Chapter 1 Introduction

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adapted from textbook slides by JFK/KWR

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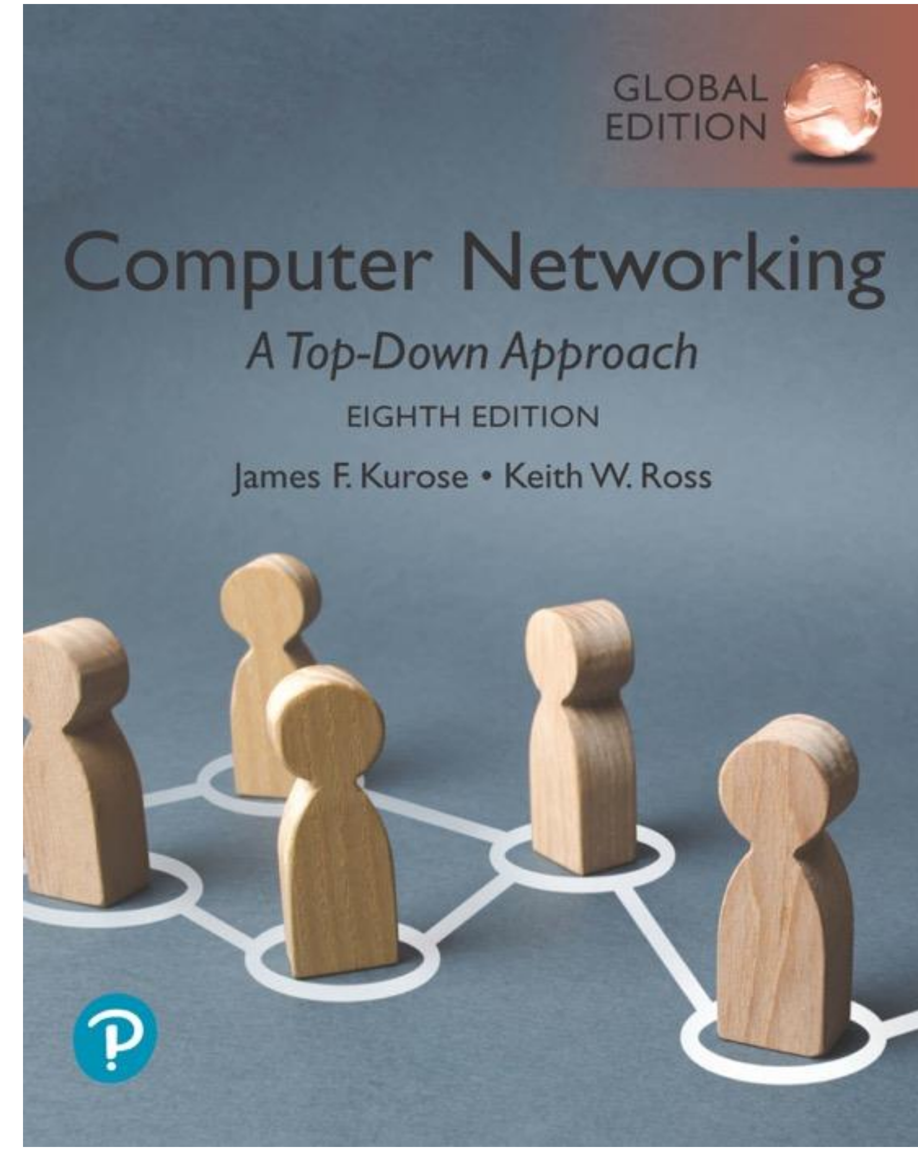


Computer Networking: A Top-Down Approach
8th edition, Global Edition
Jim Kurose, Keith Ross

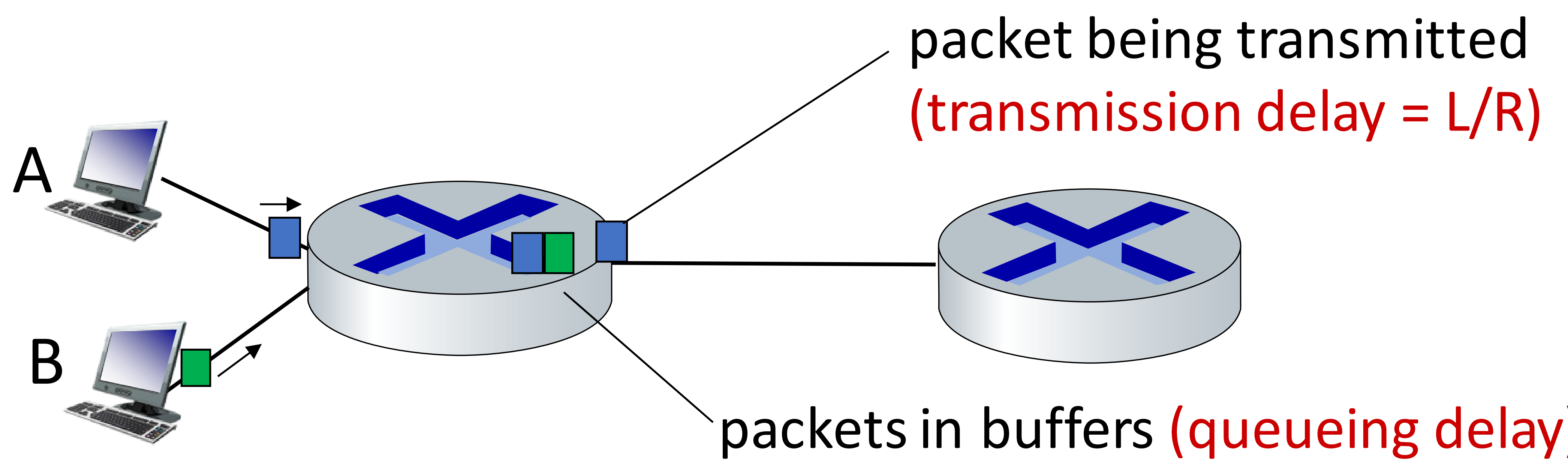
Chapter 1: roadmap

- 1.1 What is the Internet?
- 1.2 Network edge: hosts, access network, physical media
- 1.3 Network core: packet/circuit switching, internet structure
- 1.4 Performance: loss, delay, throughput
- 1.5 Protocol layers, service models
- ~~1.6 Network Under Attack~~
- 1.7 History

Queueing Dealy

packets *queue* in router buffers

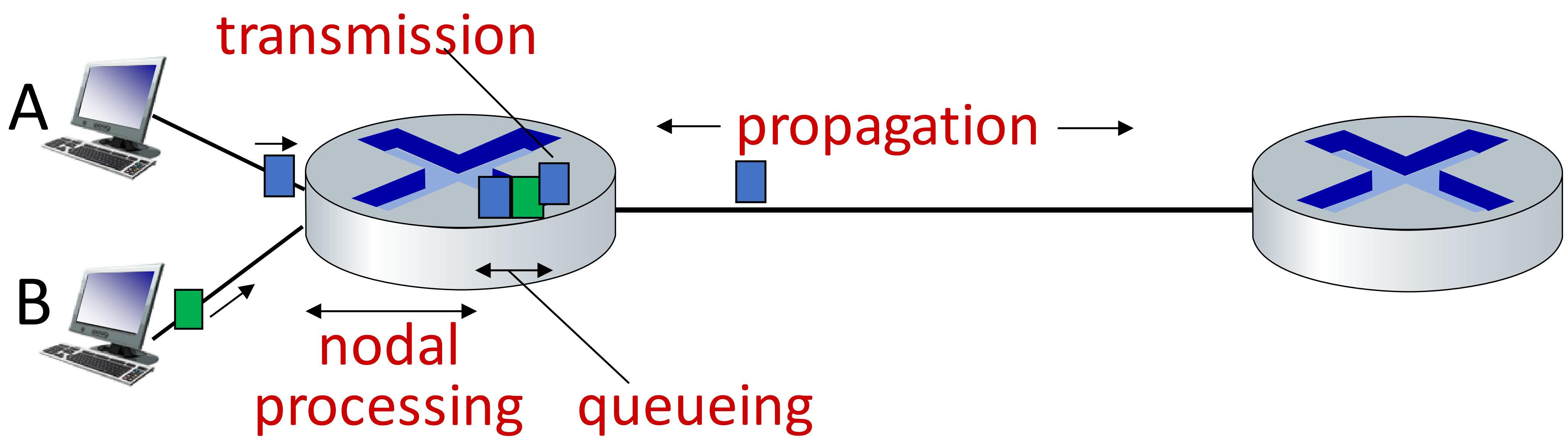
- packets queue, wait for turn.
  - e.g. when blue packet arrives, it finds 2.5 packets in front of it → queueing delay



Blue packet - *Queueing Delay = 2.5 * L/R*

Blue packet – *total Delay = 2.5*L/R + L/R ... more to come ...*

Packet delay: four sources



$$D_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

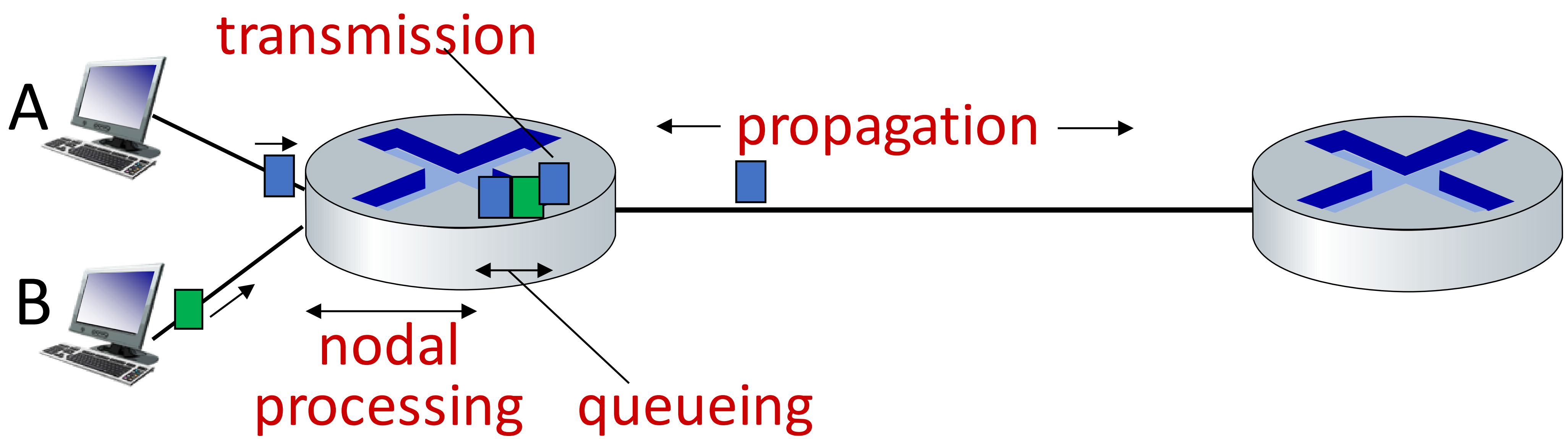
d_{proc}: nodal processing

- check bit errors
- determine output link
- typically < msec

d_{queue}: queueing delay

- time waiting at output link for transmission
- depends on congestion level of router
- $d_{\text{queue}} = 2.5*L/R$

Packet delay: four sources



$$D_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

d_{trans}: transmission delay:

- *L*: packet length (bits)
- *R*: link *transmission rate (bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay:

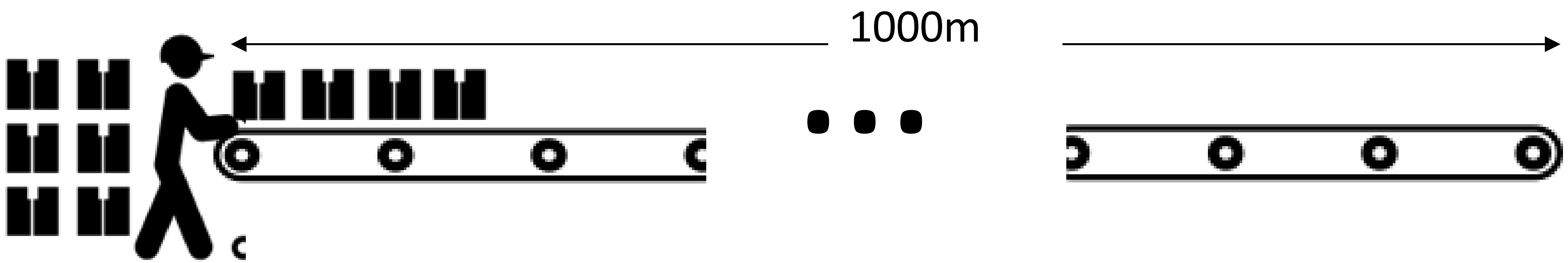
- *d*: length of physical link
- *s*: propagation speed (~2x10^8 m/sec)
- $d_{prop} = d/s$

d_{trans} and d_{prop} *very* different

* Check out the online interactive exercises: http://gaia.cs.umass.edu/kurose_ross

Conveyor belt analogy

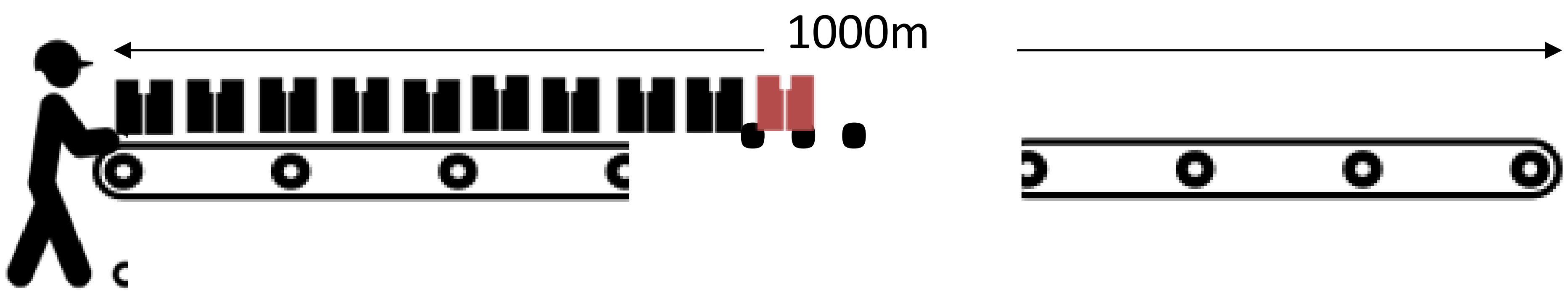
A worker is loading a batch of 10 boxes onto the conveyer belt.



- The worker takes *1* second to load one box onto belt (loading rate *1b/s*)
- conveyor belt move forward (propagation rate) at *10m/s*
- box ~ bit; 10box batch ~ packet
- *Q:* How long until the batch reaches the other end?
- time to load entire batch onto the belt
  $d_{trans} = 10b/(1b/s) = 10s$
- time for boxes to "propagate" to the other end:
  $d_{prop} = 1000m/(10m/s) = 100s$
- *A:* $d_{end\text{-}to\text{-}end} = d_{trans} + d_{prop}$
  $= 10 + 100$
  $= 110s$

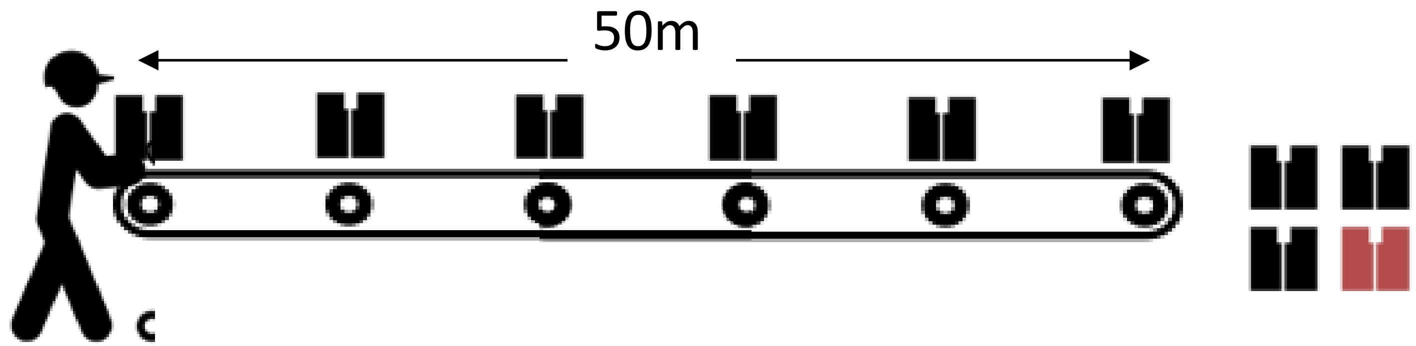
Conveyor belt analogy

A worker is loading a batch of 10 boxes onto the conveyer belt.



- at time $t{=}d_{trans}{=}10s$, where is the last box/bit?
  - Answer: the last box is being loaded onto the belt/link
- at time $t{=}d_{trans}{=}10s$, where is the first box/bit?
  - Answer: the first box hasn't reached the end (on the belt/link)
- at time $t{=}d_{prop}{=}100s$, where is the first box/bit?
  - Answer: the first box is just reaching the end

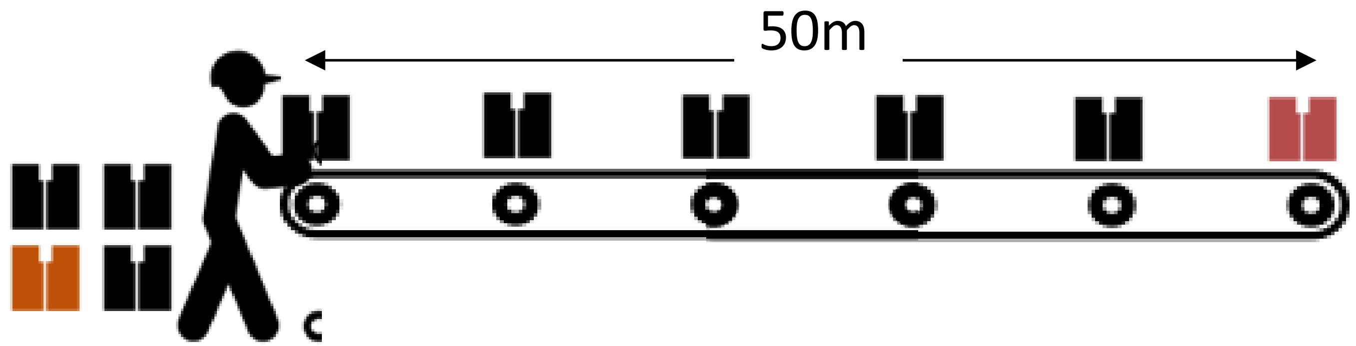
Conveyor belt analogy (more)



- suppose the belt length is 50m now
- at time $t=d_{trans}=10s$, where is the last box/bit?
  - Answer: the last box is being loaded onto the belt/link
- at time $t=d_{trans}=10s$, where is the first box/bit?
  - Answer: the fist box has reached the destination.

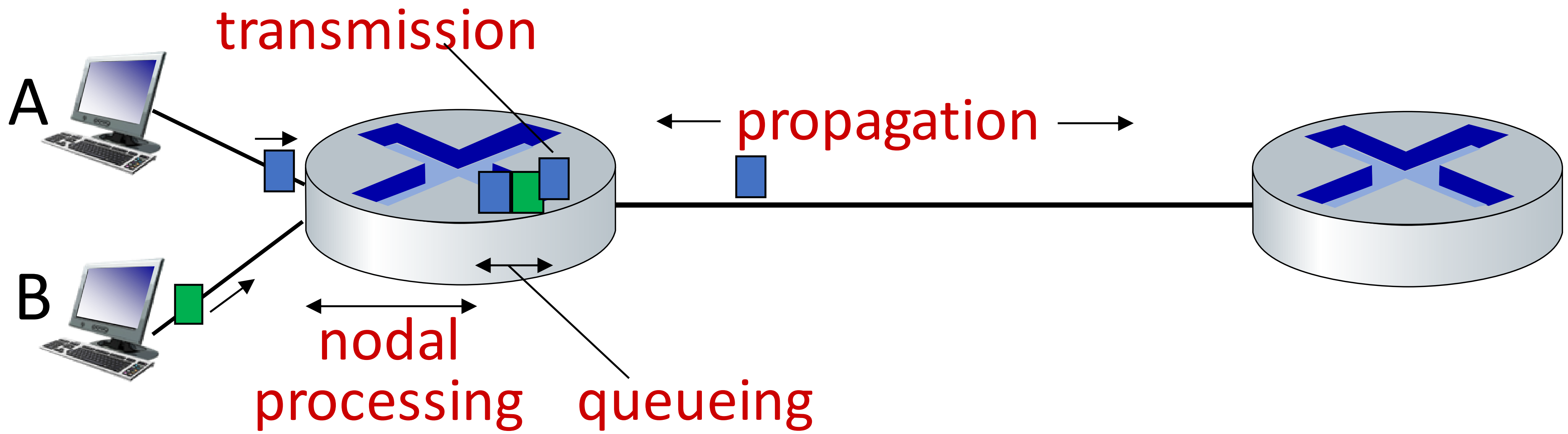
Think:
Propagation delay?

Conveyor belt analogy (more)



- suppose the belt length is 50m now
- at time $t=d_{prop}=5s$, where is the first box/bit?
  - Answer: the fist box is just reaching the destination.
- at time $t=d_{prop}=5s$, where is the last box/bit?
  - Answer: the last box is still in the source, not loaded

Packet delay: four sources



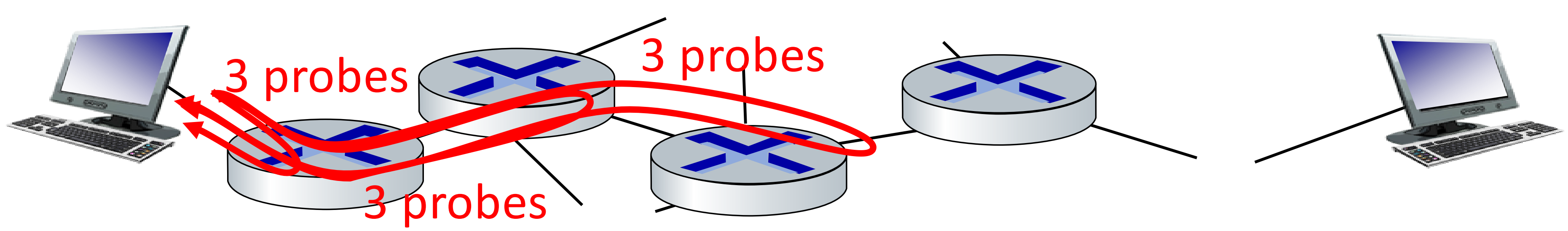
Nodal delay:

- d_{proc} = $2ms$
- d_{queue} = $2.5*L/R$
- d_{trans} = L/R
- d_{prop} = d/s

$$D_{\mathrm{nodal}} = d_{\mathrm{proc}} + d_{\mathrm{queue}} + d_{\mathrm{trans}} + d_{\mathrm{prop}} = 2ms + 2.5*L/R + L/R + d/s$$

“Real” Internet delays and routes

- what do “real” Internet delay & loss look like?
- **traceroute** program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
  - sends three packets that will reach router *i* on path towards destination (with time-to-live field value of *i*)
  - router *i* will return packets to sender
  - sender measures time interval between transmission and reply



Real Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

3 delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu  (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu  (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net  (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net  (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu  (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu  (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms  109 ms  106 ms
9  de2-1.de1.de.geant.net  (62.40.96.129)  109 ms  102 ms  104 ms
10  de.fr1.fr.geant.net  (62.40.96.50)  113 ms  121 ms  114 ms
11  renater-gw.fr1.fr.geant.net  (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net  (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

3 delay measurements to border1-rt-fa5-1-0.gw.umass.edu

trans-oceanic link

looks like delays *decrease*! Why?

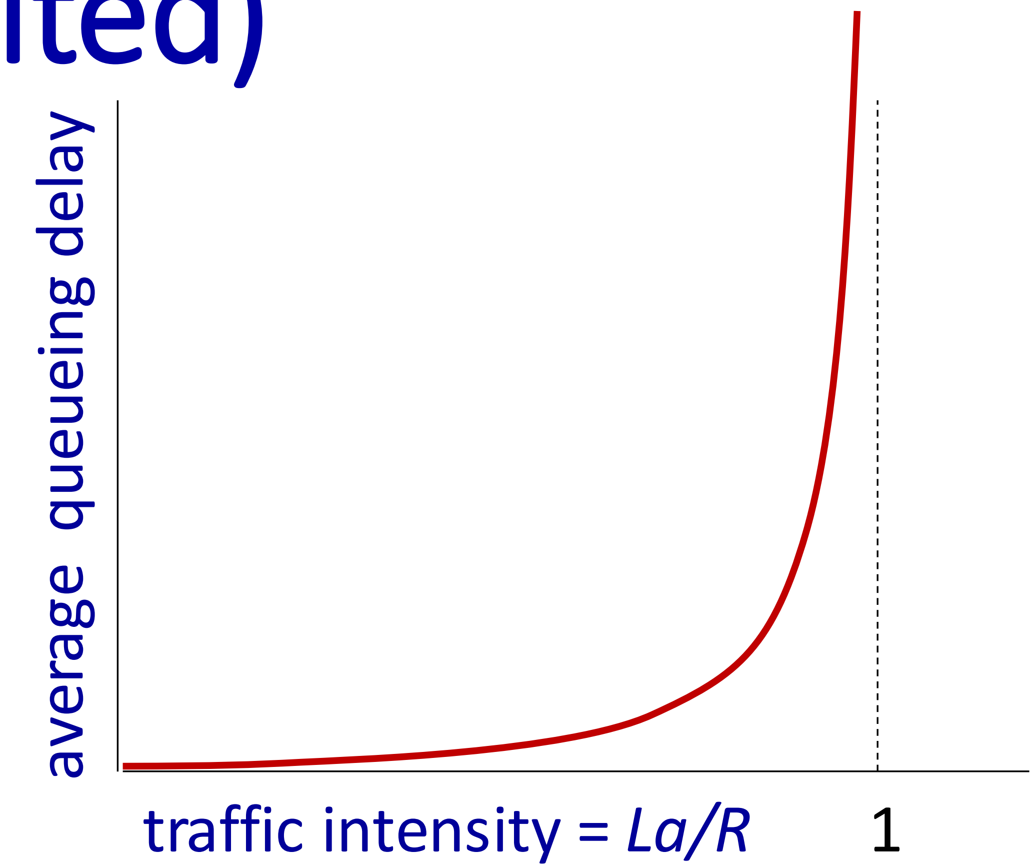
* means no response (probe lost, router not replying)

Try this in your Lab

* Do some traceroutes from exotic countries at www.traceroute.org

Packet queueing delay (revisited)

- *R:* link bandwidth (bps)
- *L:* packet length (Bytes→bits)
- *a:* average packet arrival rate (packet/s)
- Arrival rate: La (bps)
- $\boxed{\text{Traffic intensity: La/R}}$



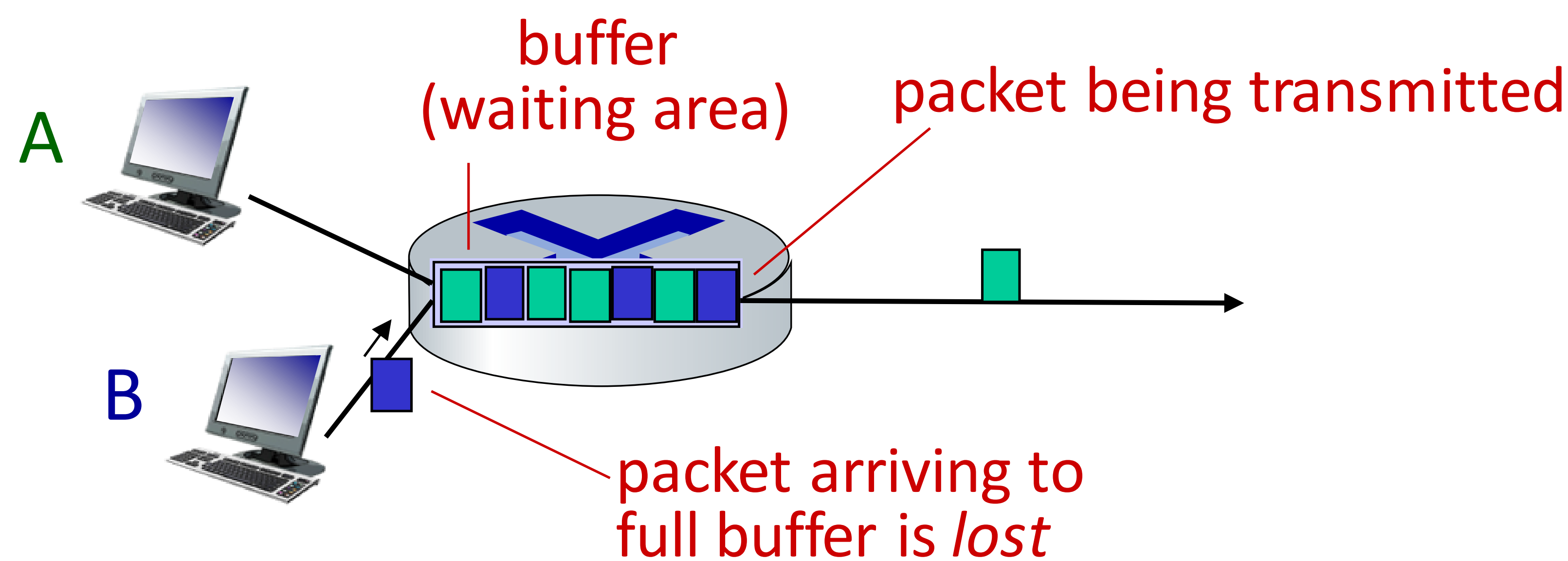
- *La/R* ~ 0: avg. queueing delay small
- *La/R* → 1: avg. queueing delay large
- *La/R* > 1: more "work" arriving is more than can be serviced - average delay infinite!

La/R ~ 0

La/R → *1*

Packet loss

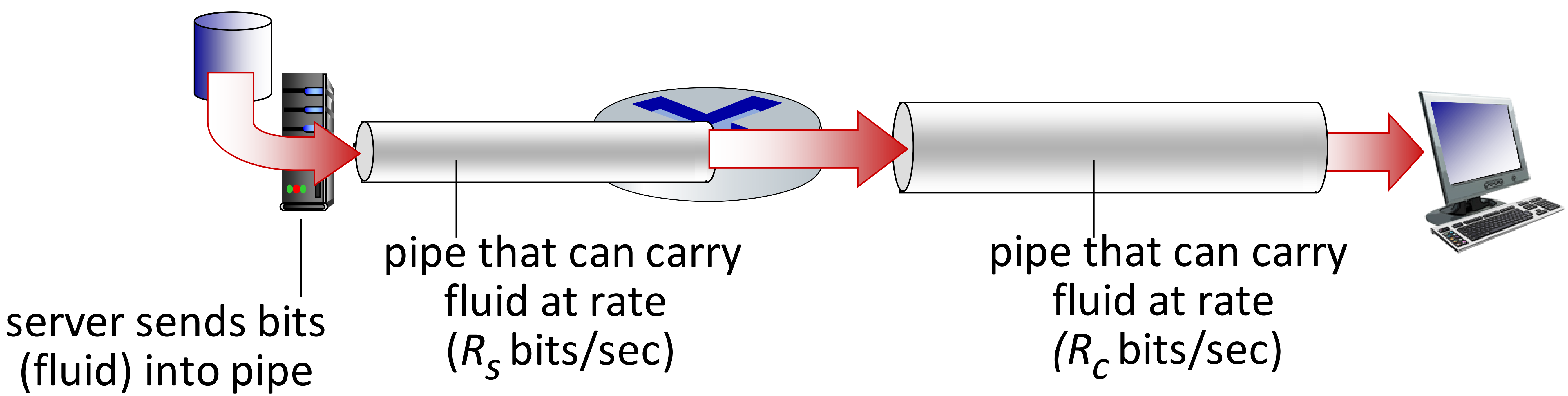
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



* Check out the Java applet for an interactive animation on queuing and loss

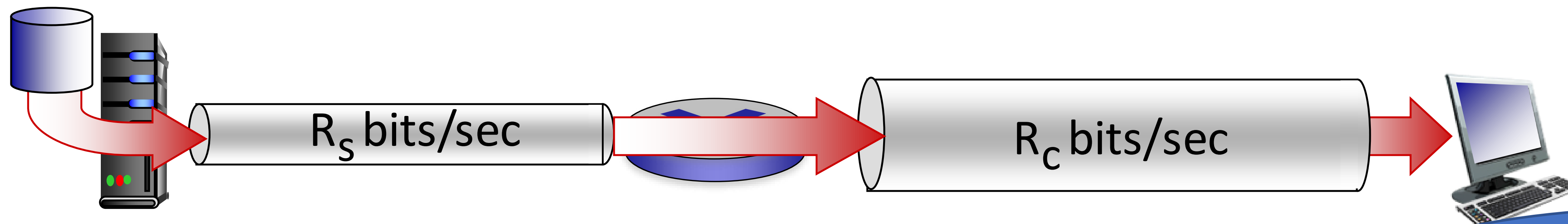
Throughput

- *throughput:* rate (bits/time unit) at which bits are being sent from sender to receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time



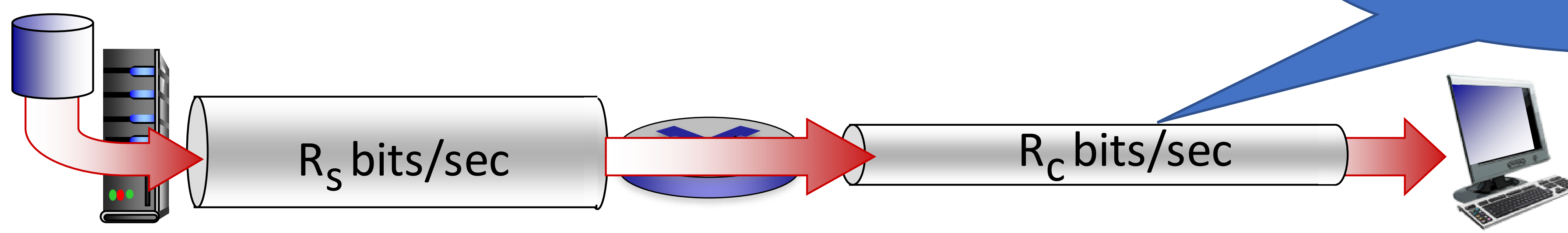
Throughput

$R_s < R_c$ What is average end-end throughput?



$R_s > R_c$ What is average end-end throughput?

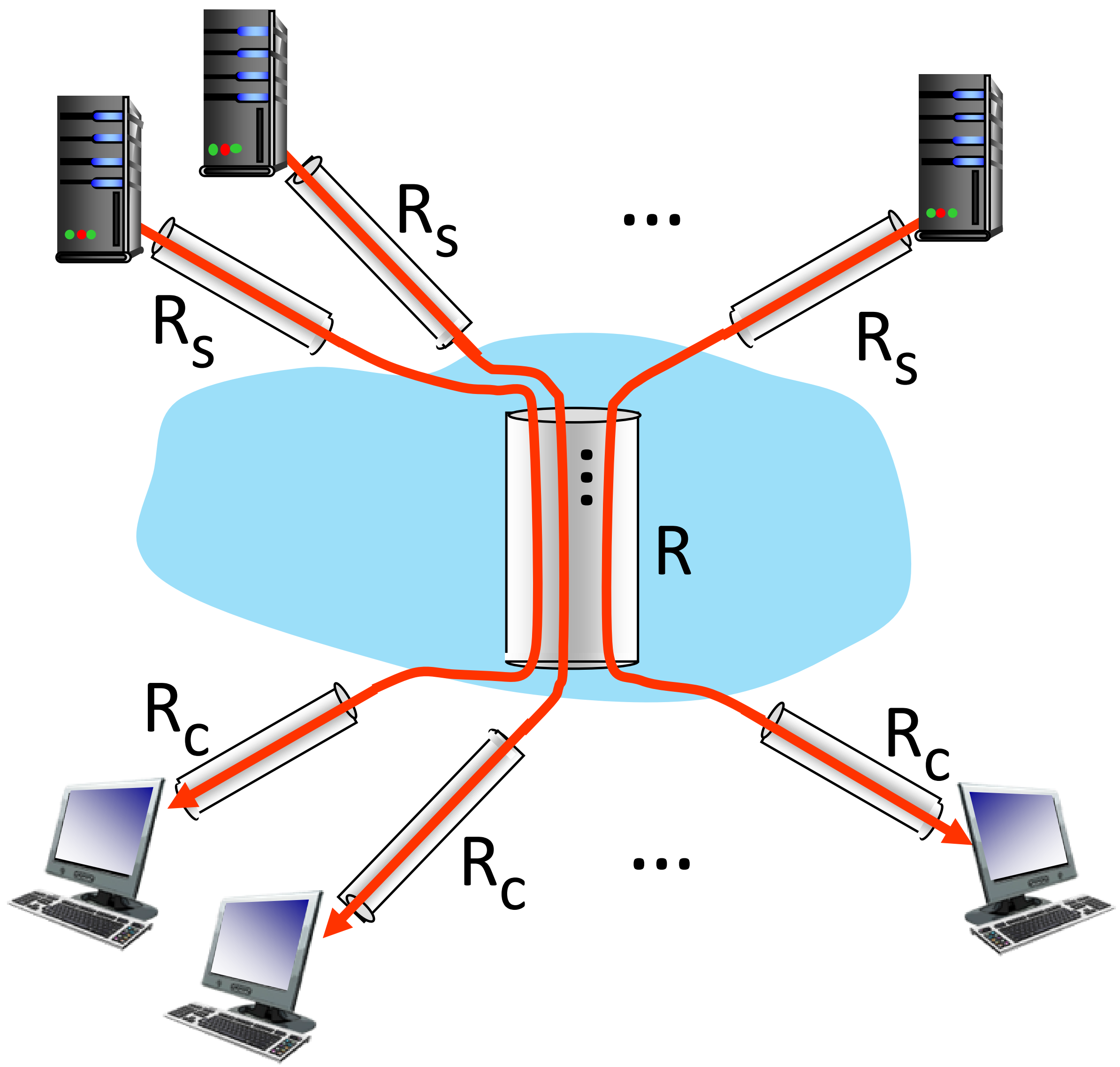
Weakest link
➔ Average throughput



bottleneck link

link on end-end path that constrains end-end throughput

Throughput: network scenario



10 connections (fairly) share backbone bottleneck link *R* bits/sec

- per-connection end-end throughput: *min(R_c,R_s,R/10)*
- in practice: R_c or R_s is often bottleneck

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/

Mid-break

- Q & A

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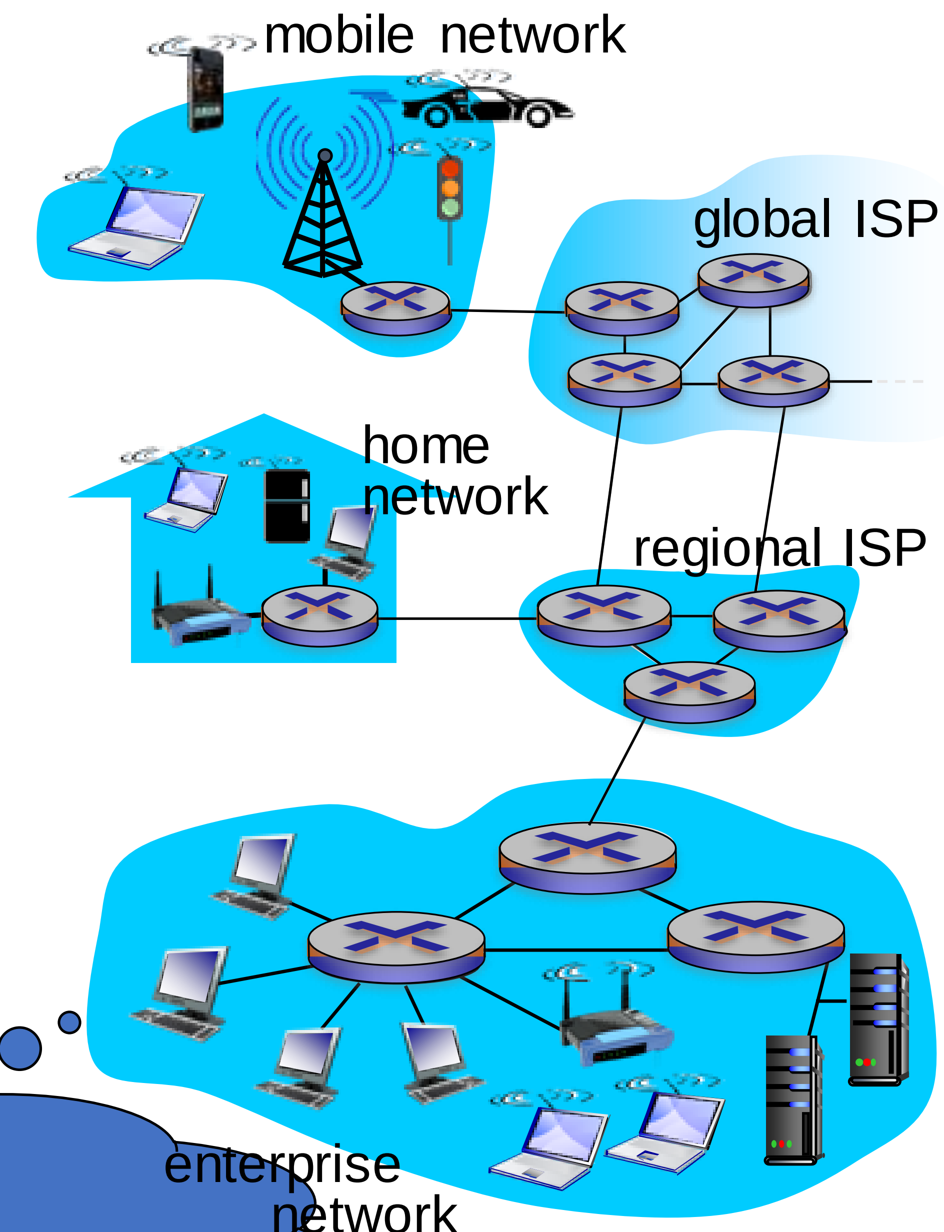
Recap Internet Intro from Week1

Networks are complex, with many "pieces":

- hosts: clients / servers
- switches/routers
- links of various media
- network types
- packet transmission

Putting pieces together

- Structure: network of networks



How do they operate?
What is the operation structure?

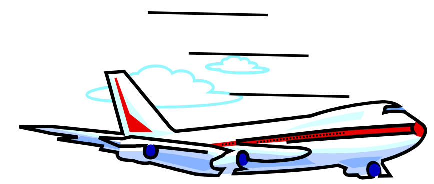
Analogy: Australia Post

letter writing	letter reading
postman pick up	postman delivery
distribute	distribute
truck delivery	truck delivery

airplane / ship transport

- a series of steps, involving services at different parts/layers

Layering of Australia Post



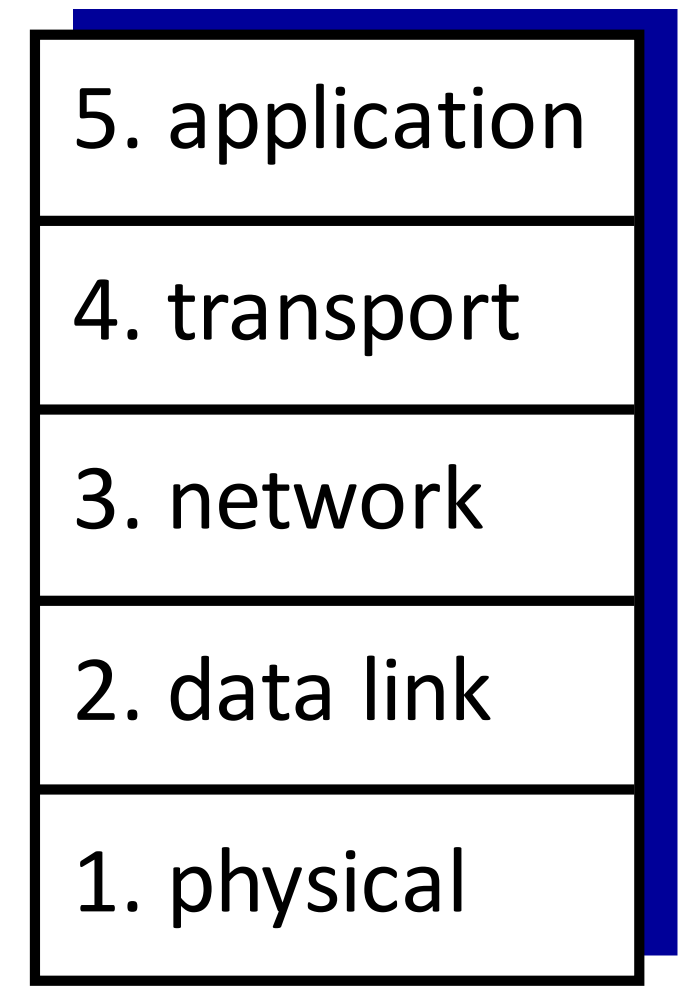
Focus on one job that you are best at!

layers: each layer implements a service

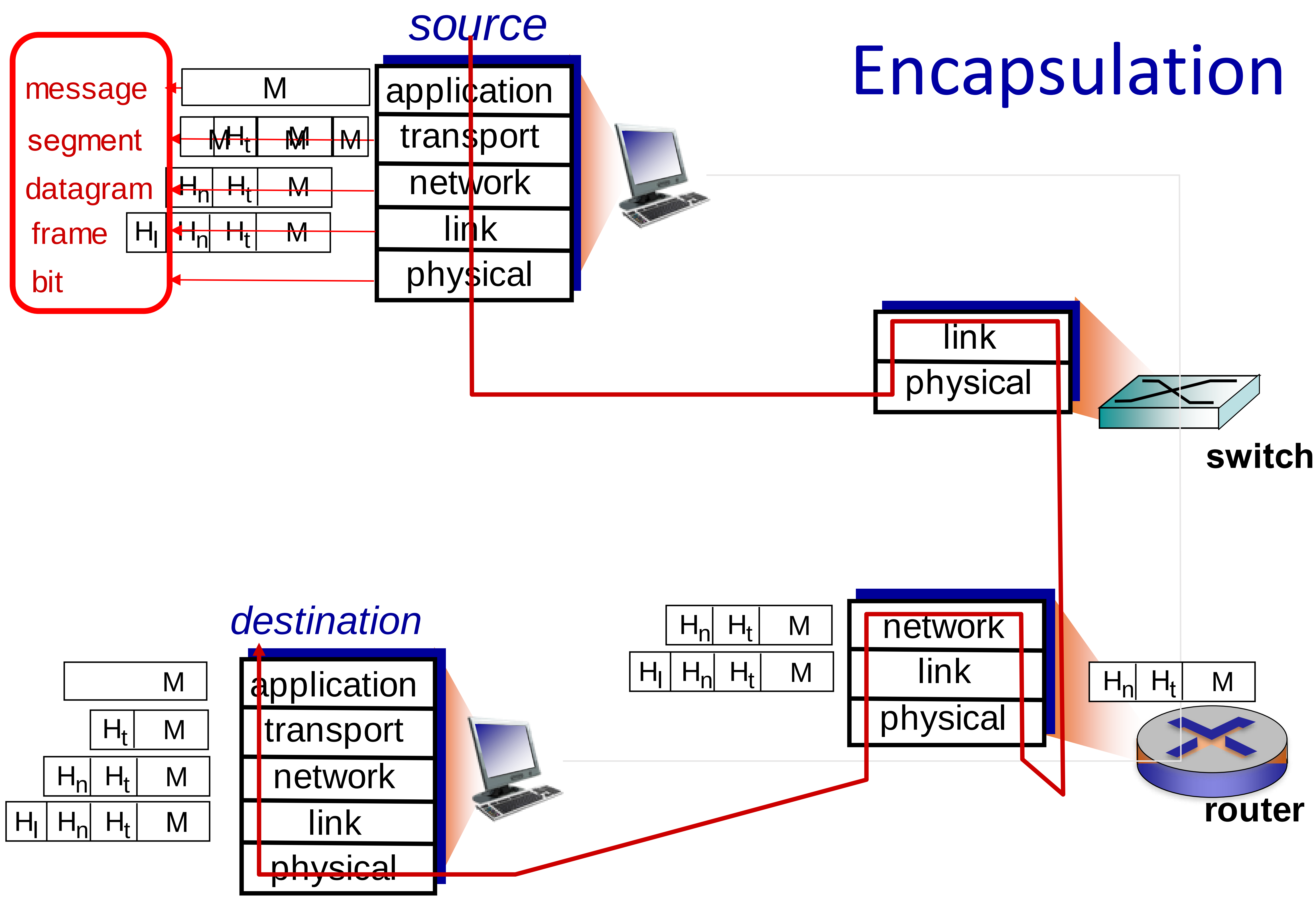
- via its own internal-layer actions
- relying on services provided by layer below

Internet protocol stack

- *Layer 5. application:* supporting network applications
  - IMAP, SMTP, HTTP
- *Layer 4. transport:* process-process data transfer
  - TCP, UDP
- *Layer 3. network:* routing of datagrams from source to destination
  - IP, routing protocols
- *Layer2. link:* data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi), PPP
- *Layer1. physical:* bits "on the wire"



Encapsulation



Why layering?

dealing with complex systems:

- explicit structure allows identification, relationship of complex system's pieces
  - layered *reference model* for discussion
- modularization eases maintenance, updating of system
  - change in layer's service *implementation*: transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system

- Focus on what you do best!

Protocol layers ⇔ Company products

5.application	Facebook, Netflix, WeChat, YouTube
4. transport	MS Windows, MacOS, Google Android
3. network	Telstra, Optus, Cisco, Juniper
2. link	Ericsson basestation, Intel WiFi chip
1. physical	CommScope, Corning, Inc. Fujikura

Focus on what you do best!

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~~1.6 Network Under Attack~~

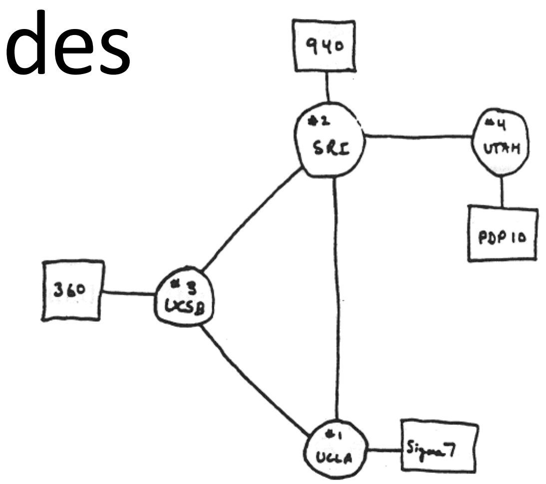
1.7 History

Internet history

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational

- 1972:
  - ARPAnet public demo
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



THE ARPA NETWORK

Internet history

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best-effort service model
- stateless routing
- decentralized control

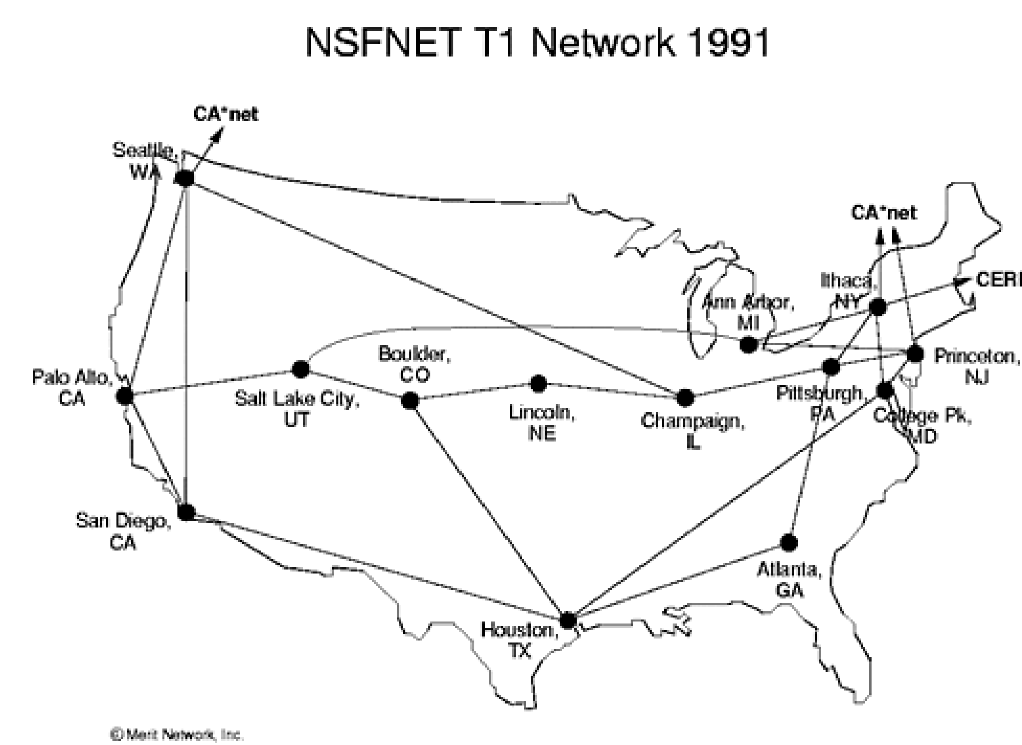
define today's Internet architecture

Internet history

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1988: TCP congestion control

- new national networks: CSnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks



Internet history

1990, 2000s: commercialization, the Web, new applications

- early 1990s: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990s: commercialization of the Web

late 1990s – 2000s:

- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

Internet history

2005-present: more new applications, Internet is "everywhere"

- ~18B devices attached to Internet (2017)
  - rise of smartphones (iPhone: 2007)
- aggressive deployment of broadband access
- increasing ubiquity of high-speed wireless access: 4G/5G, WiFi
- emergence of online social networks:
- Facebook: ~ 2.5 billion users
- service providers (Google, FB, Microsoft) create their own networks
  - bypass commercial Internet to connect "close" to end user, providing "instantaneous" access to search, video content, …
- enterprises run their services in "cloud" (e.g., Amazon Web Services, Microsoft Azure)

Chapter 1: summary

We've covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, access network, core
  - packet-switching versus circuit-switching
  - Internet structure
- performance: loss, delay, throughput
- layering, service models
- history

You now have:

- context, overview, vocabulary, "feel" of networking
- more depth, detail, *and fun* to follow*!*

Assignment 1. Internet Introduction

- Earn 5% in NetFun
  - Based on weeks 1 and 2 learning materials
  - Please answer questions in specified format - **strictly!**
- Timing
  - No time limit, has due date.
  - Submit before the due date: **Sunday, 3rd March**
  - NO late submission accepted!

Lecture done ✅

- Q & A