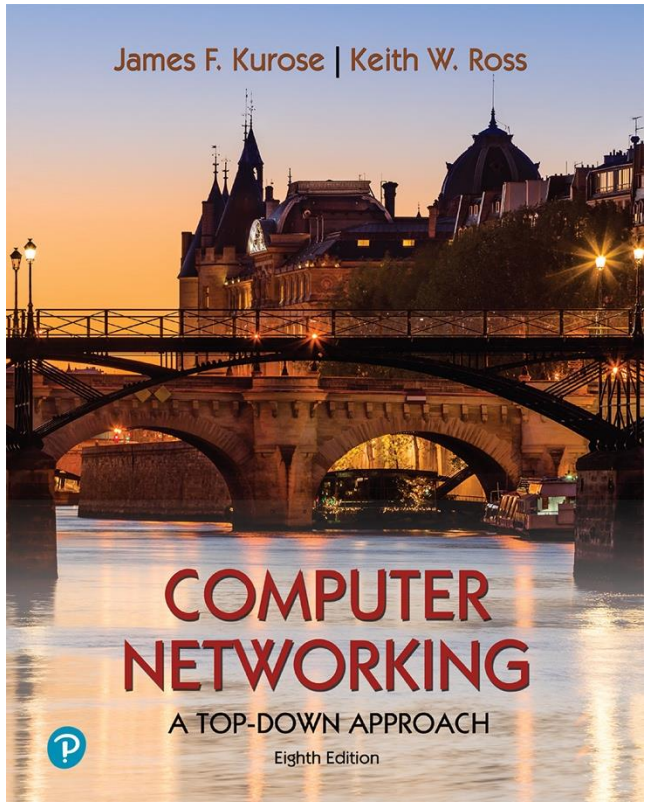
Computer Networks

Amir Mahdi Sadeghzadeh, Ph.D.

Chapter 4
Network Layer: Data Plane



Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Network layer: our goals

- understand principles behind network layer services, focusing on data plane:
  - network layer service models
  - forwarding versus routing
  - how a router works
  - addressing
  - generalized forwarding
  - Internet architecture
- instantiation, implementation in the Internet
  - IP protocol
  - NAT, middleboxes

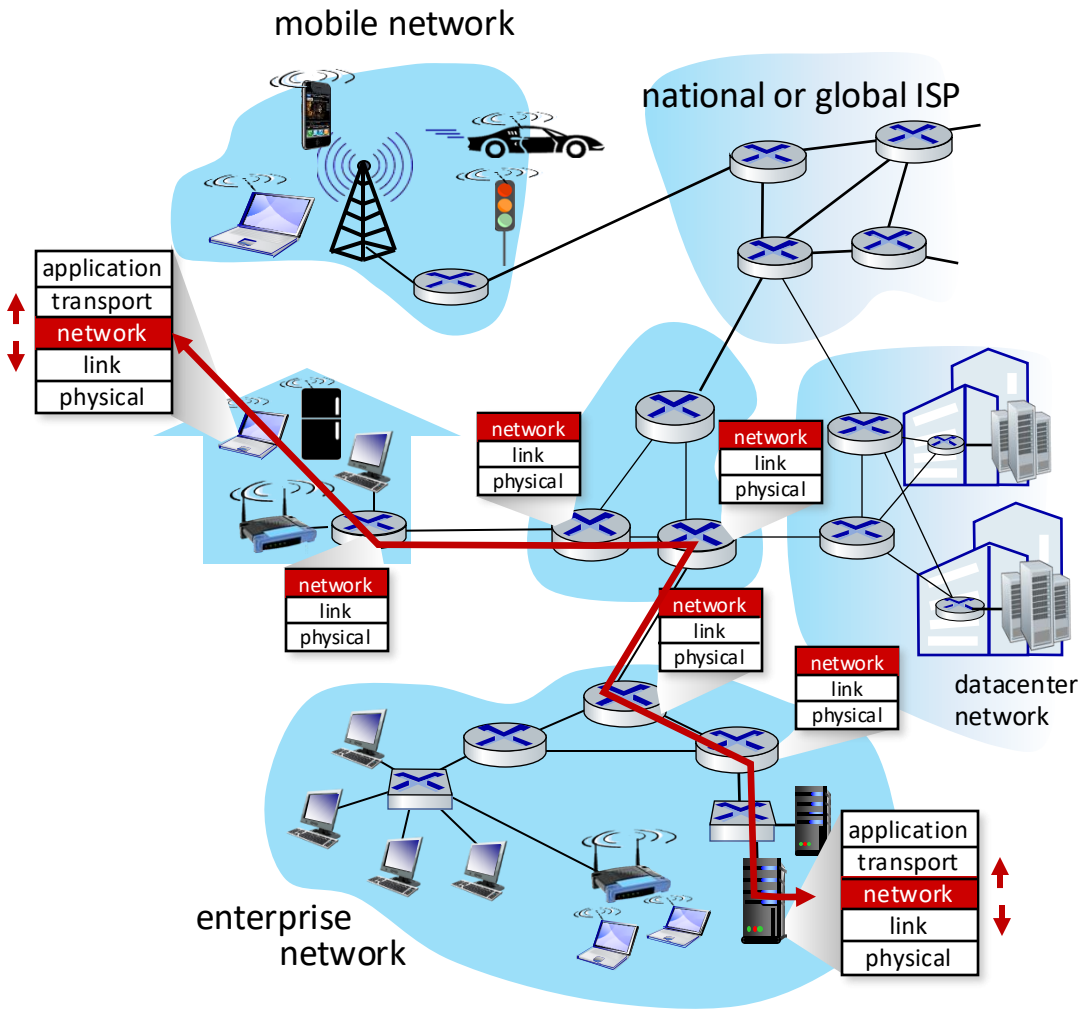
Network layer: "data plane" roadmap

- Network layer: overview
  - data plane
  - control plane
- What's inside a router
  - input ports, switching, output ports
  - buffer management, scheduling
- IP: the Internet Protocol
  - datagram format
  - addressing
  - network address translation
  - IPv6

- Generalized Forwarding, SDN
  - Match+action
  - OpenFlow: match+action in action
- Middleboxes

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

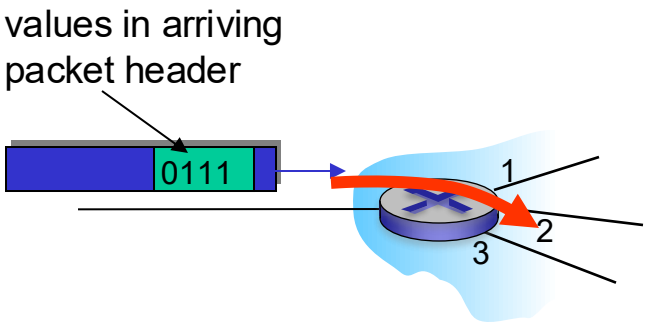
forwarding

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

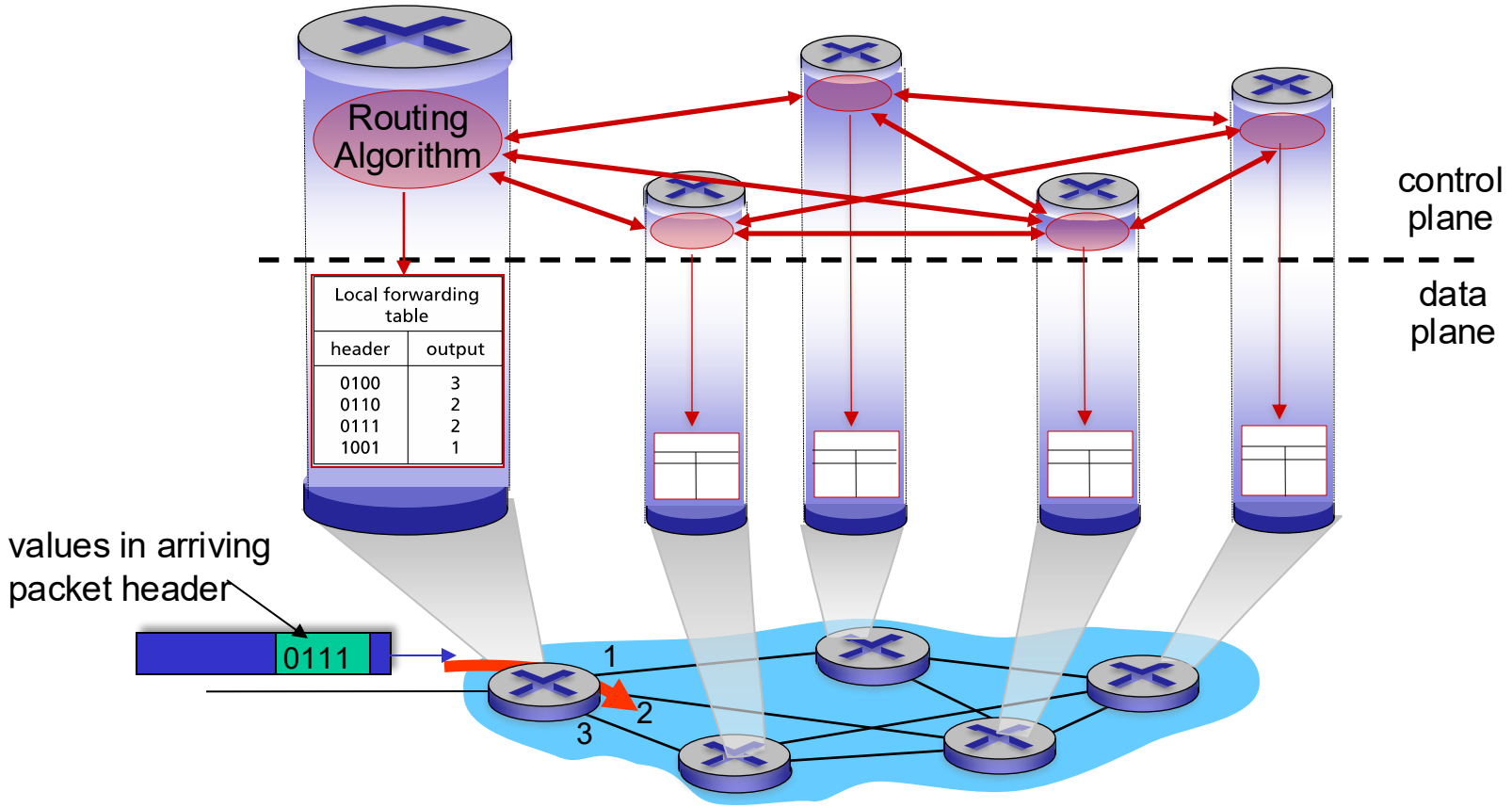


Control plane

- *network-wide* logic
- determines how datagram is routed among routers along end-end path from source host to destination host
- two control-plane approaches:
  - *traditional routing algorithms:* implemented in routers
  - *software-defined networking (SDN)*: implemented in (remote) servers

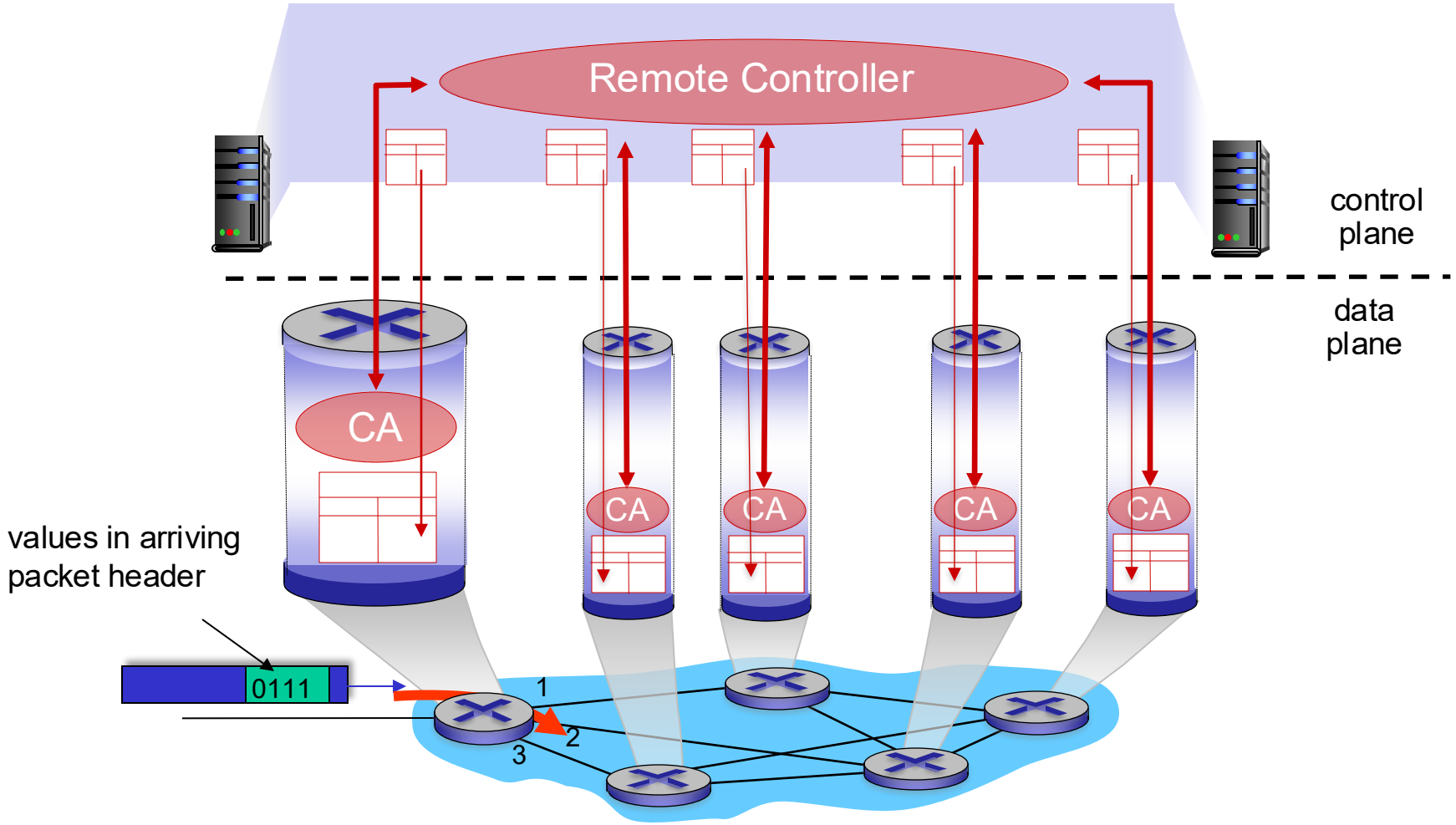
Per-router control plane

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



Software-Defined Networking (SDN) control plane

Remote controller computes, installs forwarding tables in routers



Network service model

Q: What *service model* for "channel" transporting datagrams from sender to receiver?

example services for *individual* datagrams:

- guaranteed delivery
- guaranteed delivery with less than 40 msec delay

example services for a *flow* of datagrams:

- in-order datagram delivery
- guaranteed minimum bandwidth to flow
- restrictions on changes in inter-packet spacing

Network-layer service model

Network Architecture	Service Model	Quality of Service (QoS) Guarantees ?			
		Bandwidth	Loss	Order	Timing
Internet	best effort	none	no	no	no

Internet "best effort" service model

No guarantees on:

i. successful datagram delivery to destination
ii. timing or order of delivery
iii. bandwidth available to end-end flow

Network-layer service model

Network Architecture	Service Model	Quality of Service (QoS) Guarantees ?			
		Bandwidth	Loss	Order	Timing
Internet	best effort	none	no	no	no
ATM	Constant Bit Rate	Constant rate	yes	yes	yes
ATM	Available Bit Rate	Guaranteed min	no	yes	no
Internet	Intserv Guaranteed (RFC 1633)	yes	yes	yes	yes
Internet	Diffserv (RFC 2475)	possible	possibly	possibly	no

Reflections on best-effort service:

- simplicity of mechanism has allowed Internet to be widely deployed adopted
- sufficient provisioning of bandwidth allows performance of real-time applications (e.g., interactive voice, video) to be "good enough" for "most of the time"
- replicated, application-layer distributed services (datacenters, content distribution networks) connecting close to clients' networks, allow services to be provided from multiple locations
- congestion control of "elastic" services helps

It's hard to argue with success of best-effort service model

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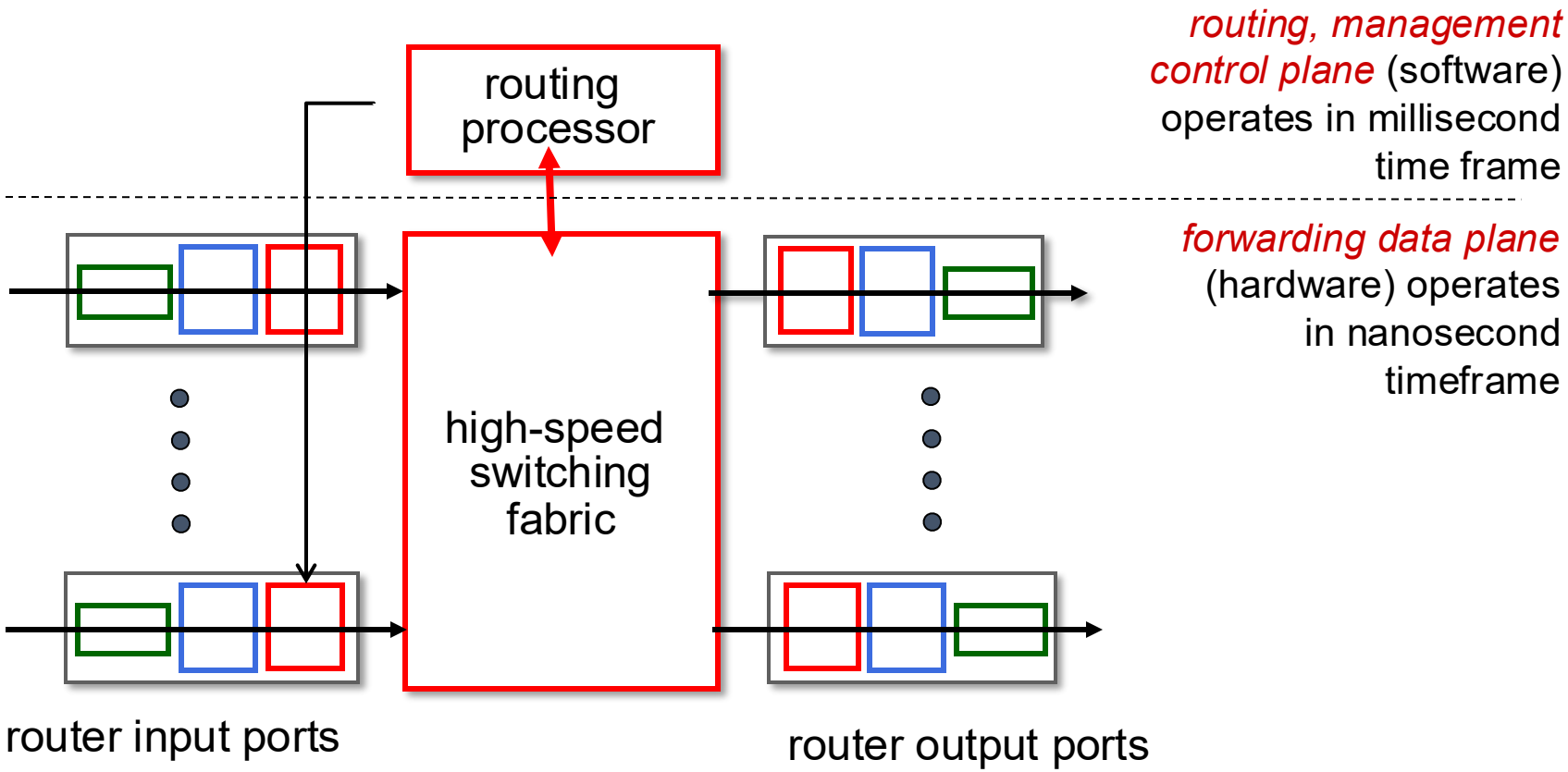
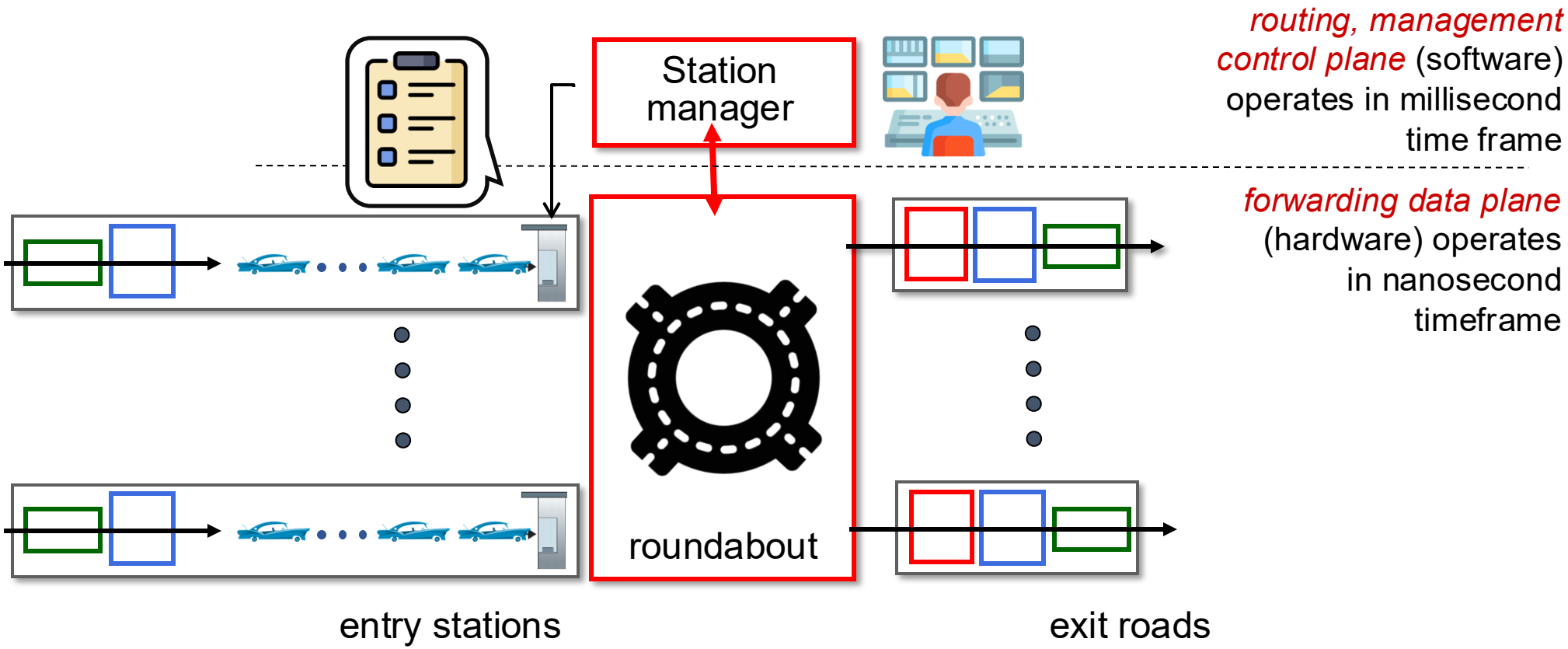
Router architecture overview

high-level view of generic router architecture:

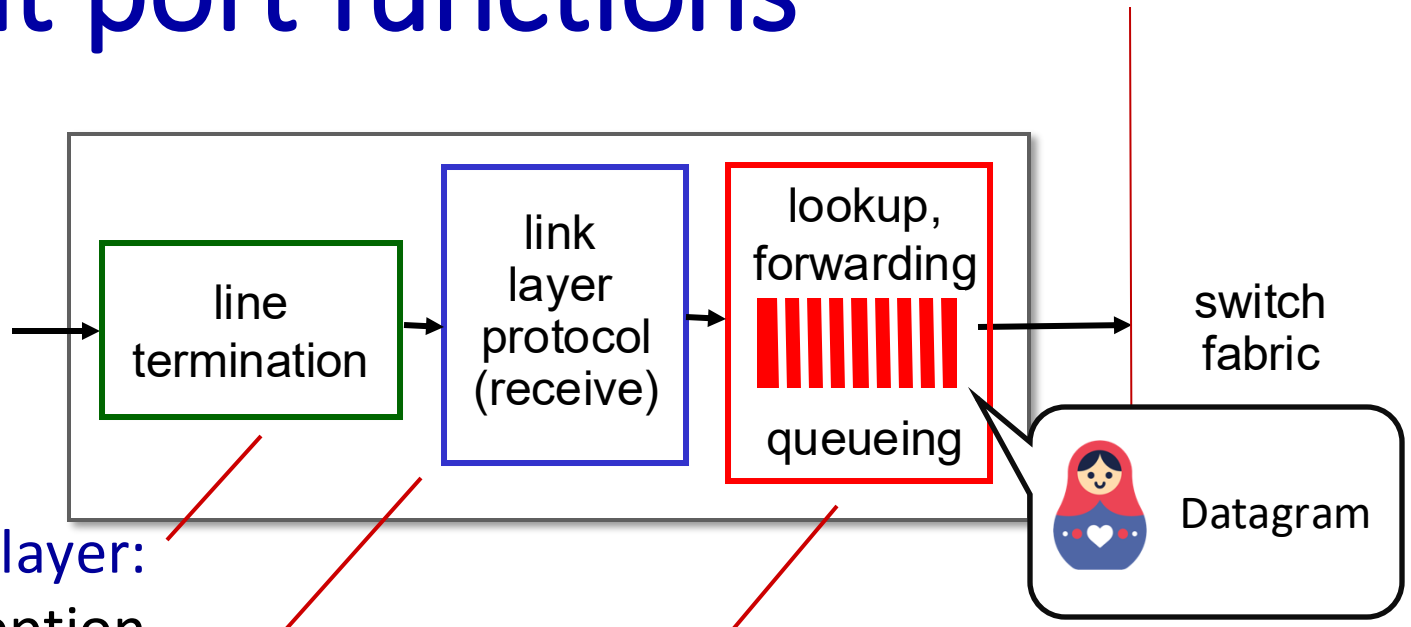


Router architecture overview

analogy view of generic router architecture:



Input port functions



physical layer:
bit-level reception

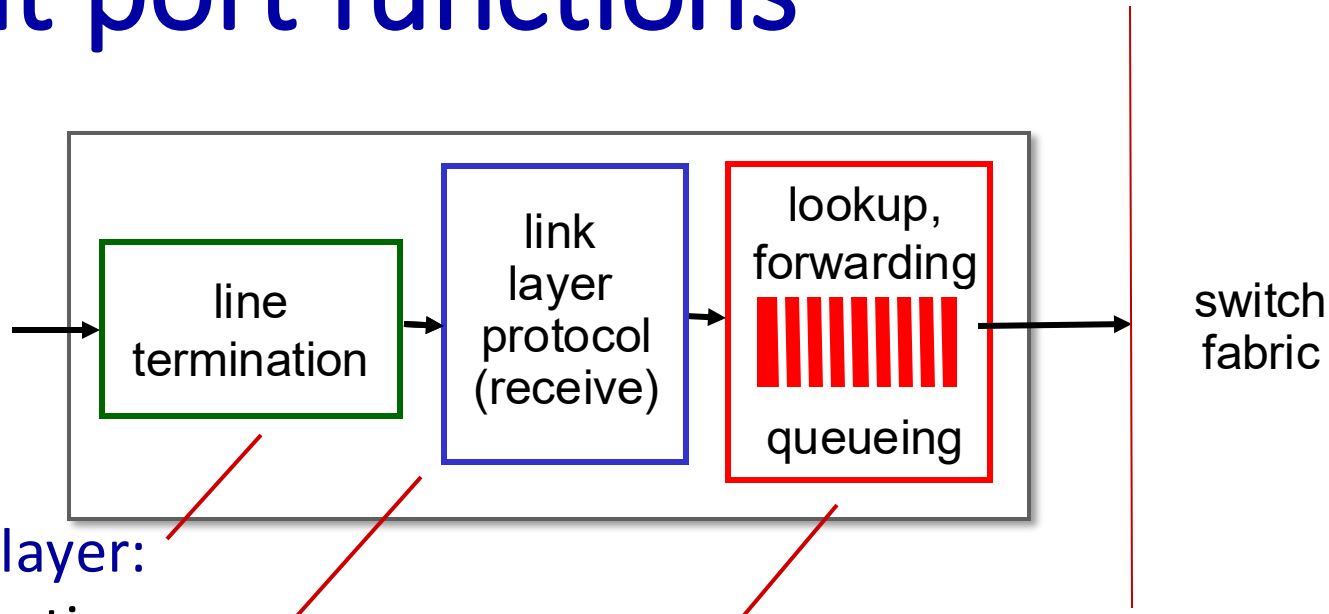
link layer:
e.g., Ethernet (chapter 6)


Frame

decentralized switching:

- using header field values, lookup output port using forwarding table in input port memory *("match plus action")*
- goal: complete input port processing at 'line speed'
- input port queuing: if datagrams arrive faster than forwarding rate into switch fabric

Input port functions



physical layer:
bit-level reception

link layer:
e.g., Ethernet
(chapter 6)

decentralized switching:

- using header field values, lookup output port using forwarding table in input port memory *("match plus action")*
- destination-based forwarding: forward based only on destination IP address (traditional)
- generalized forwarding: forward based on any set of header field values