

Chapter 4

Network Layer: Data Plane

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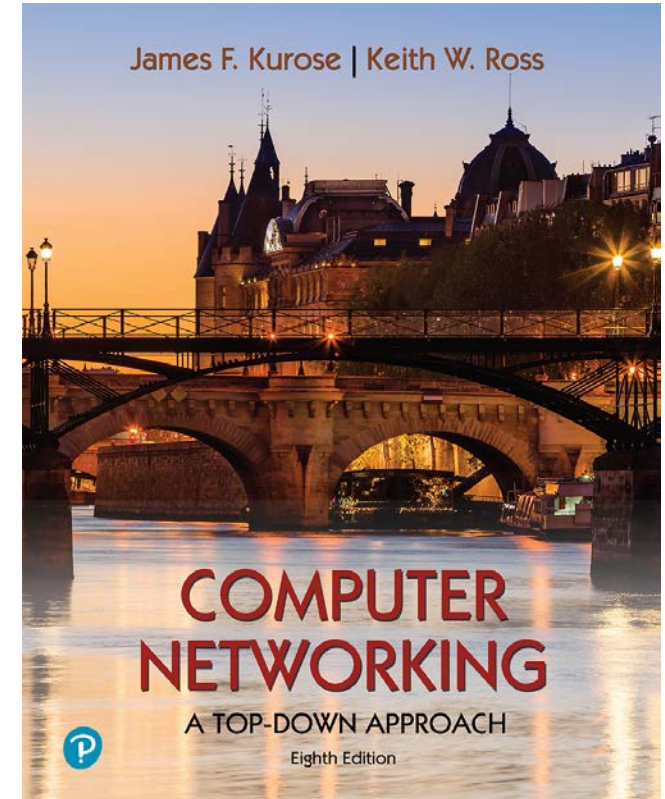
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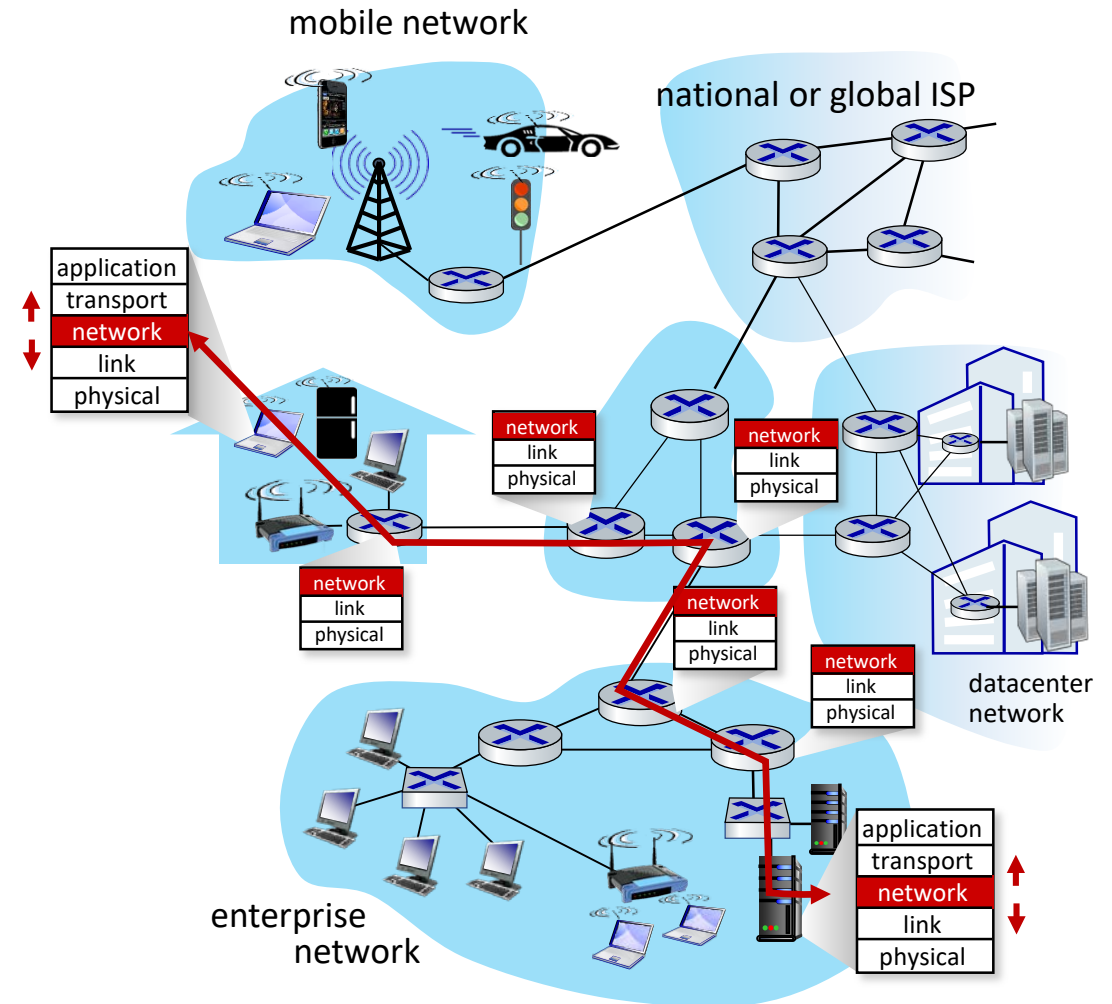
Computer Networking: A Top-Down Approach

8th edition

Jim Kurose, Keith Ross
Pearson, 2020

Network-layer services and protocols

- transport segment from sending to receiving host
 - **sender:** encapsulates segments into datagrams, passes to link layer
 - **receiver:** delivers segments to transport layer protocol
- network layer protocols in *every Internet device*: hosts, routers
- **routers:**
 - examines header fields in all IP datagrams passing through it
 - moves datagrams from input ports to output ports to transfer datagrams along end-end path



Two key network-layer functions

network-layer functions:

- *forwarding*: move packets from a router's input link to appropriate router output link
- *routing*: determine route taken by packets from source to destination
 - *routing algorithms*

analogy: taking a trip

- *forwarding*: process of getting through single interchange
- *routing*: process of planning trip from source to destination



forwarding



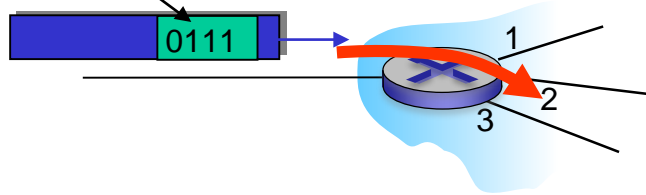
routing

Network layer: data plane, control plane

Data plane:

- *local*, per-router function
- determines how datagram arriving on router input port is forwarded to router output port

values in arriving
packet header

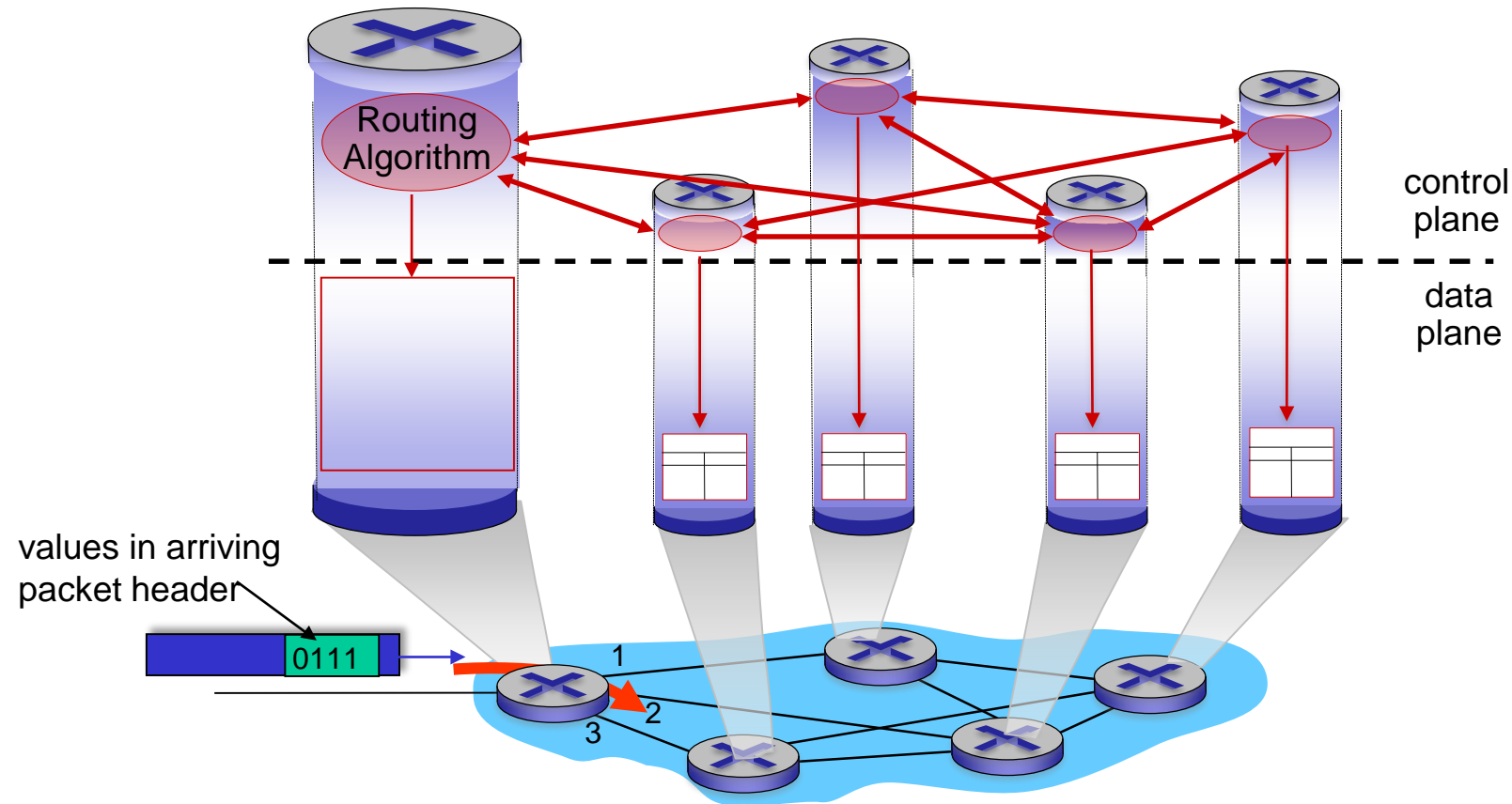


Control plane

- *network-wide* logic
- determines how datagram is routed among routers along end-end path from source host to destination host

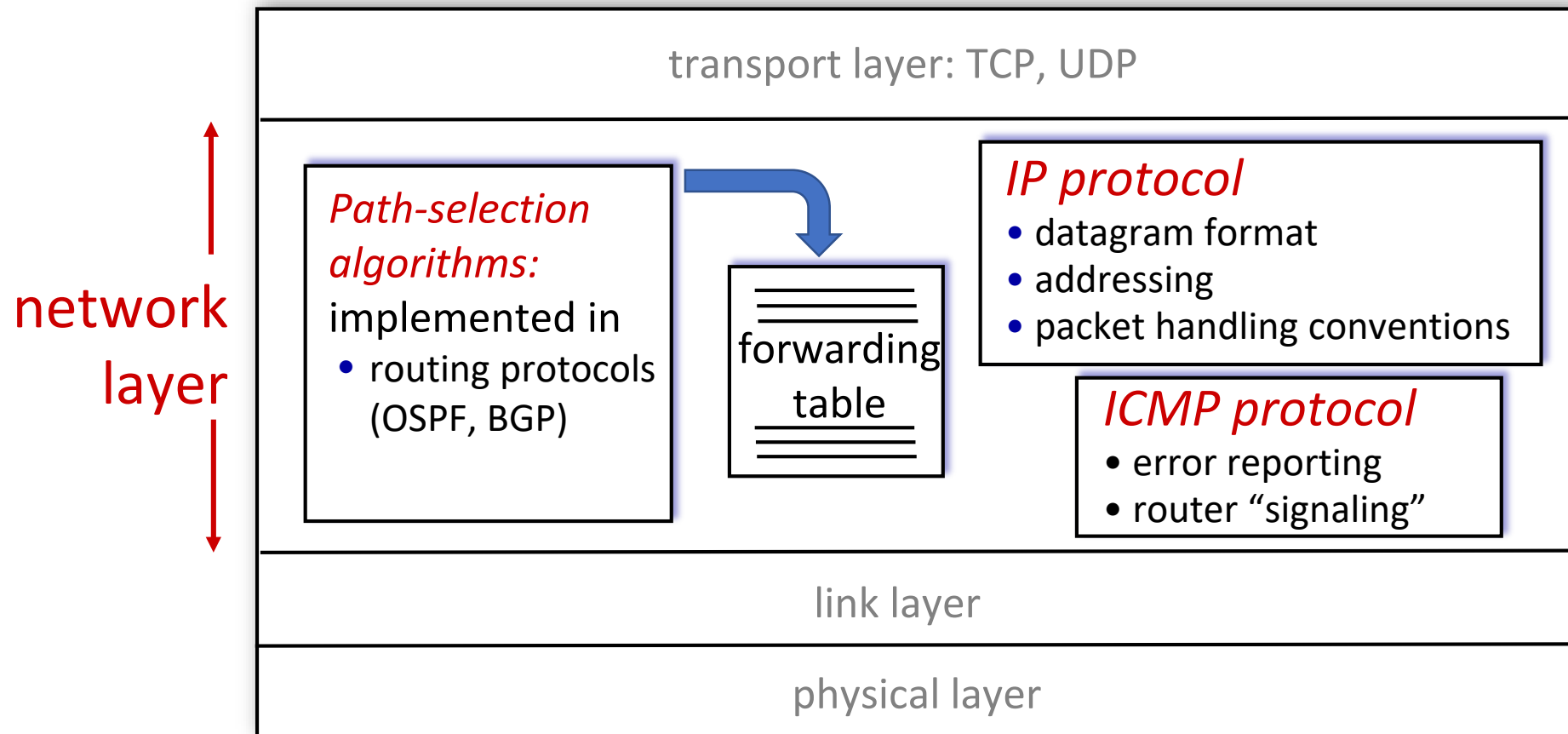
Per-router control plane

Individual routing algorithm components *in each and every router* interact in the control plane



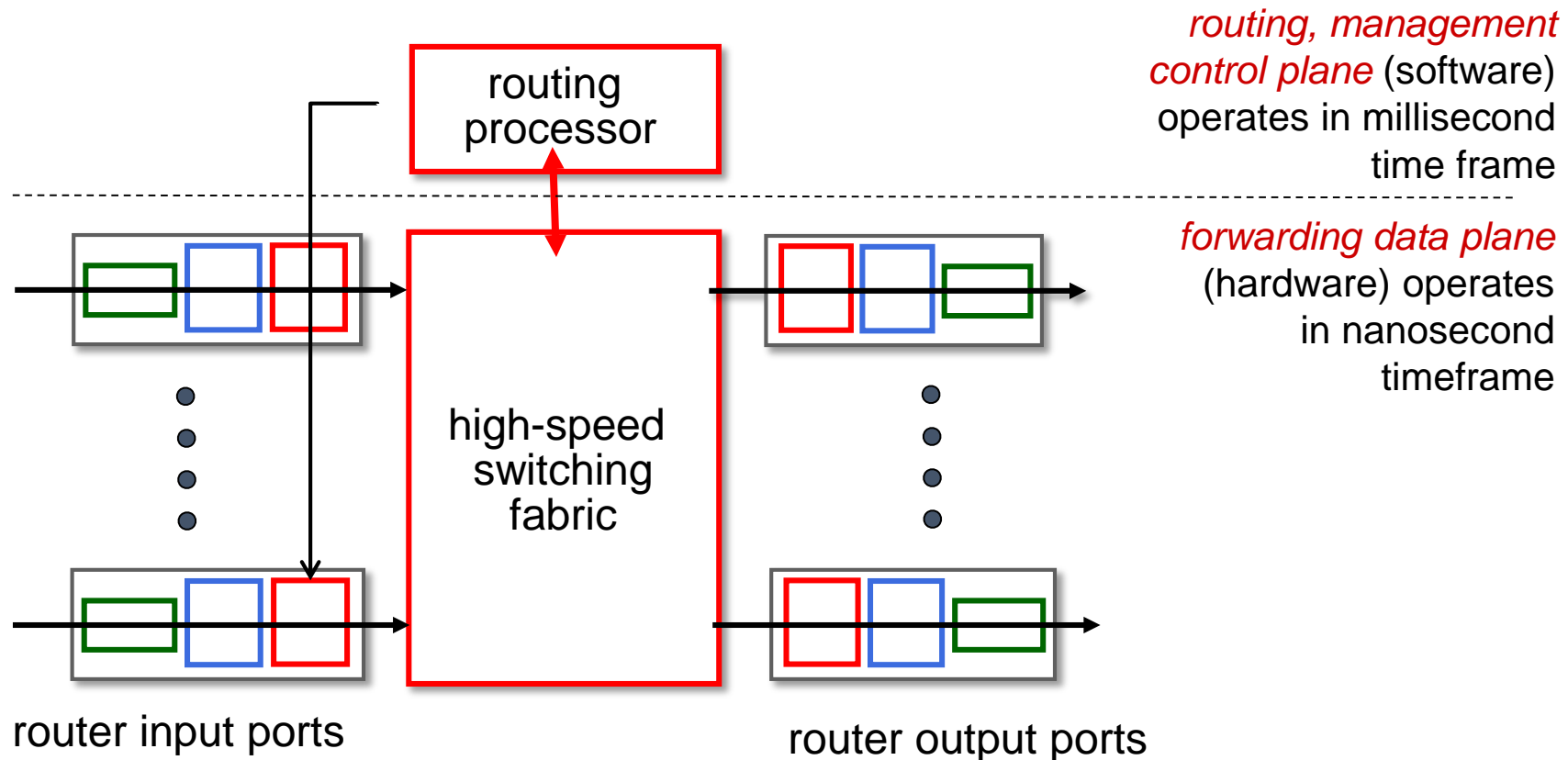
Network Layer: Internet

host, router network layer functions:

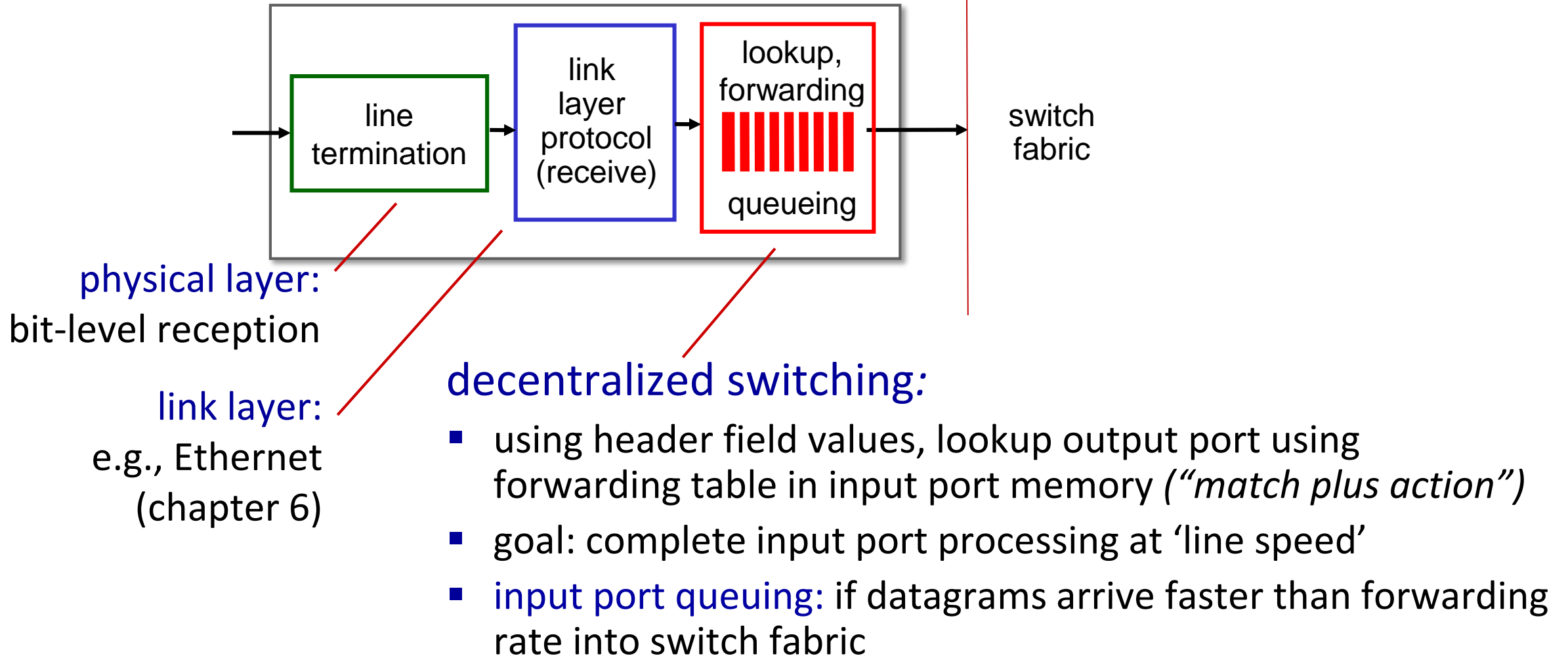


Router architecture overview

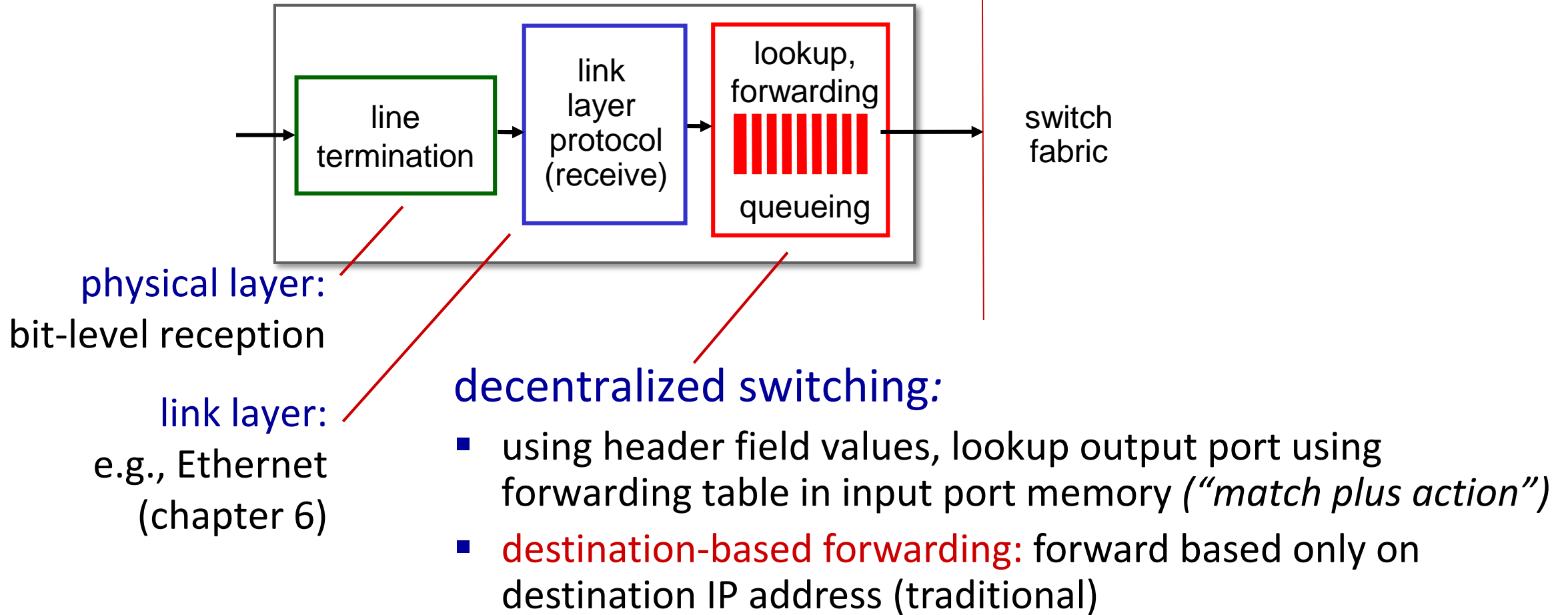
high-level view of generic router architecture:



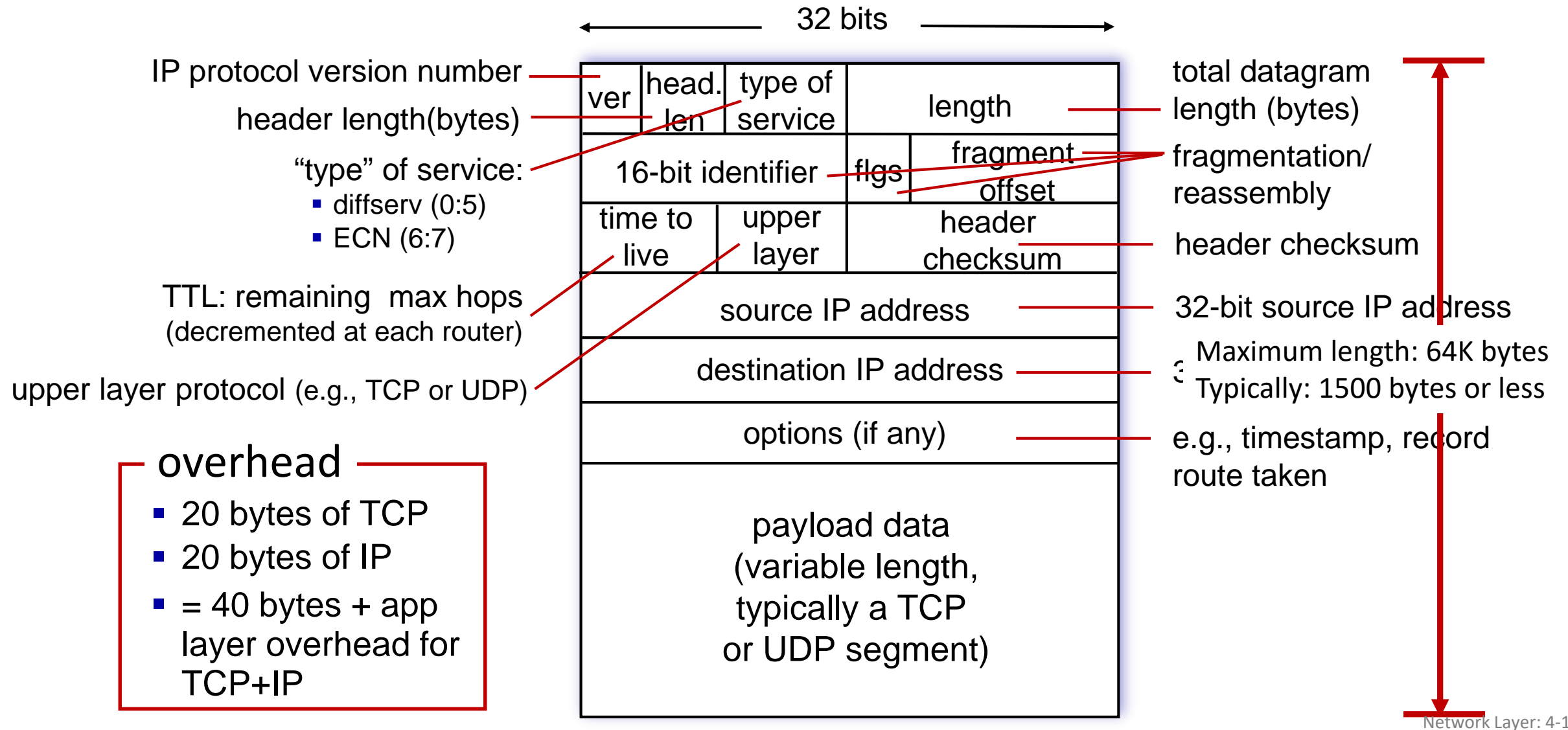
Input port functions



Input port functions



IP Datagram format



Destination-based forwarding

<i>forwarding table</i>	
Destination Address Range	Link Interface
11001000 00010111 00010000 00000000 through 11001000 00010111 00010000 00000100	n 3
11001000 00010111 00010000 00000111	
11001000 00010111 00011000 11111111	
11001000 00010111 00011001 00000000 through 11001000 00010111 00011111 11111111	2
otherwise	3

Q: but what happens if ranges don't divide up so nicely?

Longest prefix matching

longest prefix match

when looking for forwarding table entry for given destination address, use *longest* address prefix that matches destination address.

Destination Address Range	Link interface
11001000 00010111 00010*** *****	0
11001000 00010111 00011000 *****	1
11001000 00010111 00011*** *****	2
otherwise	3

examples:

11001000 00010111 00010110 10100001 which interface?

11001000 00010111 00011000 10101010 which interface?

Longest prefix matching

longest prefix match

when looking for forwarding table entry for given destination address, use *longest* address prefix that matches destination address.

Destination Address Range	Link interface
11001000 00010111 00010*** *****	0
11001000 00010111 00011000 *****	1
11001000 match! 1 00011*** *****	2
otherwise	3

examples:

11001000 00010111 00010110 10100001 which interface?
11001000 00010111 00011000 10101010 which interface?

Longest prefix matching

longest prefix match

when looking for forwarding table entry for given destination address, use *longest* address prefix that matches destination address.

Destination Address Range				Link interface
11001000	00010111	00010***	*****	0
11001000	00010111	00011000	*****	1
11001000	00010111	00011***	*****	2
otherwise				3

match!

examples:

11001000	00010111	00010110	10100001	which interface?
11001000	00010111	00011000	10101010	which interface?

Longest prefix matching

longest prefix match

when looking for forwarding table entry for given destination address, use *longest* address prefix that matches destination address.

Destination Address Range	Link interface
11001000 00010111 00010*** *****	0
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match!

examples:

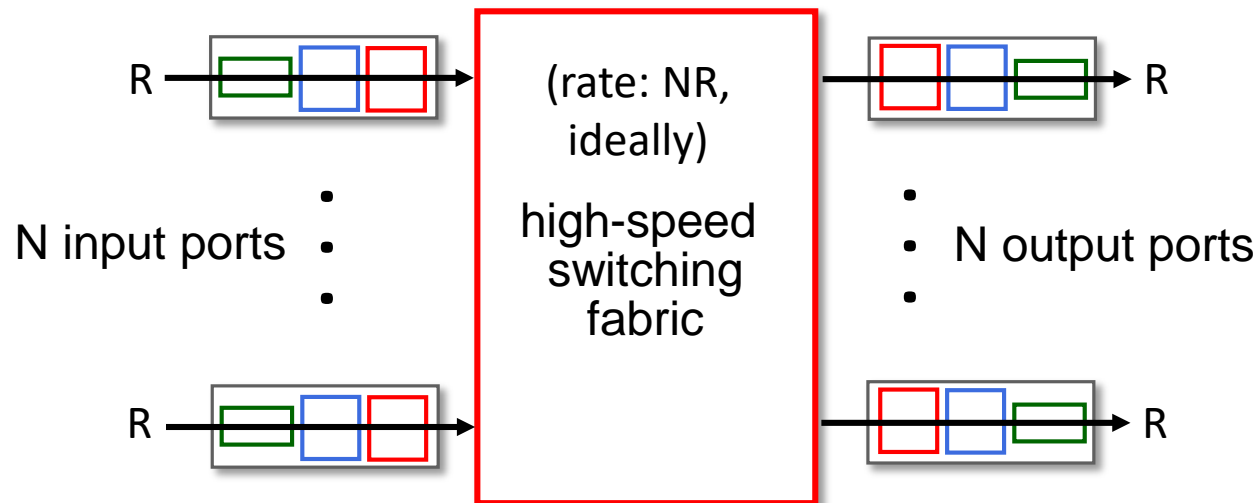
11001000 00010111 00010110 10100001	which interface?
11001000 00010111 00011000 10101010	which interface?

Longest prefix matching

- we'll see *why* longest prefix matching is used shortly, when we study addressing
- longest prefix matching: often performed using ternary content addressable memories (TCAMs)
 - *content addressable*: present address to TCAM: retrieve address in one clock cycle, regardless of table size
 - Cisco Catalyst: ~1M routing table entries in TCAM

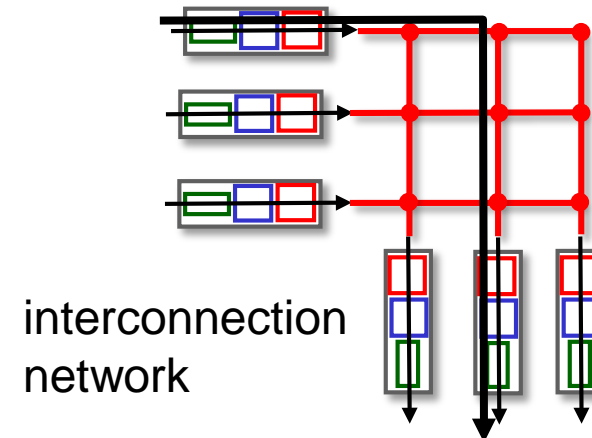
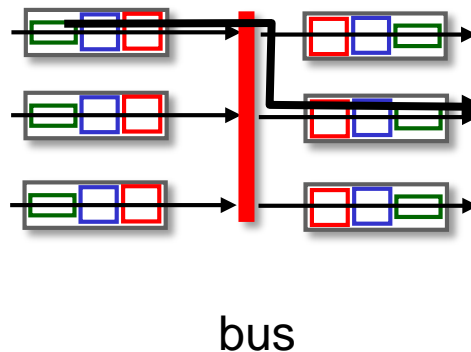
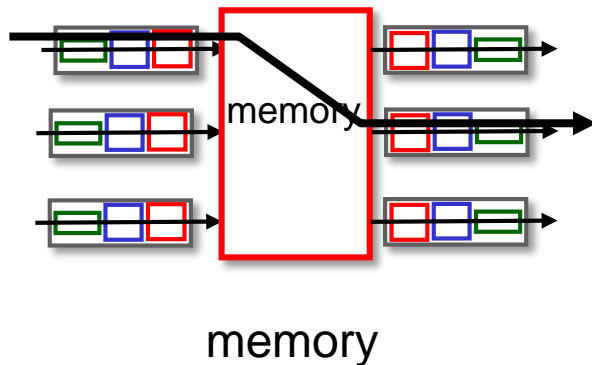
Switching fabrics

- transfer packet from input link to appropriate output link
- **switching rate**: rate at which packets can be transferred from inputs to outputs
 - often measured as multiple of input/output line rate
 - N inputs: switching rate N times line rate desirable



Switching fabrics

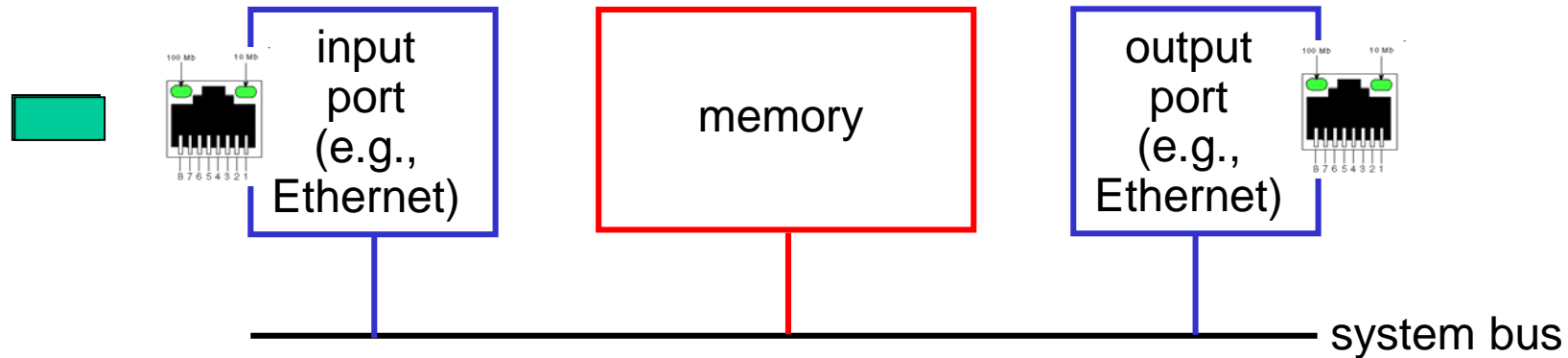
- transfer packet from input link to appropriate output link
- **switching rate**: rate at which packets can be transferred from inputs to outputs
 - often measured as multiple of input/output line rate
 - N inputs: switching rate N times line rate desirable
- three major types of switching fabrics:



Switching via memory

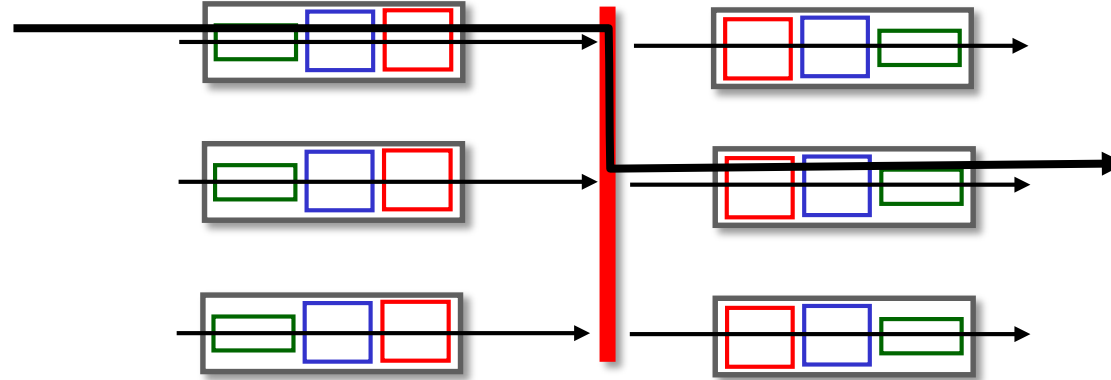
first generation routers:

- traditional computers with switching under direct control of CPU
- packet copied to system's memory
- speed limited by memory bandwidth (2 bus crossings per datagram)



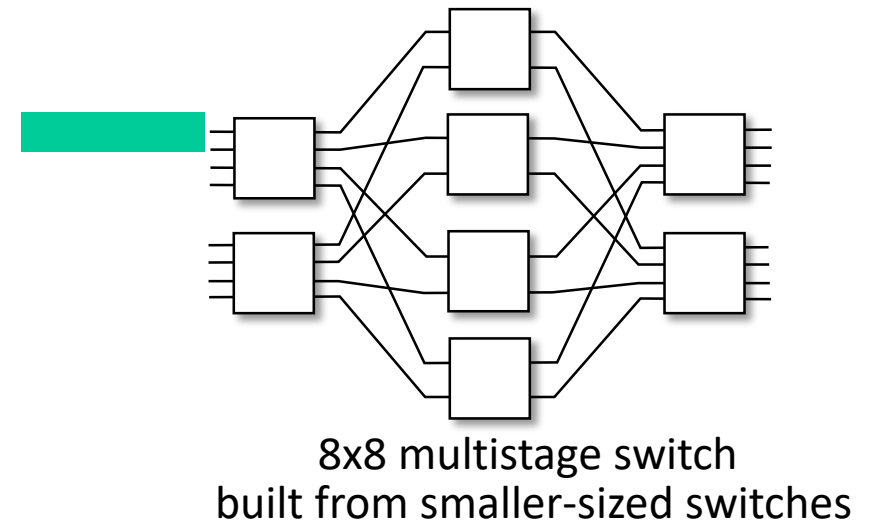
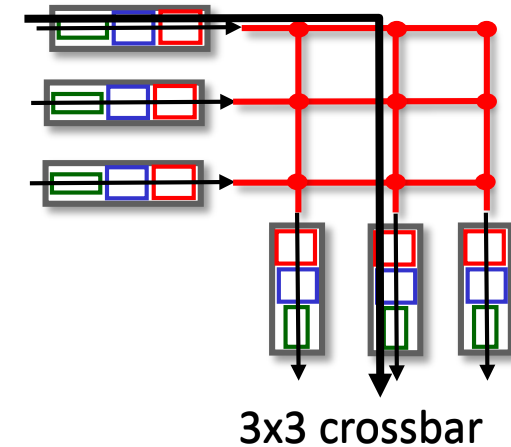
Switching via a bus

- datagram from input port memory to output port memory via a shared bus
- *bus contention*: switching speed limited by bus bandwidth
- 32 Gbps bus, Cisco 5600: sufficient speed for access routers



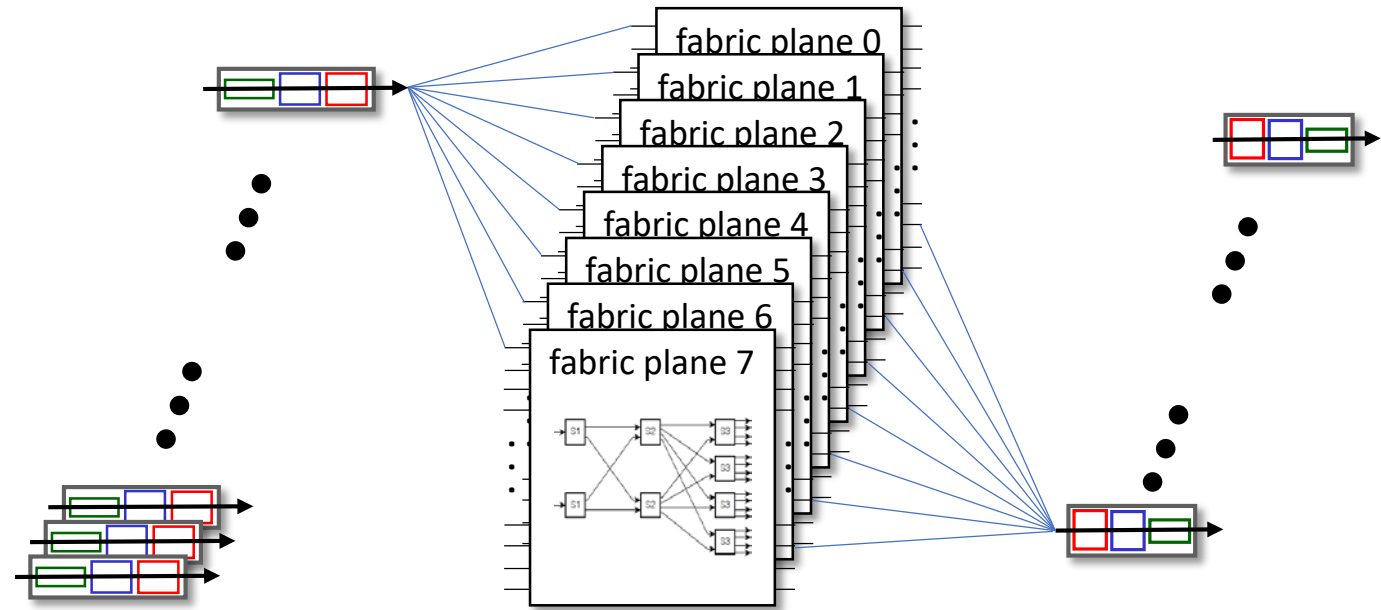
Switching via interconnection network

- Crossbar, Clos networks, other interconnection networks initially developed to connect processors in multiprocessor systems
- **multistage switch**: $n \times n$ switch from multiple stages of smaller switches
- **exploiting parallelism**:
 - fragment datagram into fixed length cells on entry
 - switch cells through the fabric, reassemble datagram at exit



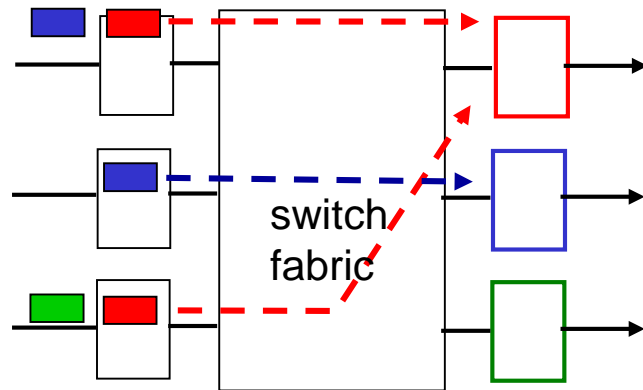
Switching via interconnection network

- scaling, using multiple switching “planes” in parallel:
 - speedup, scaleup via parallelism
- Cisco CRS router:
 - basic unit: 8 switching planes
 - each plane: 3-stage interconnection network
 - up to 100's Tbps switching capacity

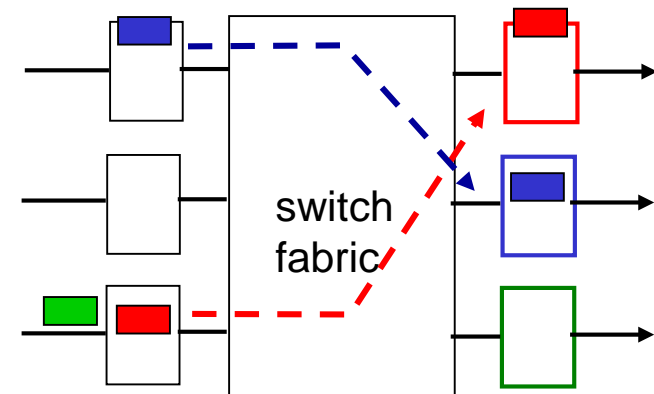


Input port queuing

- If switch fabric slower than input ports combined -> queueing may occur at input queues
 - queueing delay and loss due to input buffer overflow!
- **Head-of-the-Line (HOL) blocking:** queued datagram at front of queue prevents others in queue from moving forward

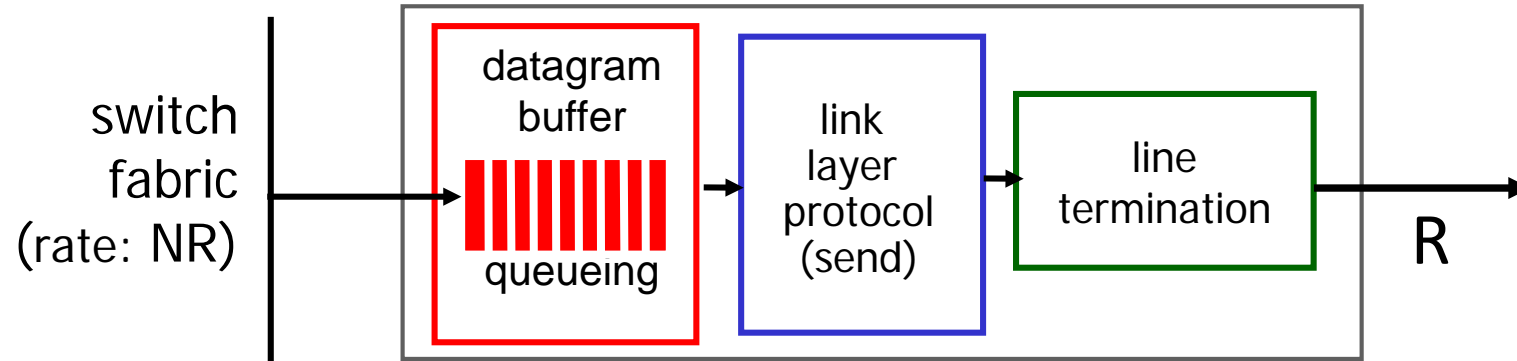


output port contention: only one red datagram can be transferred. lower red packet is *blocked*



one packet time later: green packet experiences HOL blocking

Output port queuing



This is a really important slide

- **Buffering** required when datagrams arrive from fabric faster than link transmission rate. **Drop policy**: which datagrams to drop if no free buffers?



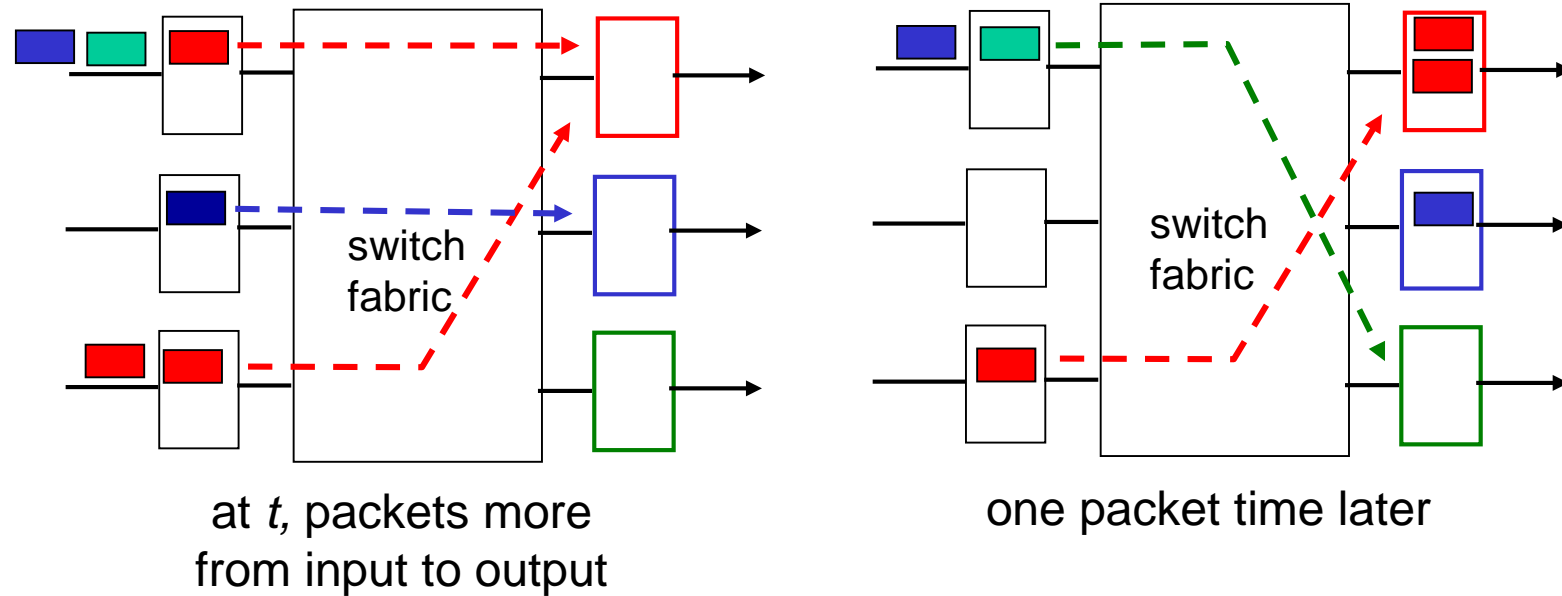
Datagrams can be lost due to congestion, lack of buffers

- **Scheduling discipline** chooses among queued datagrams for transmission



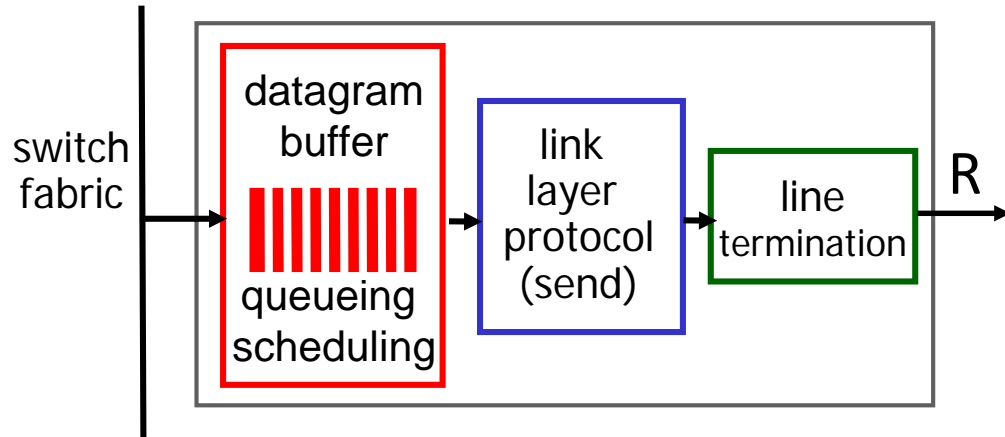
Priority scheduling – who gets best performance, network neutrality

Output port queuing

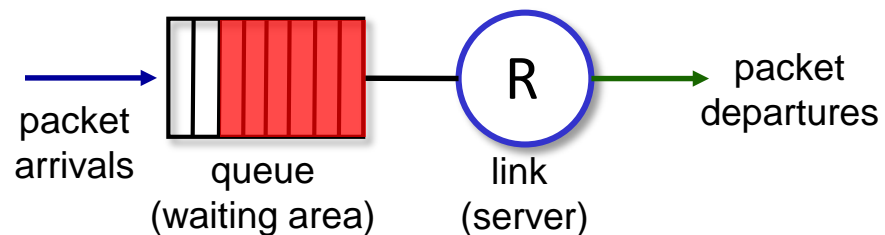


- buffering when arrival rate via switch exceeds output line speed
- *queueing (delay) and loss due to output port buffer overflow!*

Buffer Management



Abstraction: queue



buffer management:

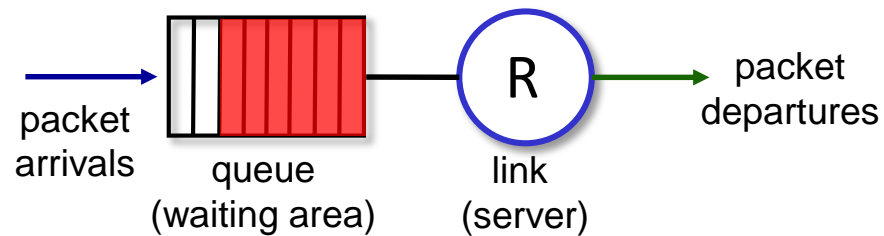
- **drop:** which packet to add, drop when buffers are full
 - **tail drop:** drop arriving packet
 - **priority:** drop/remove on priority basis
- **marking:** which packets to mark to signal congestion (ECN, RED)

Packet Scheduling: FCFS

packet scheduling: deciding which packet to send next on link

- first come, first served

Abstraction: queue



FCFS: packets transmitted in order of arrival to output port

- also known as: First-in-first-out (FIFO)
- real world examples?