1: Network Layer

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CSC450 – COMPUTER NETWORKS | WITNER 2019-20

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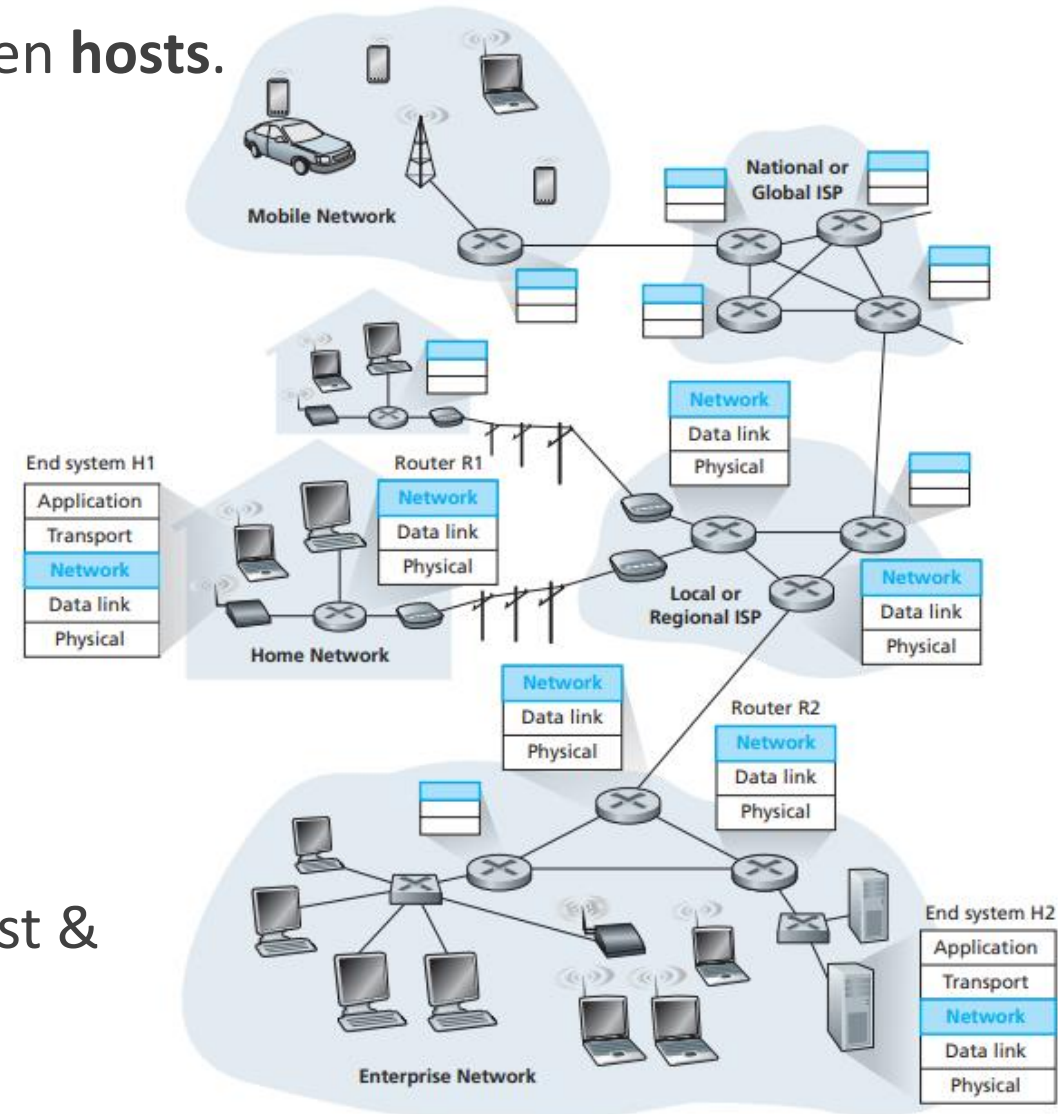
# OUTLINE

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- Introduction.
- Network layer functions & service models.
- Virtual circuit networks.
- Datagram networks.
- Forwarding function.
  - Router architecture.
  - Input processing.
  - Switching.
  - Output processing.
  - Queueing.

# INTRODUCTION

- **Network layer** provides **logical** communication between **hosts**.
  - **Transports datagrams** from one host to another.
- On **sending** host:
  - **Takes** segment from transport layer.
  - **Encapsulates** segment into datagram.
  - **Sends** datagram to the router.
- On **receiving** host:
  - **Receives** datagram from router.
  - **Extracts** transport-layer segment.
  - **Delivers** segment up to transport layer.
- **Network layer** protocols are implemented in **every** host & router.



# NETWORK LAYER FUNCTIONS

- **Two key network layer functions:**

- **Forwarding** (*data plane*).

- **Determines** how datagram arriving on router **input** port is **forwarded** to router **output** port.
    - **Local, per-router** logic.
    - Forwarding function.

- **Routing** (*control plane*).

- **Determines** how datagram is **routed** among routers along **end-to-end** path from **source** host to **destination** host.
    - **Network-wide** logic.
    - Routing algorithms.

# FORWARDING VS ROUTING

- **Forwarding process:**

- Router **forwards** a datagram by matching its header value with the corresponding output link in the **forwarding table**.

- **Routing process:**

- Routing algorithm **determines** the values that are **inserted** into **forwarding table** based on routing protocol messages.

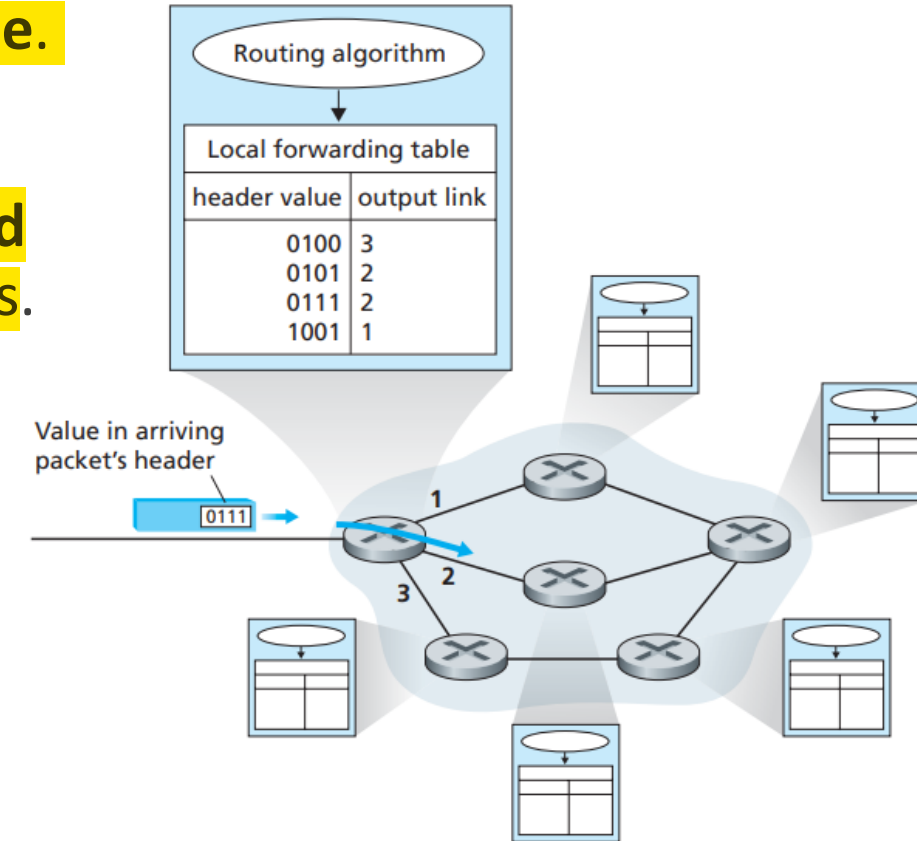
- **Two types of routing algorithms:**

- **Centralized.**

- Algorithm executes on central site and downloads routing information to each router.

- **Decentralized.**

- Distributed routing algorithms running on each router.



Routing algorithm & forwarding table

# NETWORK LAYER SERVICE MODELS

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- **Network layer** provides **two service models**:
  - Host-to-host **connectionless** service.
    - **Internet** (TCP/IP) model.
    - **Datagram networks**.
    - **IP** network layer **protocol** provides **best-effort service**.
      - Almost “no service at all”.
  - Host-to-host **connection-oriented** service.
    - **Asynchronous Transfer Mode** (ATM) model.
    - **Virtual circuit** (VC) networks.

# VIRTUAL CIRCUIT NETWORKS

- **Virtual circuit** network use **connections** at the **network level** – **virtual circuits (VCs)**.

- **VC consists of:**

- **Path** (links/routers) between the **source** and **destination** hosts.
- **VC number** for each link.
- **Entries** in **forwarding table** in each router.

- **VC goes through three phases:**

- **VC setup.**

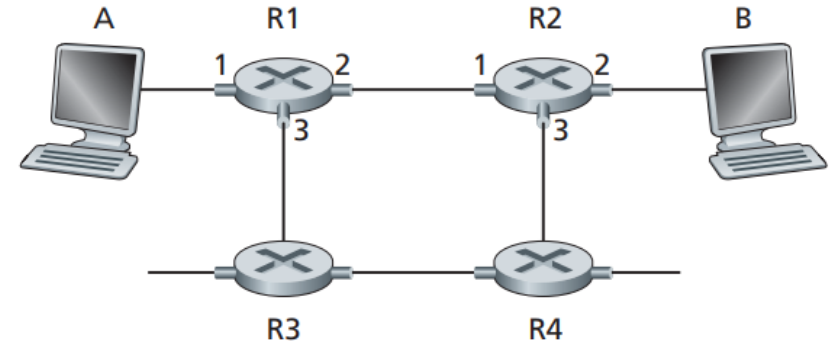
- Path is chosen.
- Connection is established.
- Circuit information stored in routers.

- **Data transfer.**

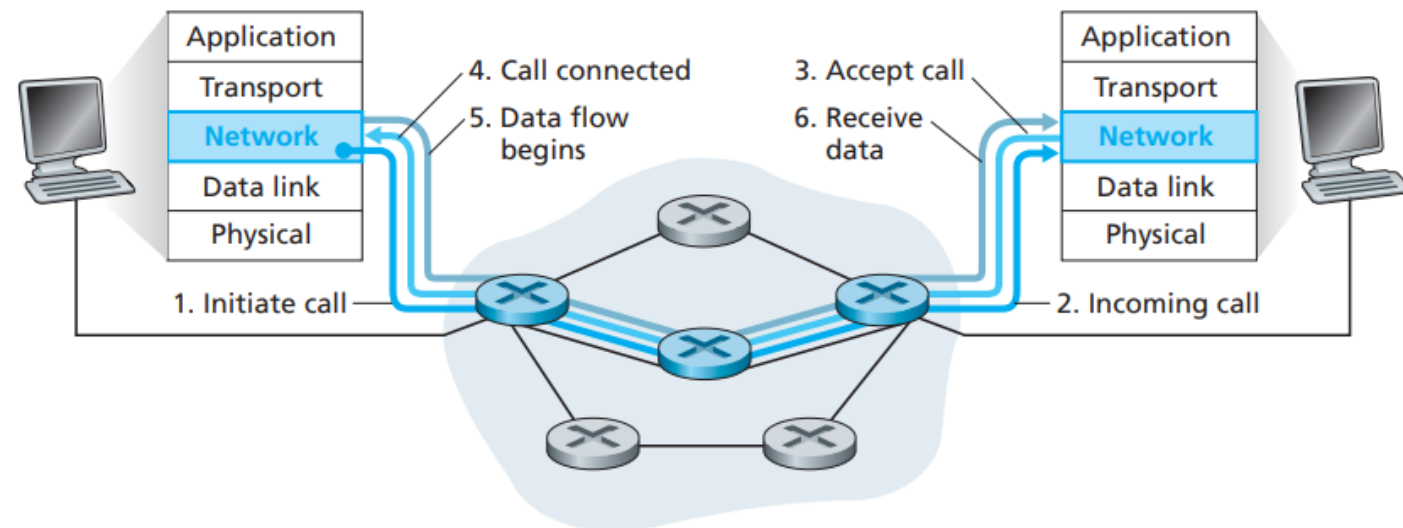
- Packets are forwarded along the path.

- **VC teardown.**

- Circuit information is removed from routers.



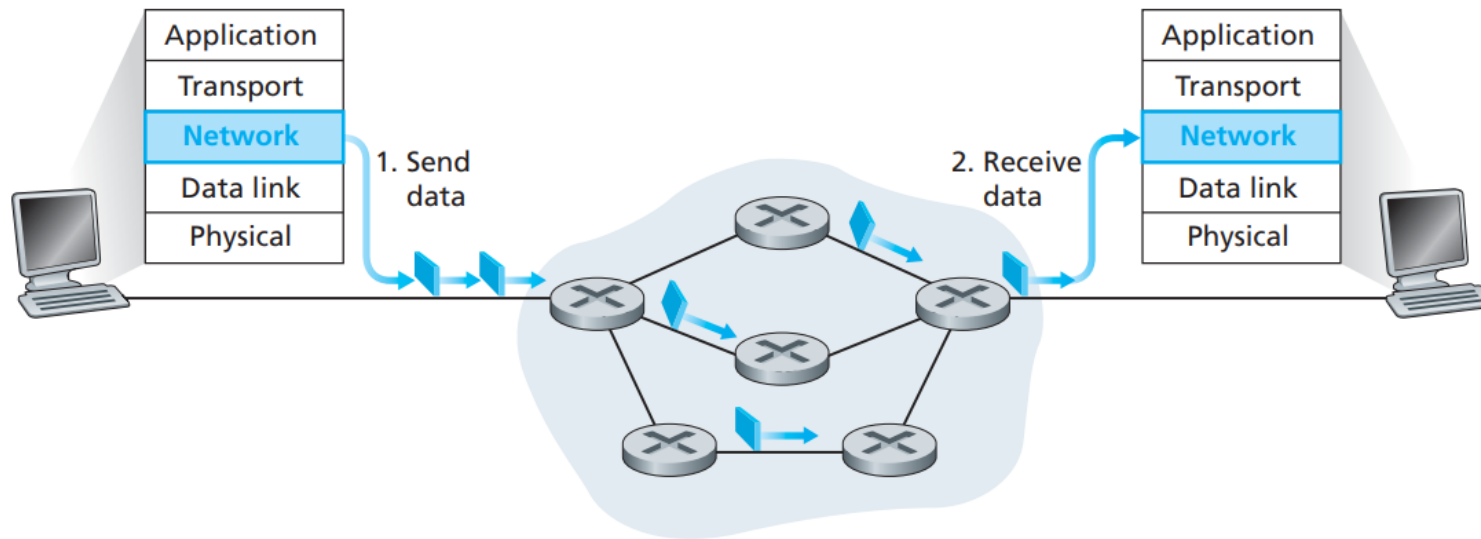
A simple virtual circuit network



Phases of VC network

# DATAGRAM NETWORKS (1)

- **Datagram network** is a **connectionless** network model.
  - Each **packet** contains **destination** host address.
    - Routers use this address to **forward** the packet.
  - Each **router** has a **forwarding table** that maps **addresses** to **link interfaces**.
    - Routing table gives **next hop** for each destination address.



Datagram network



# DATAGRAM NETWORKS (2)

- **Routers use longest prefix matching rule to forward packet to an appropriate link.**
  - When looking for **forwarding link interface** for given **destination address**, use **longest address prefix** that matches **destination address**.

- **Example:**

- **Forwarding table:**

Destination address range	Link interface
11001000 00010111 00010*** *****	0
11001000 00010111 00011000 *****	1
11001000 00010111 00011*** *****	2
Otherwise	3

- **Destination addresses:**

- 11001000 00010111 00010110 10100001 →
    - 11001000 00010111 00011000 10101010 →

# FORWARDING: ROUTER ARCHITECTURE

- **Four components of router architecture:**

- **Input ports.**

- Physical-layer functions.
- Link-layer functions.
- Look up forwarding table.

- **Switching fabric.**

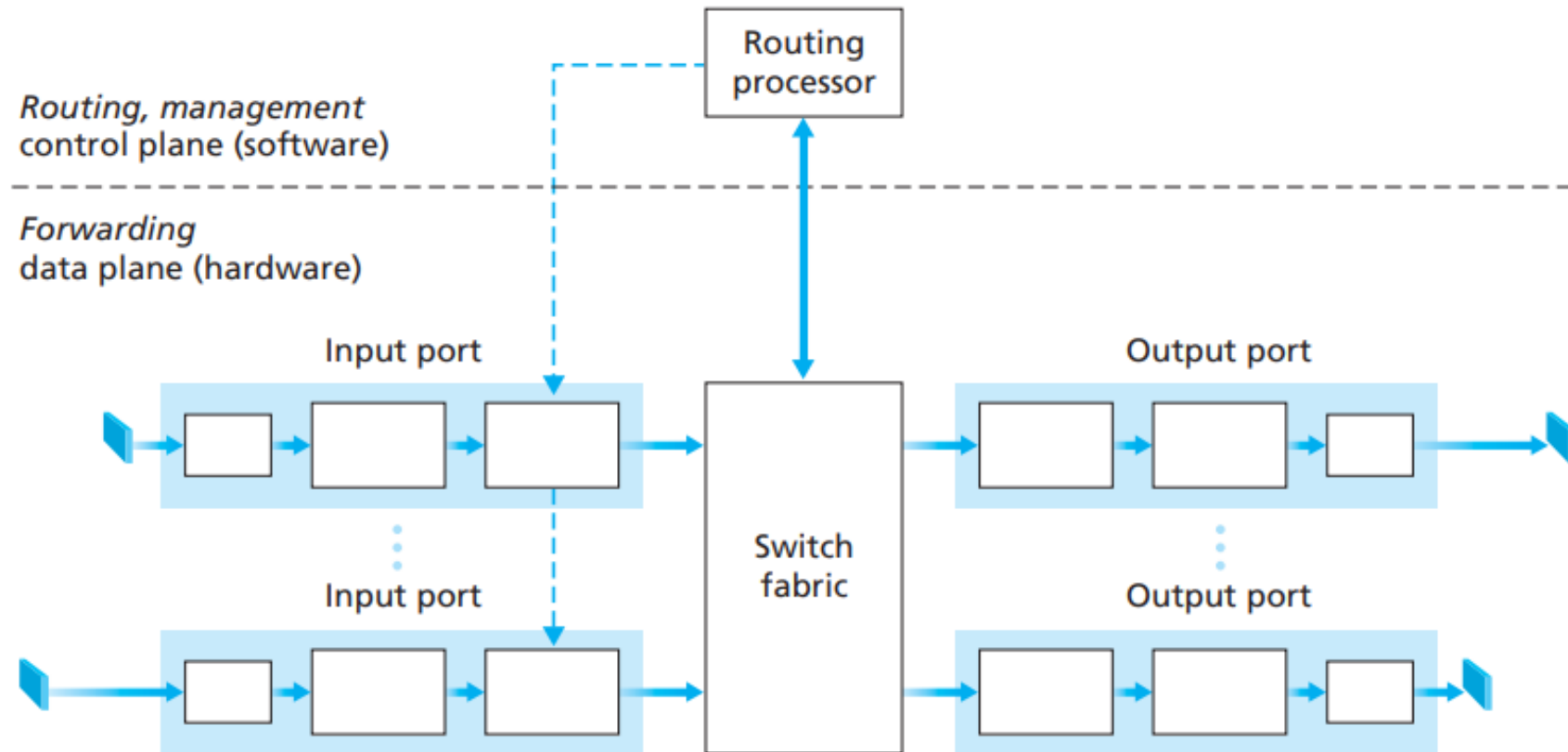
- Connects I/O port.

- **Output ports.**

- Store packets.
- Link-layer functions.
- Physical layer function.

- **Routing processor.**

- Executes routing protocols.
- Maintains routing tables.
- Computes forwarding tables.

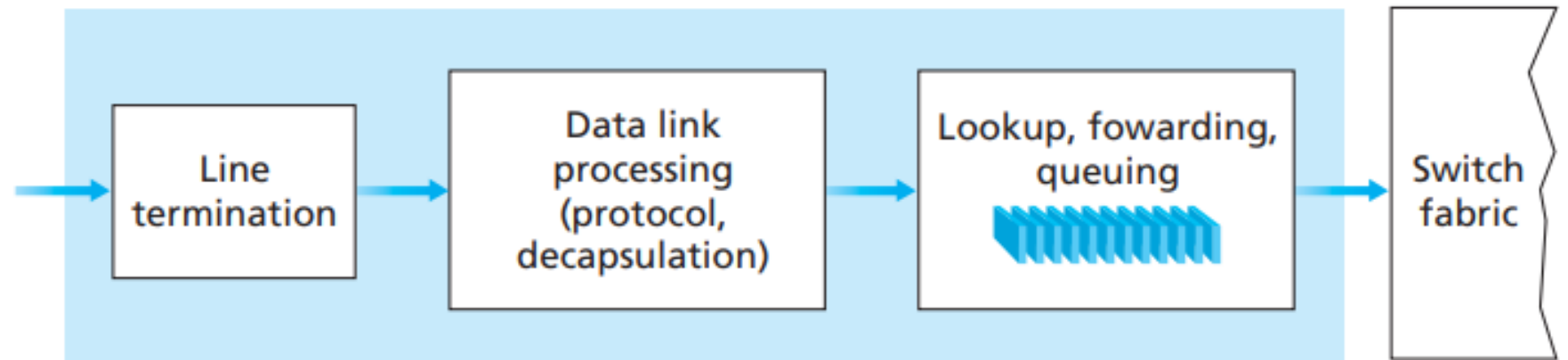


Router architecture

# FORWARDING: INPUT PROCESSING

- **Input port** consists of **three parts**:

- **Physical layer.**
  - Bit-level reception.
- **Data link layer.**
  - De-capsulation.
- **Decentralized switching.**
  - **Lookup** forwarding destination.
    - Longest prefix match.
  - **Forward** datagrams.
  - **Queue** datagrams.



Input port processing

# FORWARDING: SWITCHING

- **Packets are forwarded** from **input** ports to **output** ports through **switching fabric**.

- **Three types of switching fabric:**

- **Switching via memory.**

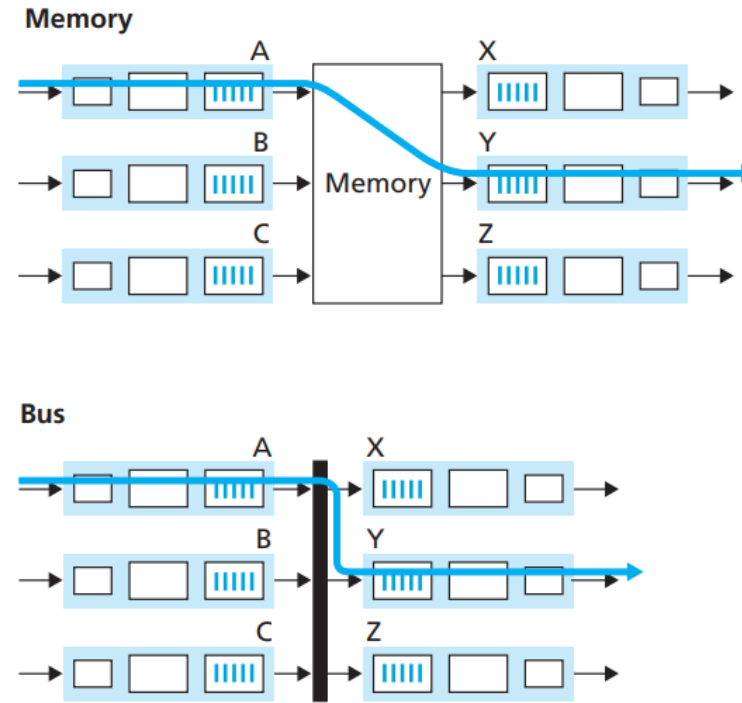
- First generation routers.
- Traditional computers with switching under direct control of CPU.

- **Switching via bus.**

- Datagram transferred from input port to output port via shared bus.

- **Switching via interconnection network.**

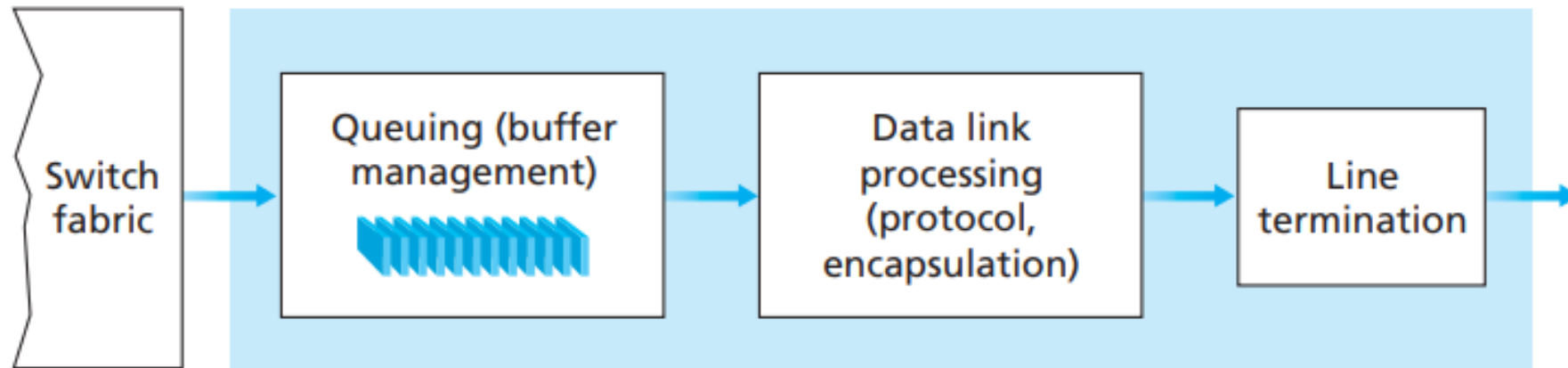
- Overcome bus limitation.
- Interconnection nets used to connect processors in multiprocessors.



Three switching techniques

# FORWARDING: OUTPUT PROCESSING

- **Output port consists of the same parts as input port.**
  - **De-queues** packets for transmission.
  - **Encapsulates** on data link layer.
  - **Sends** bits on physical layer.



Output port processing

# FORWARDING: QUEUEING

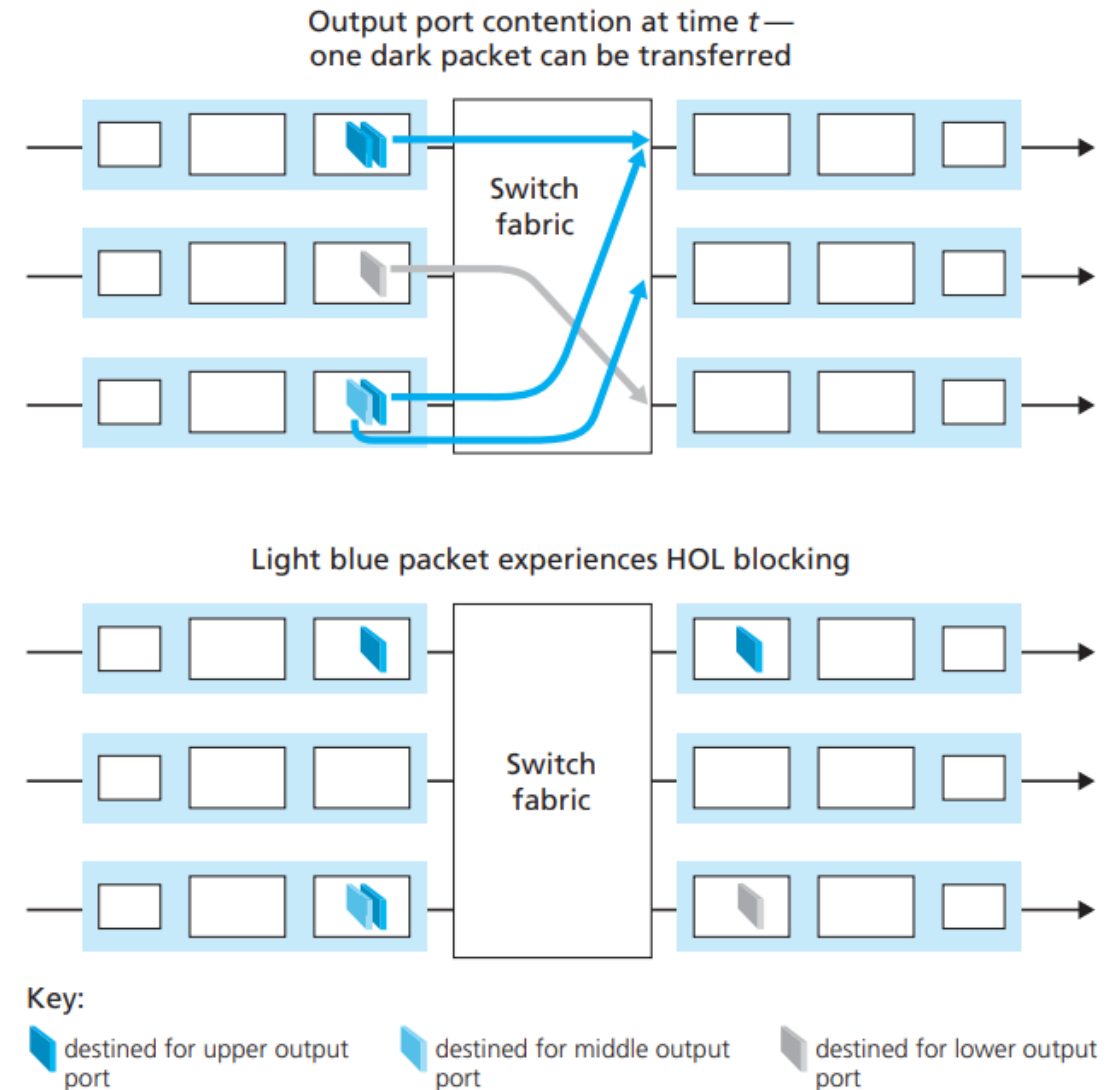
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- **Queueing** of packets can occur on both **input ports** and **output ports**.
- **Depends on:**
  - **Traffic load;**
  - **Speed of switching fabric;**
  - **Speed of line.**
- Main cause of **delays & packet loss**.

# QUEUEING: INPUT PORTS

- **Input ports queueing.**

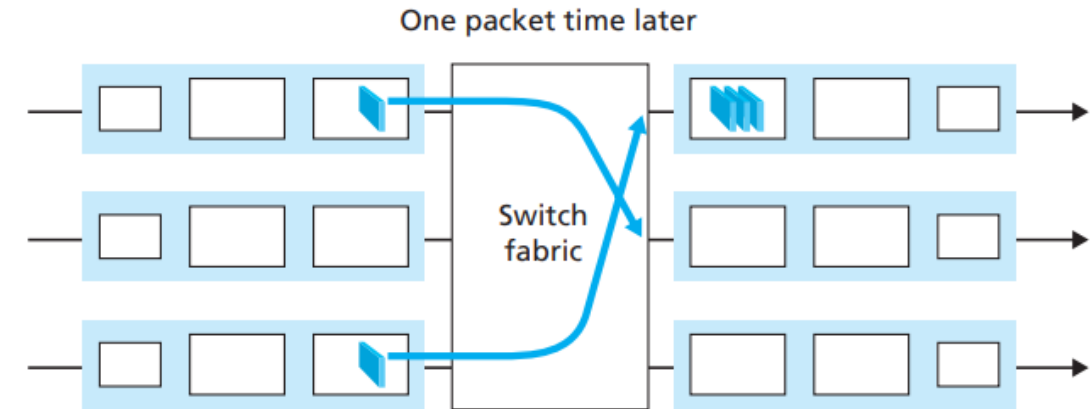
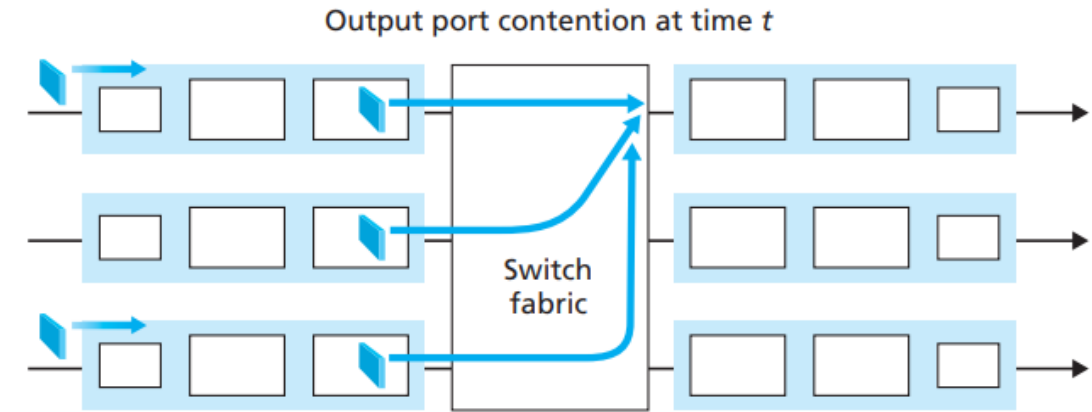
- **Cause:** switching fabric is **slower** than input ports combined.
- Input ports **buffer overflow** → queueing **delays** and **packet loss**.
- **Head-of-the-line (HOL) blocking** issue.
  - Queued datagram at **front** of queue **prevents** others in queue from **moving forward**.



# QUEUEING: OUTPUT PORTS

- **Output ports queueing.**

- **Cause:** datagrams arrive from fabric **faster** than the transmission rate.
  - Arrival rate via switch **exceeds** output line speed.
- **Scheduling algorithms** choose among queued datagrams for transmission.



Output port queueing



# SUMMARY

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- Forwarding & routing.
- Network layer service models.
- Virtual circuit networks.
- Datagram networks.
- Router input & output ports.
- Switching fabric.
- Queueing.