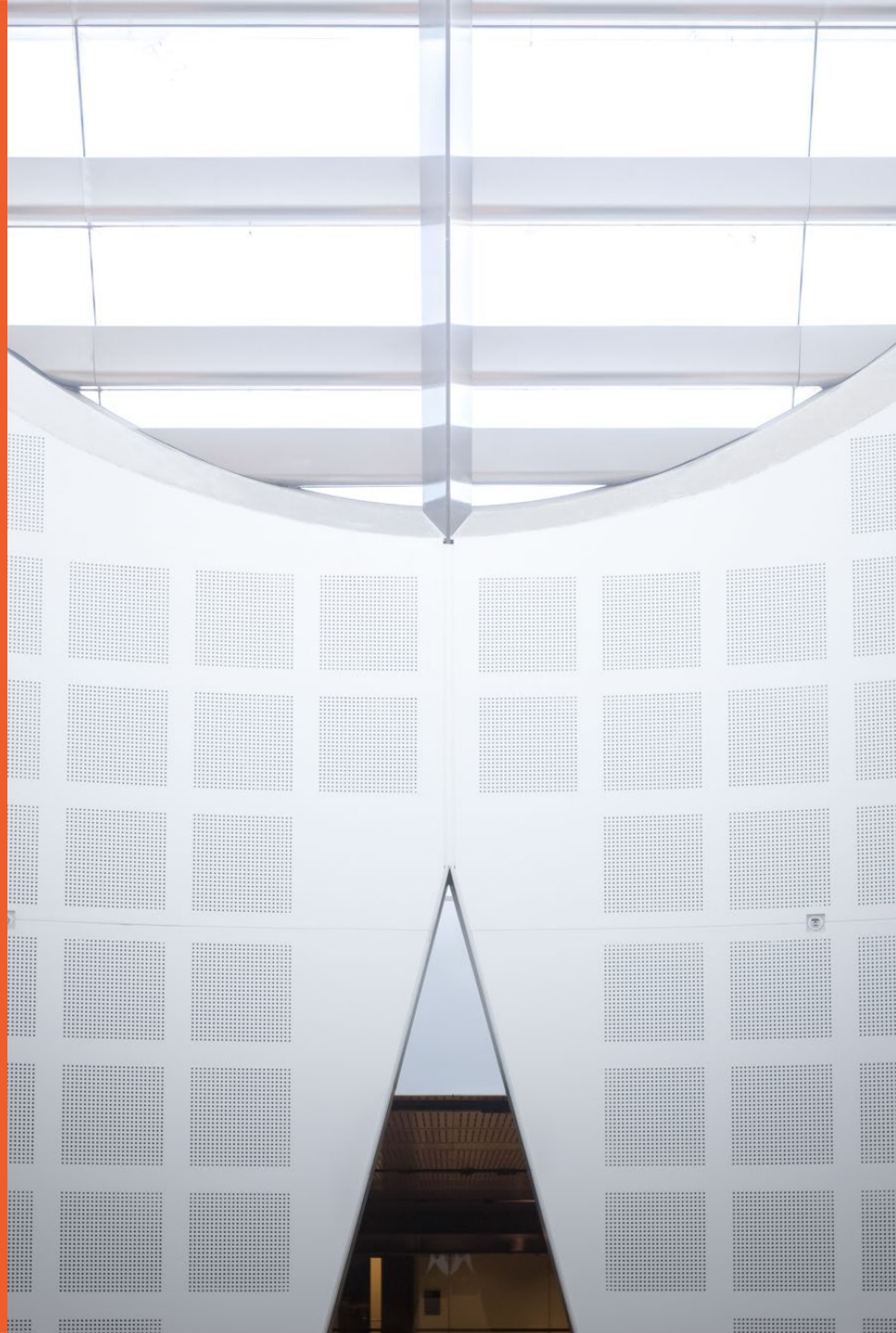
COMP9121: Design of Networks and Distributed Systems

Week 1: Introduction and Overview

Wei Bao

School of Computer Science

THE UNIVERSITY OF SYDNEY



Welcome

Emergency procedures (on campus)

- In the unlikely event of an emergency, we may need to evacuate the building.
- If we need to evacuate, we will ask you to take your belongings and follow the green exit signs.
- We will move a safe distance from the building and maintain physical distancing whilst waiting until the emergency is over.
- In some circumstances, we might be asked to remain inside the building for our own safety. We call this a lockdown or shelter-in-place.
- More information is available at www.sydney.edu.au/emergency.

Keeping our campus COVID-safe

- The University is following NSW Government and NSW Health guidance to prevent the spread of COVID-19, respiratory-type illnesses and other illnesses.
- All staff, students and visitors are required to follow our health and safety advice. This includes staying at home if unwell, isolating and testing, and to not return unless recovered or as advised by your health professional.
- Visit our website for more information about our COVID-19 response.

Health and safety advice

Stay home if you are sick

Wash hands regularly

Avoid physical greetings

Cough or sneeze into your elbow or tissue

Keep 1.5m away from others where possible

Avoid crowding entrances and exits

sydney.edu.au/covid-19

THE UNIVERSITY OF SYDNEY

COVID-19 support and care

- If you become infected with COVID-19 during the semester, or need to stay at home, please notify your unit of study coordinator, as with any unexpected absence.
- If COVID-19 illness impacts assessment, use the usual mechanisms including simple extensions and special consideration to arrange reasonable adjustments.
- Other helpful study information can be found on the Study Information page of Student website.

Student support

- Visit the Student life, wellbeing and support webpage to find out about the student services, resources and events available to support you while you study:
  - Health and wellbeing
  - Academic Support
  - Personal support
  - Getting connected

Questions about getting started this semester? Come visit us at a Welcome Hub

Anderson Stuart
Welcome Hub

Carslaw West
Welcome Hub

Safer Communities Office

- Support and case management for people who have experienced sexual misconduct, domestic/family violence, bullying/harassment or issues relating to modern slavery.
- Contact the team
  - 8:30 am to 5:30 pm Monday to Friday, Sydney local time
  - phone: +61 2 8627 6808
  - email: safer-communities.officer@sydney.edu.au.
  - campus: Level 5, Jane Foss Russell building, City Road, Darlington Campus
- Make a report
  - Visit the website to make a complaint or disclosure of sexual misconduct to the University.

Agenda

- Unit arrangements
- Expectations
- Assessment
  - Unit details
  - Policies
- Workplace Health and Safety
- Assistance
- Advice

COMP9121: Places

- Lecture: Thursday, 6 to 8pm
  - Location: H70.1110.University of Sydney Business School. ABS Lecture Theatre
  - Same building 1130 on 15/8
  - Concurrent online Zoom session
- Lab: depends on your timetable
  - J12-114; J12-130B; H70-3090; H70-3120; H70-3300; Thursday 8 to 9 pm
  - J02-315; F10A-030; H04-154; H04-158; Friday 5 to 6 pm
  - H04-154; H04-156; J02-315; F10A-030; Friday 6 to 7 pm
  - J02-315; Friday 7 to 8 pm
  - F10A-030; Monday (next week) 6 to 7 pm
  - Go to the lab you are scheduled for
  - You can attend a later lab session *if there is space and the tutor agrees*, but ask the tutor before joining in.
- Do not miss class, except for illness, emergencies, etc
- Get help from staff if you feel you are falling behind

COMP9121: People

- Unit coordinator and lecturer: Wei Bao
  - wei.bao@sydney.edu.au
  - Office: J12-425
  - https://www.sydney.edu.au/engineering/about/our-people/academic-staff/wei-bao.html
  - Office hour: By appointment
  - Clearly note COMP9121 in the email title when you contact me
- Background
  - Research: Networking, Mobile Computing, Internet of Things, Distributed Machine Learning.
  - University of Toronto
  - Deputy Director of MIT
  - Director of MCS

COMP9121: People

› Tutors:

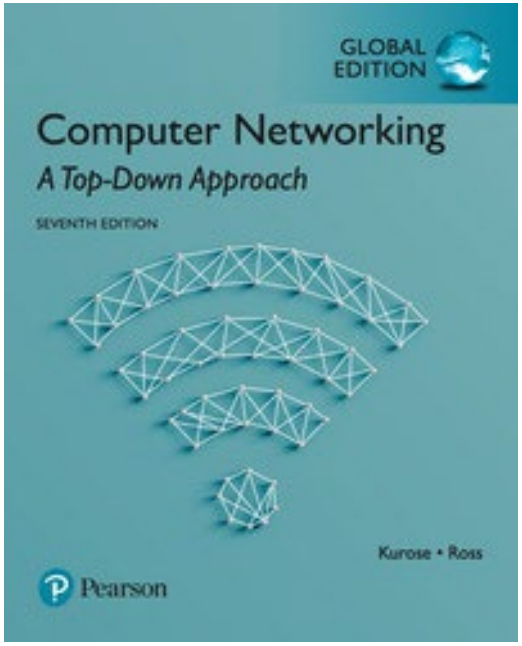
- Liming Ge
- liming.ge@sydney.edu.au
- Sen Fu
- sen.fu@sydney.edu.au
- Binghan Wu
- binghan.wu@sydney.edu.au
- Tung Anh Nguyen
- tung6100@sydney.edu.au
- Xinyi Sheng
- xshe9923@uni.sydney.edu.au
-

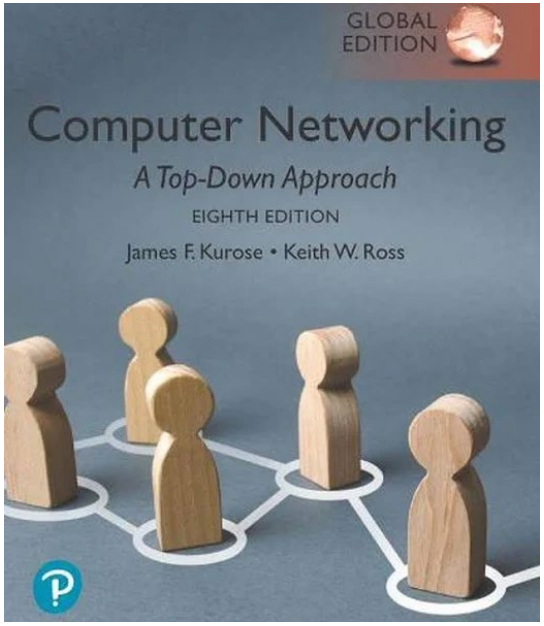
COMP9121: Resources

- Canvas: https://canvas.sydney.edu.au/
  - Login using Unikey and password
  - Link to Units website: https://sydney.edu.au/units/
    - Official schedule, list of learning outcomes, etc
  - Copies of slides
  - Lab instructions
  - Assignment instructions
  - Lecture videos
  - *Submit official assignment work here*;
  - See your grades; etc
- Ed Discussion
  - Only for discussion.
  - Not for assignment submission.
  - No discussion on assignment questions.

Reference book

Computer Networking: A TopDown Approach 7th or 8th edition, Jim Kurose and Keith Ross,

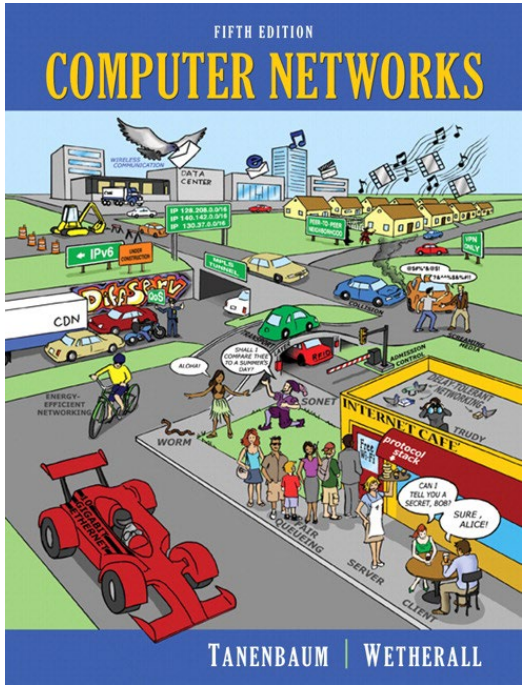




Some of the information on the slides of this course is taken from the companion material of this textbook

Reference book

Some materials are also from Computer Networks 5th edition, Andrew Tanenbaum and David Wetherall, Pearson, October 2010



Expectations

- Students attend scheduled classes, and devote an *extra* 6-9 hrs per week
  - doing assessments
  - preparing and reviewing for classes
  - revising and integrating the ideas
  - practice and self-assess
- Students are responsible learners
  - Participate in classes, constructively
    - Respect for one another (criticize ideas, not people)
    - Humility: none of us knows it all; each of us knows valuable things
  - Check Canvas site at least once a week!
  - Notify academics whenever there are difficulties
  - Notify group partners honestly and promptly about difficulties

COMP9121: Assessment

› W6: Assignment 1, 20%

– Covers W1—W6

› W12: Assignment 2, 20%

– Covers W6—W12

Both individual

Coding, experiment (e.g., Wireshark), calculation, extended answer

› Exam period: Final exam, 60%

– Covers everything

– School of CS policy: you must get at least 40% of the marks available on the exam, in order to pass the unit. (40% barrier on exam, less than 40% in the exam is automatically a FAIL.)

Special Consideration (University policy)

- If your performance on assessments is affected by illness or misadventure
- Follow proper bureaucratic procedures
  - Have professional practitioner sign special USyd form
  - Submit application for special consideration online, upload scans
  - Note you have only a quite short deadline for applying
  - http://sydney.edu.au/current_students/special_consideration/
- Also, notify coordinator by email *as soon as anything begins to go wrong*
- There is a similar process if you need special arrangements e.g. for religious observance, military service, representative sports

Late assessments

- Suppose you hand in work after the deadline:
- If you have not been granted special consideration or arrangements
  - A penalty of 5% of the maximum marks will be taken per day (or part) late. After ten days, you will be awarded a mark of zero.
- *e.g. If an assignment is worth 40% of the final mark and you are one hour late submitting, then the maximum marks possible would be 38%.*
- *e.g. If an assignment is worth 40% of the final mark and you are 28 hours late submitting, then the maximum marks possible marks would be 36%.*
- Warning: submission sites get very slow near deadlines
- Submit early; you can resubmit if there is time before the deadline

Academic Integrity (University policy)

- "The University of Sydney is unequivocally opposed to, and intolerant of, plagiarism and academic dishonesty.
  - Academic dishonesty means seeking to obtain or obtaining academic advantage for oneself or for others (including in the assessment or publication of work) by dishonest or unfair means.
  - Plagiarism means presenting another person's work as one's own work by presenting, copying or reproducing it without appropriate acknowledgement of the source." [from site below]
- http://sydney.edu.au/elearning/student/EI/index.shtml
- Submitted work is compared against other work (from students, the internet, etc)
  - TurnitIn for textual tasks (through Canvas), other systems for code
- Penalties for academic dishonesty or plagiarism can be severe
- Complete self-education AHEM1001

Academic Integrity

THE UNIVERSITY OF SYDNEY

Academic integrity

- Academic integrity refers to behaving honestly, ethically and responsibly in relation to all elements of your study at the university, including assessments.
- Always submit your own work, sit your own tests, and take your own examinations.
- Acknowledge any contributions in your assignment which are not your original thoughts, ideas or words.
- Academic Honesty Education Module – all commencing students must complete by census date. Continuing students can self-enrol at any time.

What is academic dishonesty?

The following are some behaviours that are academically dishonest:

- **Plagiarism** (this is the most common form)
- **Collusion** or illegitimate co-operation
- **Recycling** (using your own work from previous assessments)
- **Cheating,** including **contract cheating**
  - sharing questions or accessing solutions on online "help sites"
  - receiving coaching from a private tutoring company on how to complete an assignment
  - asking someone else to write your assignment (for payment or not)
- **Exam cheating** (using prohibited materials, working with others)
- **Fabrication** or falsification of sources, data or results

What are the consequences?

- The University has strong mechanisms for detection of potential academic dishonesty.
- Suspected breaches are reported to the faculty educational integrity team for investigation.
- The University is deeply committed to ensuring the integrity of its educational programs and treats integrity breaches seriously. As a result, the **academic consequences** for cheating are numerous.
- You may:
  - need to resubmit a task with a mark penalty or
  - receive a 0 for the assessment or even the unit of study
  - be suspended or even excluded from your studies for serious misconduct

Understanding contract cheating

Commercial cheating services are **ILLEGAL** in Australia. Illegal cheating services offer to:

- Sell you essays, assignments, study notes or exams
- Ask you to upload previous work from your course
- Sit exams on your behalf

If you use cheating services, you can face disciplinary action in accordance with USYD's policies. Resulting action can include:

- Failing the unit of study or course
- Suspension or exclusion from your studies
- Losing your professional accreditation
- Being blackmailed by cheating service operators
- For international students, losing your visa

Be aware of illegitimate services

- Be aware of any services that are not affiliated with the University.
- In the online environment, malicious organisations masquerading as 'online help sites and platforms' are preying on students.
  - These organisations may pressure you to pay for online assistance, then turn to **blackmail** when you change your mind.
  - Essays or solutions bought from the internet are usually **poor quality**, badly written and often **wrong**.
  - You won't acquire the skills and knowledge required for your degree, making it difficult to complete further assessments

As a student, you can contact the Office of Educational Integrity to report something anonymously or seek advice.

THE UNIVERSITY OF SYDNEY

Support services

The Office of Educational Integrity

- Report anonymously or seek advice: educational.integrity@sydney.edu.au

Learning Hub

- The Learning Hub (Academic Language and Learning) offers workshops, online resources and individual consultations on study and writing skills.
- The Learning Hub (Mathematics) offers bridging courses, drop-in services and online resources.

Library

- Check out the Library's online resources and referencing and citation styles.
- You can also chat with a Peer Learning Advisor about your studies, including referencing questions

Counselling and mental health support

- The University's Counselling and Psychological Services provide self and time-management workshops and online resources.

Special Arrangements and Consideration

- Apply for special consideration if impacted by short-term illness or misadventure

Disability Services

- Register for Disability Support

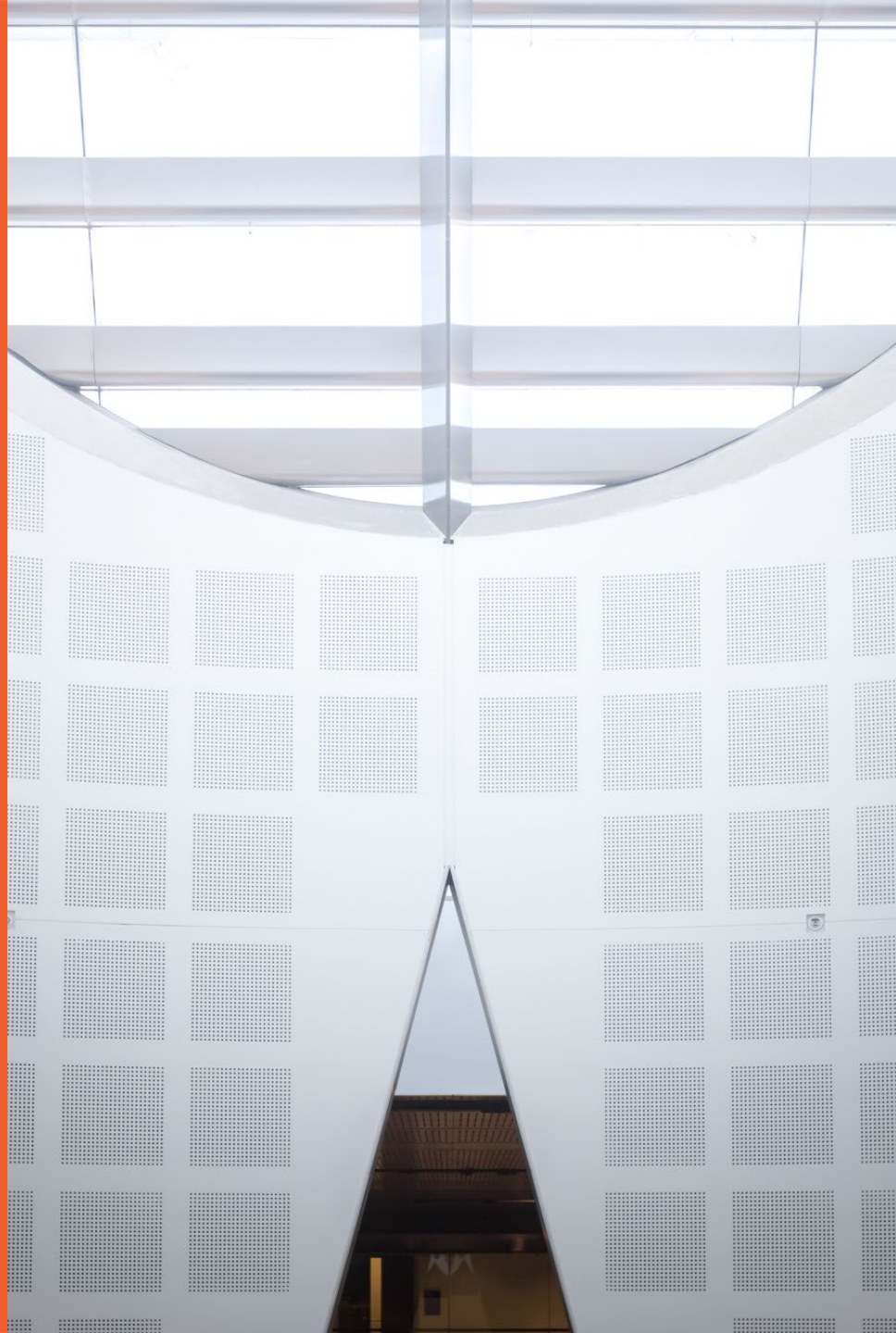
Student organisations

- SRC (undergraduate students)
- SUPRA (postgraduate students)

WHS Induction

School of Computer Science

THE UNIVERSITY OF SYDNEY



General Housekeeping – Use of Labs

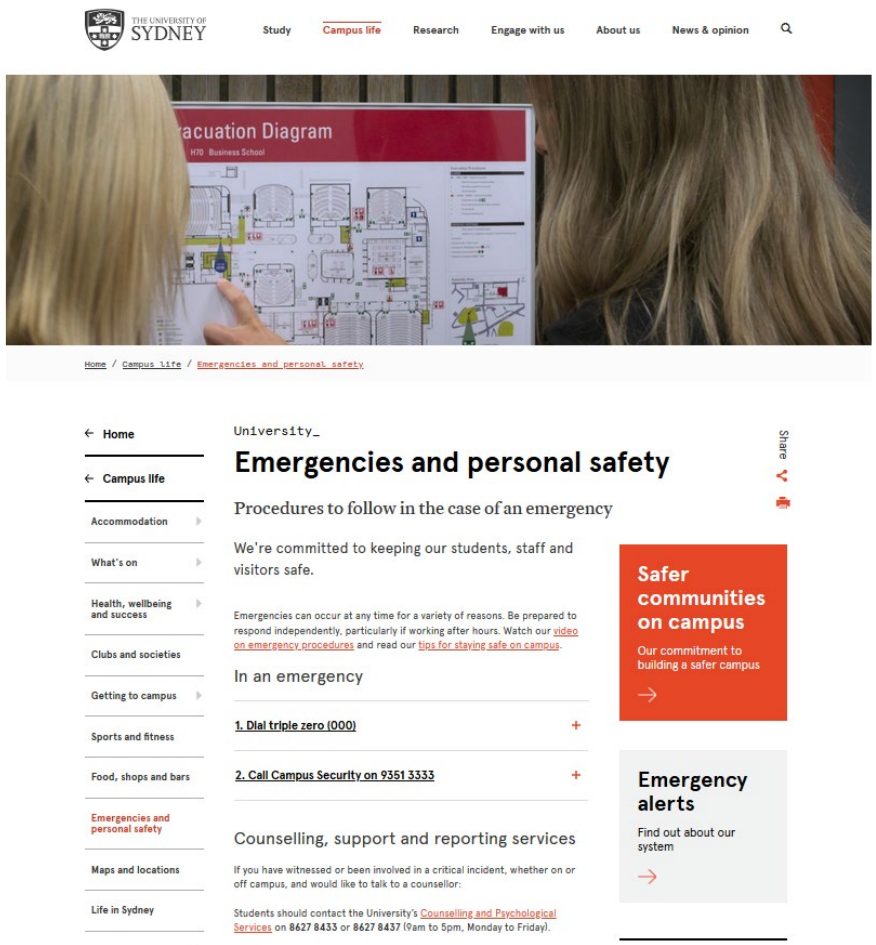
- Keep work area clean and orderly
- Remove trip hazards around desk area
- No food and drink near machines
- No smoking permitted within University buildings
- Do not unplug or move equipment without permission





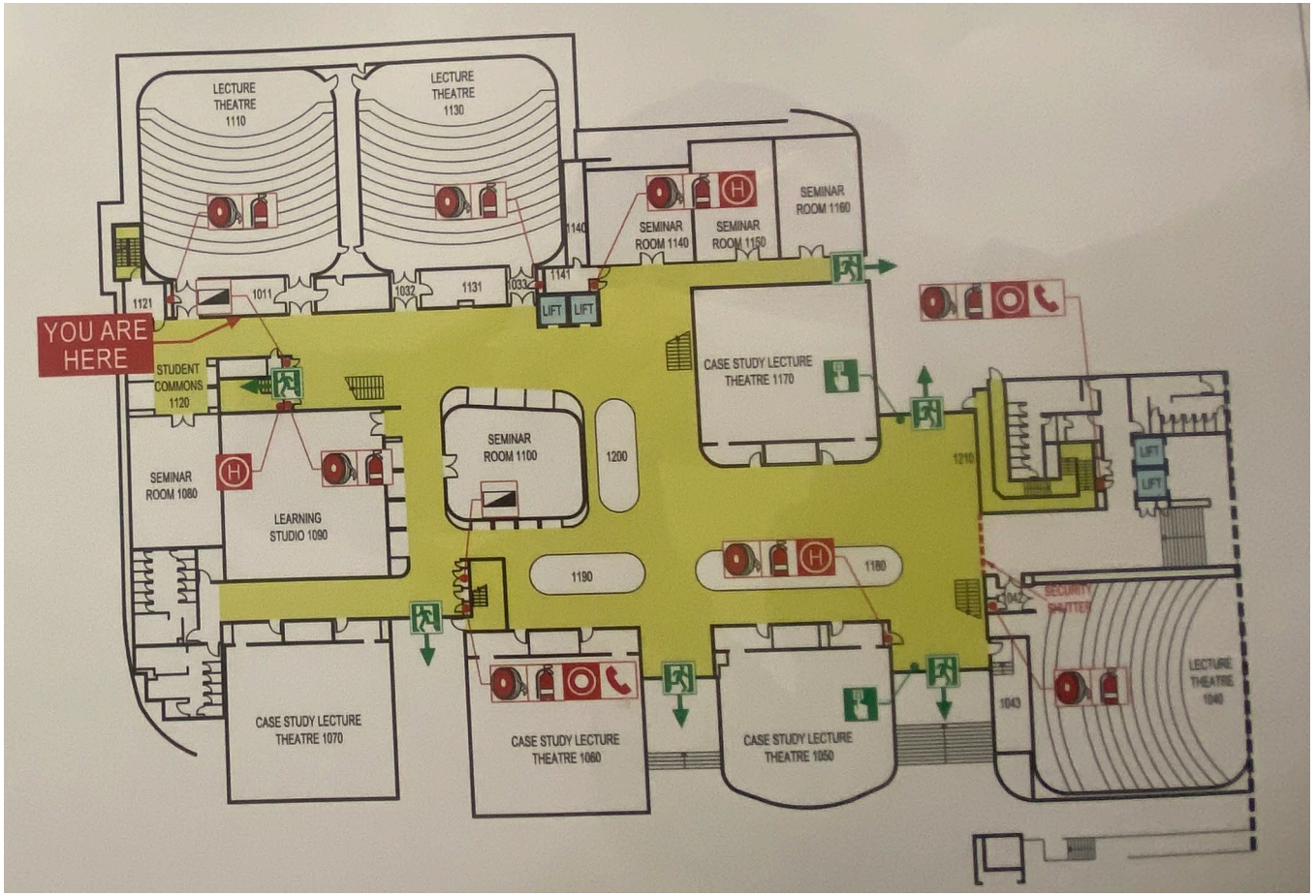
EMERGENCIES – Be prepared

https://sydney.edu.au/campus-life/safety-security.html



EMERGENCIES

WHERE IS YOUR CLOSEST SAFE EXIT ?



EMERGENCIES

Evacuation Procedures

ALARMS

BEEP...BEEP... - Prepare to evacuate

1. Check for any sign of immediate danger
2. Shut down equipment & processes
3. Collect any nearby personal items

WHOOP...WHOOP... - Evacuate the building

1. Follow the Exit signs
2. Escort visitors & those who require assistance
3. Do not use the lifts
4. Proceed to the Assembly Area

EMERGENCY RESPONSE

1. Warn anyone in immediate danger
2. Fight the fire or contain the emergency, if safe & trained to do so

If necessary...

3. Close the door, if safe to do so
4. Activate the 'Emergency Call Point (White)' or the 'Manual Call Point (Red)'
5. Evacuate via your closet safe exit
6. Report the emergency to 0-000 & 9351 3333

School of Computer Science Safety Contacts

CHIEF WARDEN

Greg Ryan
Level 1W 103
9351 4360
0411 406 322

FIRST AID OFFICERS

Julia Ashworth
Level 5W
8627 9058

Will Calleja
Level 1W 103
9036 9706
0422 001 964

Muhammad Sajjad Akbar
Level 3E
0470 257 750

Orally REPORT all INCIDENTS & HAZARDS to your SUPERVISOR

OR

Postgraduate HDR: Julia Ashworth 8627 9058

Postgraduate CW: Keiko Narushima 8627 0872

CS School Manager: Priyanka Magotra 8627 4295

Assistance

- There are a wide range of support services available for students: https://sydney.edu.au/campus-life/health-wellbeing-success.html
- Please make contact, and get help
- You are not required to tell anyone else about this
- If you are willing to inform the unit coordinator, they may be able to work with other support to reduce the impact on this unit
  - e.g. provide advice on which tasks are most significant

Do you have a disability?

You may not think of yourself as having a ‘disability’ but the definition under the **Disability Discrimination Act (1992)** is broad and includes temporary or chronic medical conditions, physical or sensory disabilities, psychological conditions and learning disabilities.

The types of disabilities we see include:
Anxiety // Arthritis // Asthma // Autism // ADHD
Bipolar disorder // Broken bones // Cancer
Cerebral palsy // Chronic fatigue syndrome
Crohn’s disease // Cystic fibrosis // Depression
Diabetes // Dyslexia // Epilepsy // Hearing impairment //
Learning disability // Mobility impairment // Multiple sclerosis // Post-traumatic stress // Schizophrenia //
Vision impairment
and much more.

Students needing assistance must register with Disability Services. It is advisable to do this as early as possible. Please contact us or review our website to find out more.

THE UNIVERSITY OF SYDNEY

Disability Services Office
sydney.edu.au/disability
02-8627-8422

Student life, wellbeing and suppo

sydney.edu.au/students/support.html

THE UNIVERSITY OF SYDNEY

Get help in an emergency: We are committed to providing a safe environment for all students. More information

Current students

Home / Student life, wellbeing and support

Student life, wellbeing and support

Everything you need to know about the student services, resources and events available to support you while you study.

- Health and wellbeing
- Academic support
- Personal support
- Get connected

Careers

Right from your first year at university, you have access to an abundance of career counselling services and resources to help put you in the best career position by the end of your degree.

Transition to Sydney

Whether an international student travelling to Sydney from overseas, or a domestic student transitioning to uni life, we have info and support services to help you settle in.

Support with your study decisions

Our Advising hub provides one-on-one support to help you make study-related decisions that will help you achieve your personal and academic goals.

Book an appointment now.

All University of Sydney Students have free access to:

Innowell

The right resources and support at the right time to maintain and improve your physical and mental health.

TalkCampus

Free and instant support for your mental health and wellbeing anytime of the day, anywhere in the world.

All University of Sydney **International Students** have free access to:

Sonder

24/7 safety and wellbeing app to get you the support you need whenever and wherever you are.

Other support

- Learning support
  - http://sydney.edu.au/study/academic-support/learning-support.html
- International students
  - http://sydney.edu.au/study/academic-support/support-for-international-students.html
- Aboriginal and Torres Strait Islanders
  - http://sydney.edu.au/study/academic-support/aboriginal-and-torres-strait-islander-support.html
- Student organization (can represent you in academic appeals etc)
  - http://srcusyd.net.au/ or http://www.supra.net.au/
- Please make contact, and get help
- You are not required to tell anyone else about this
- If you are willing to inform the unit coordinator, they may be able to work with other support to reduce the impact on this unit
  - eg provide advice on which tasks are most significant

Advice

- Metacognition
  - Pay attention to the learning outcomes in Canvas
  - Self-check that you are achieving each one
  - Think how each assessment task relates to these
- Time management
  - Watch the due dates
  - Start work early, submit early
- Networking and community-formation
  - Make friends and discuss ideas with them
  - Know your tutor, lecturer, coordinator
  - Keep them informed, especially if you fall behind
    - Don’t wait to get help
- Enjoy the learning!

Syllabus

1. Introduction
2. Link layer 1
3. Link layer 2
4. Network layer 1
5. Network layer 2
6. Network layer 3
7. Network layer 4, Transport layer 1
8. Transport layer 2
9. Application layer 1
10. Application layer 2, Network security 1
11. Network security 2
12. Network security 3, Review
13. Recent advances in networks.

1. Delay and bit error
2. Link Layer
3. Link layer simulator
4. Network layer
5. Routing algorithms
6. Wireshark
7. NAT
8. TCP and Telnet
9. TCP and cross-layer analysis
10. DNS and HTTP
11. Hash and public/private keys
12. TLS and firewalls
13. Q and A, Assignment Solutions

Network Overview

What is the Internet?

› "Nuts and bolts" view

PC

server

wireless laptop

smartphone

› millions of connected computing devices:

- *hosts* = *end systems*
- running *network apps*

wireless links

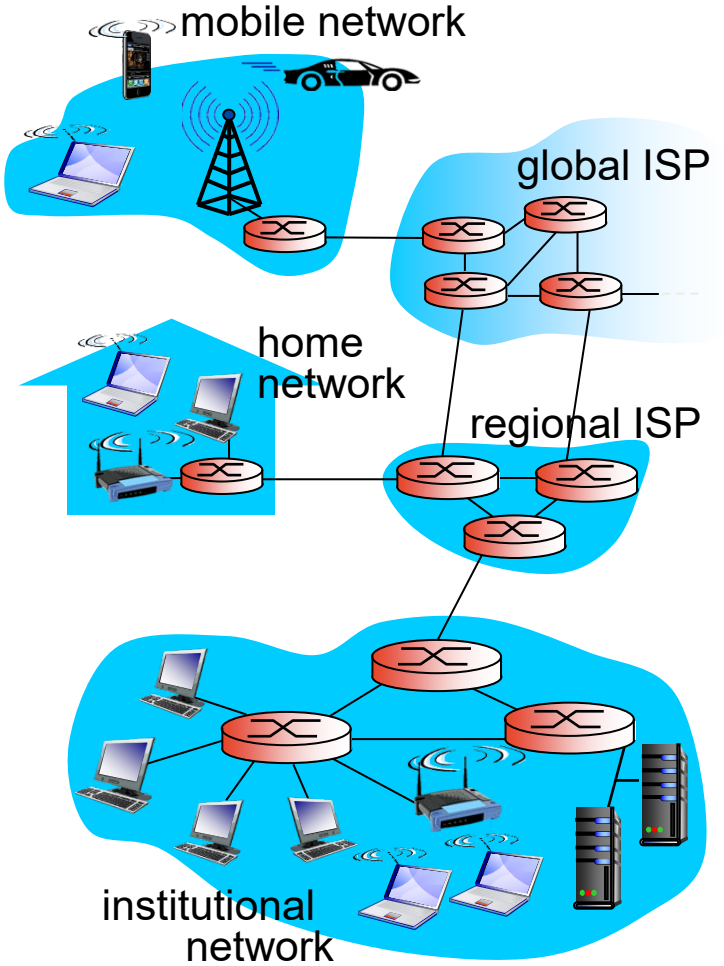
wired links

› *communication links*

- fiber, copper, radio, satellite

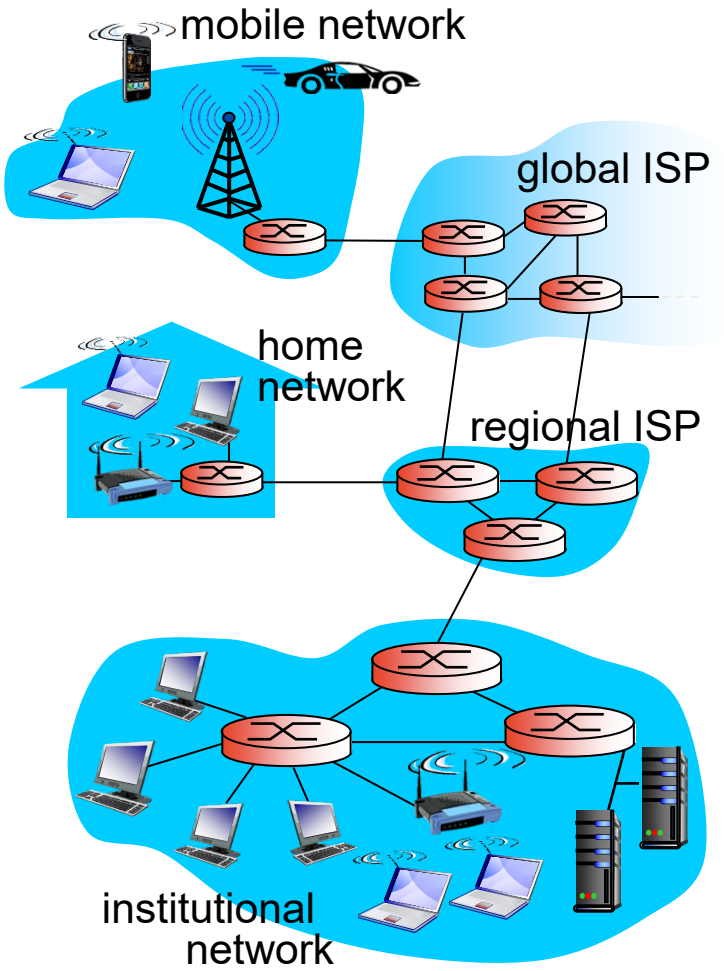
router

› *Packet switches:* forward packets (chunks of data)



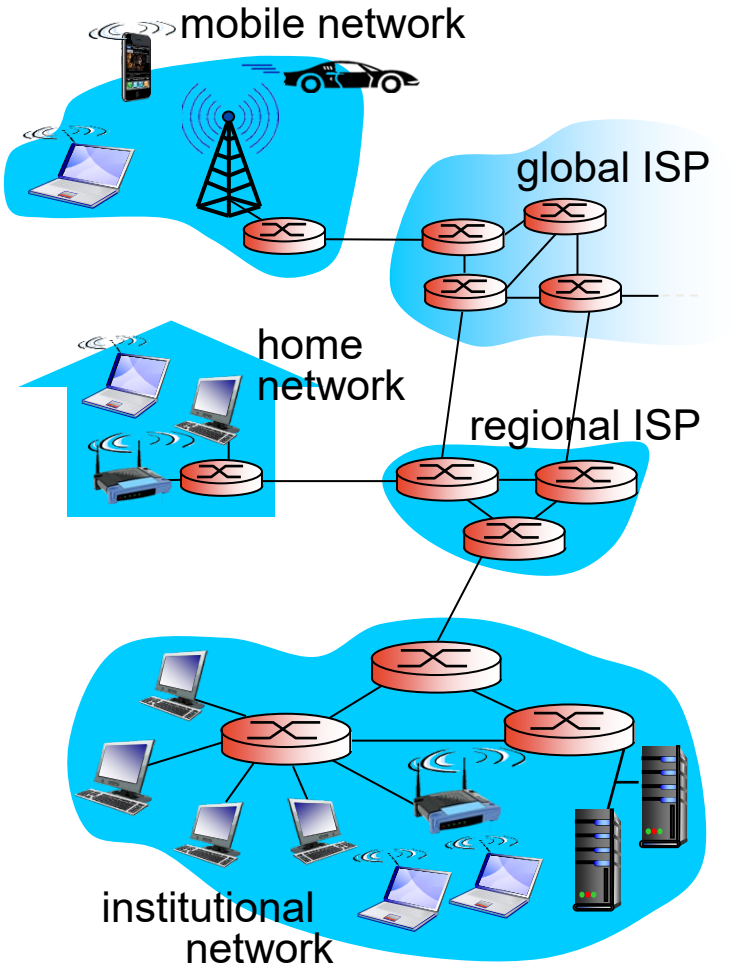
What is the Internet?

- *Internet:* "network of networks"
  - Interconnected ISPs
  - ISP: Internet Service Provider
- *protocols* control sending, receiving of messages
  - e.g., TCP, IP, HTTP, 802.11
  - Transmission Control Protocol/Internet Protocol
  - HyperText Transfer Protocol
- *Internet standards*
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What is the Internet?

- *Infrastructure that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social nets, …
- *provides programming interface to apps*
  - hooks that allow sending and receiving app programs to "connect" to Internet
  - analogous to postal service



What is a protocol?

human protocols:

- "what's the time?"

… specific msgs sent

… specific actions taken when msgs received, or other events

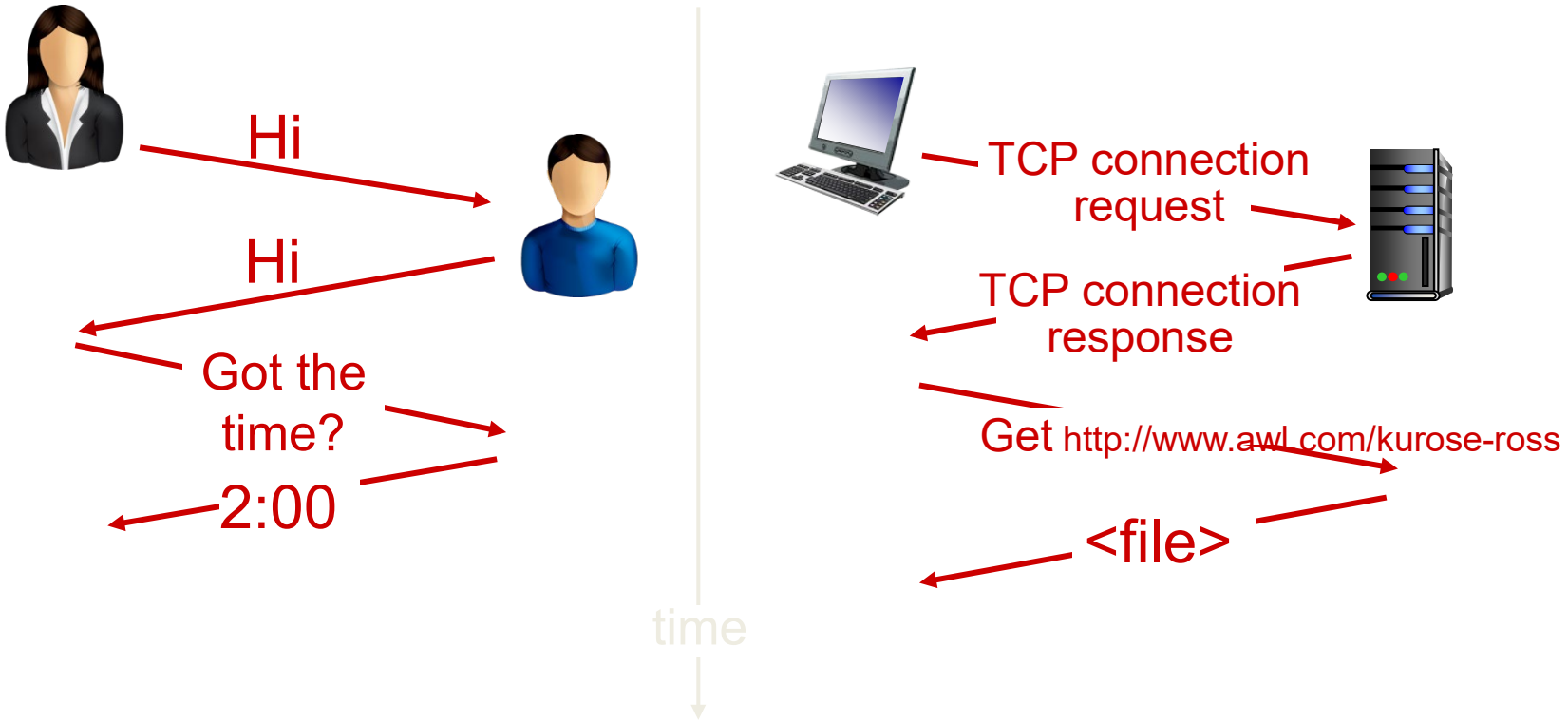
network protocols:

- machines rather than humans
- all communication activity in Internet governed by protocols

protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

What is a protocol?

› a human protocol and a computer network protocol:



Layering

Layers

Networks are complex, with many "pieces":

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

is there any hope of *organizing* structure of network?

…. or at least our discussion of networks?

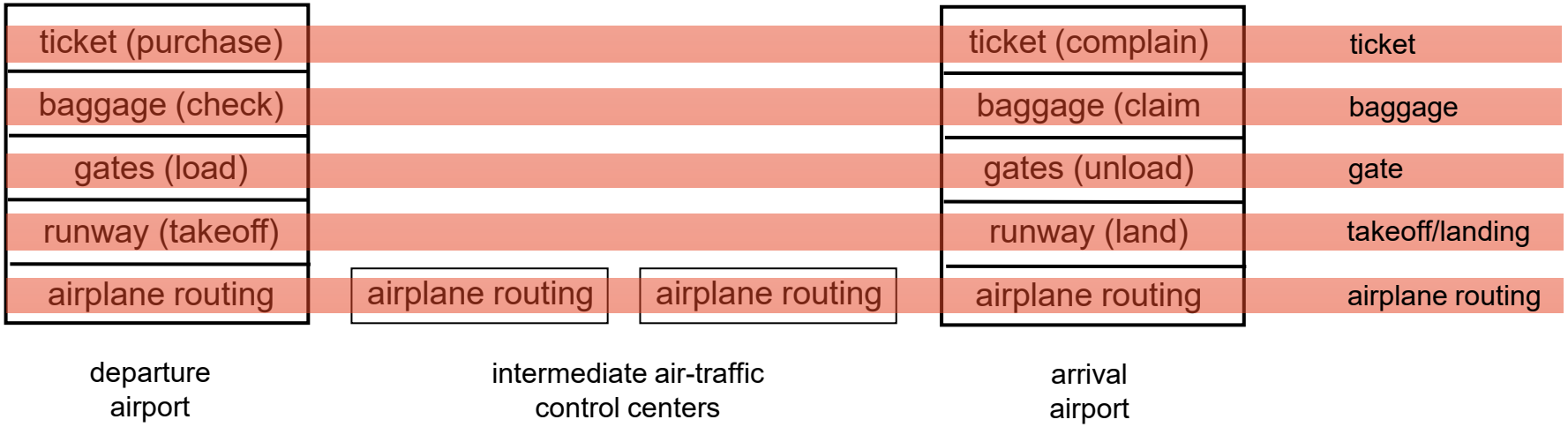
Airline analogy

Organization of air travel

› a series of steps

Airline analogy

Layering of airline functionalities

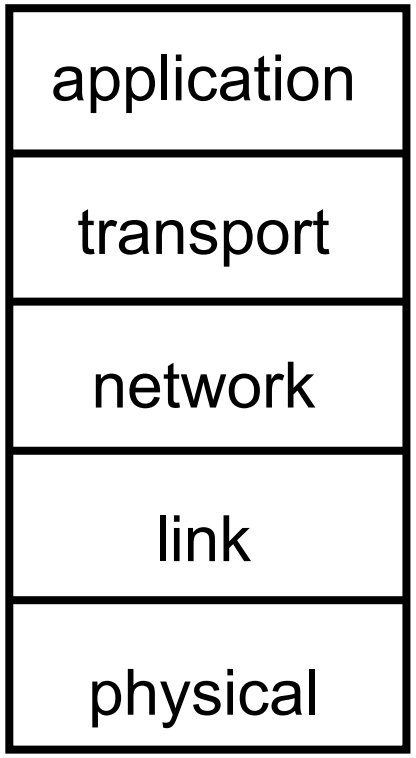


layers: each layer implements a service

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

Internet Protocol Stack

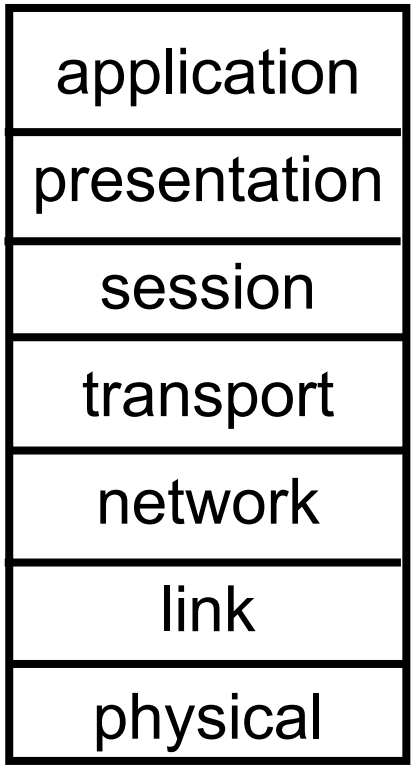
- *application:* supporting network applications
  - FTP, SMTP, HTTP
- *transport:* process-process data transfer
  - TCP, UDP
- *network:* routing of packets from source to destination
  - IP, routing protocols
- *link:* data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi)
- *physical:* bits "on the wire"



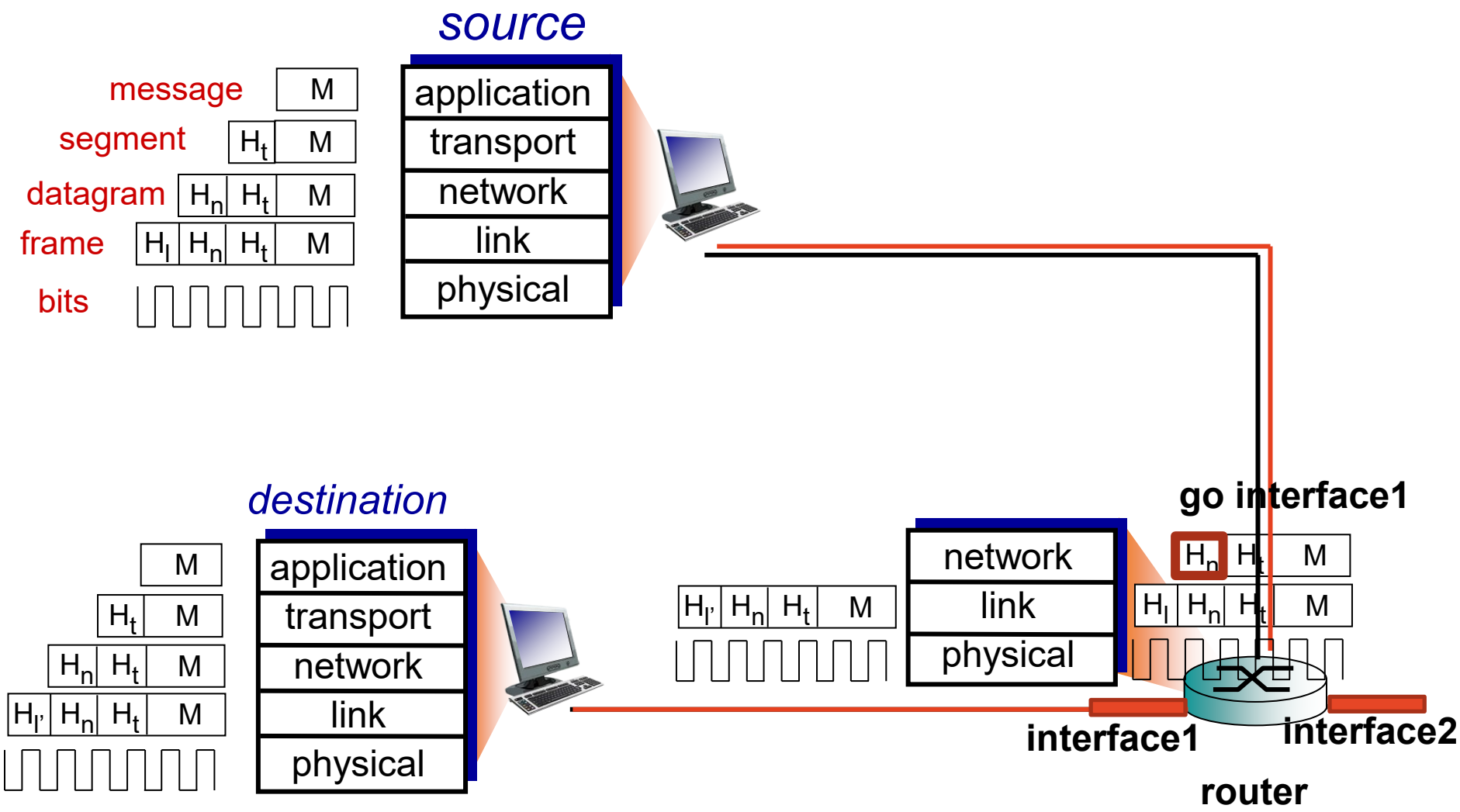
relying on services provided by layer below

ISO/OSI reference model

- *ISO: International Organization for Standardization*
- *OSI: Open Systems Interconnection*
- *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session:* synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed,* must be implemented in application
  - needed?



Encapsulation and packet



Network Edge and Core

Network edge

› *network edge:*

- hosts: clients and servers
- servers often in data centers

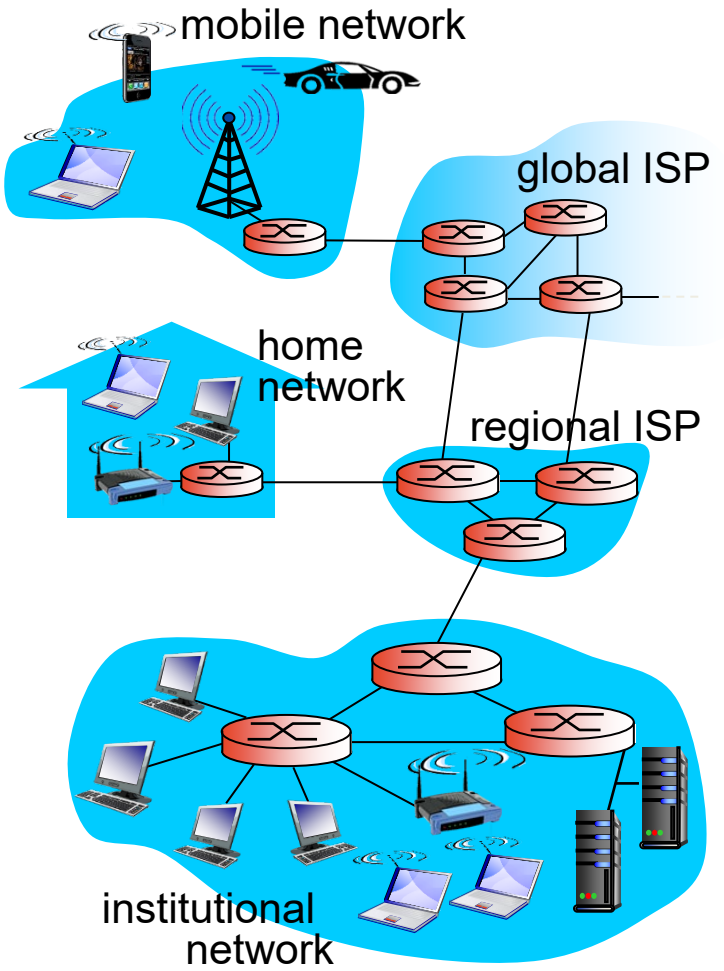
› *access networks, physical media:*

- wired,
- wireless communication links

› *network core:*

- interconnected routers
- network of networks

Q: Cite one network edge?

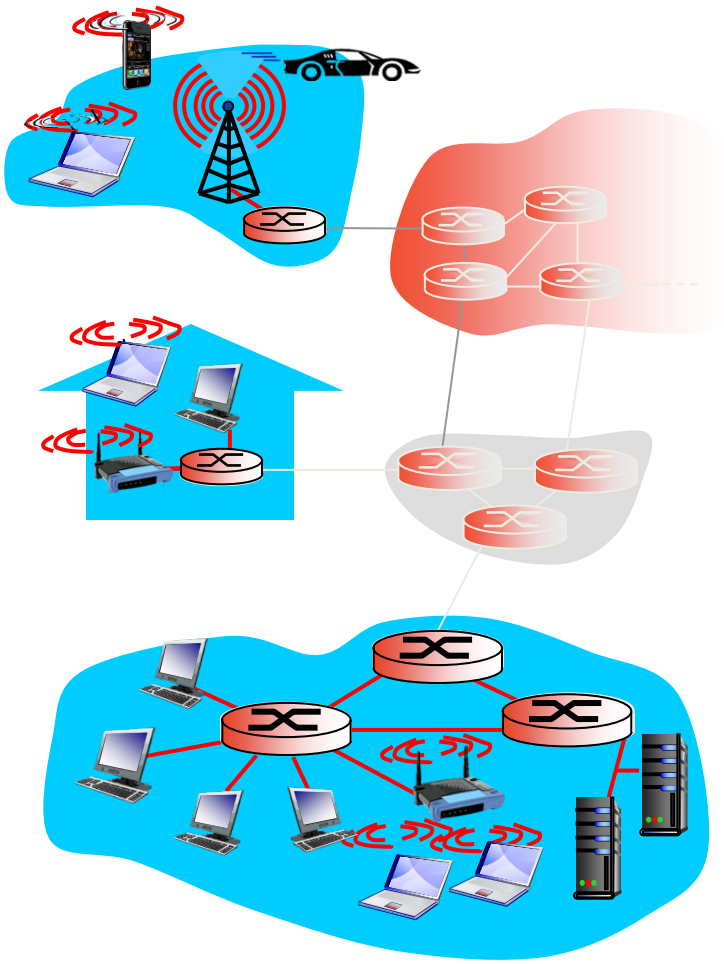


Access networks and physical media

Q: How to connect end systems to edge router?

- residential access nets
- institutional access networks (school, company)
- mobile access networks

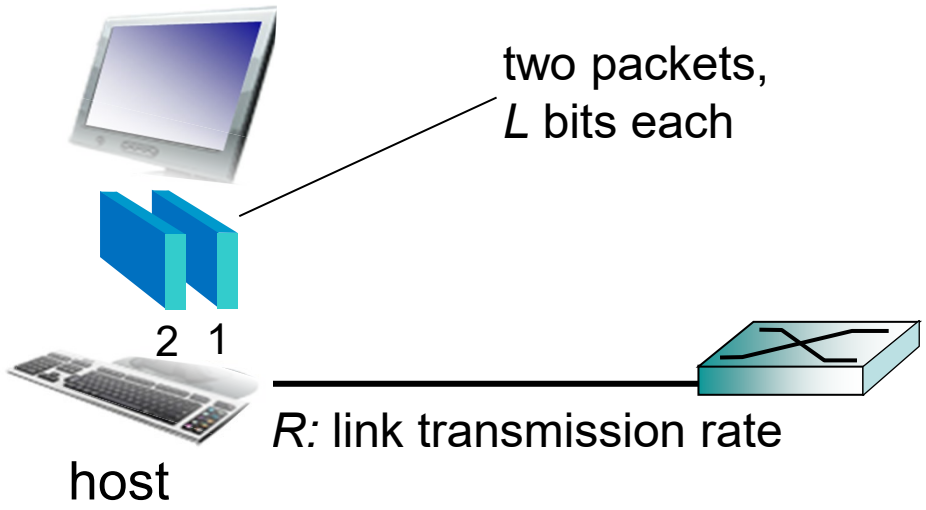
- Bandwidth, or data rate (bits per second) of access network.



Host: sends packets of data

Host sending function:

- takes application message
- breaks into smaller chunks, known as *packets*, of length *L* bits
- transmits packet into access network at *transmission rate R*
  - link transmission rate, aka link *capacity, aka link bandwidth*



$$\text{packet transmission time} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

The network core

network core:

› mesh of interconnected routers

› how to transmit from end to end?

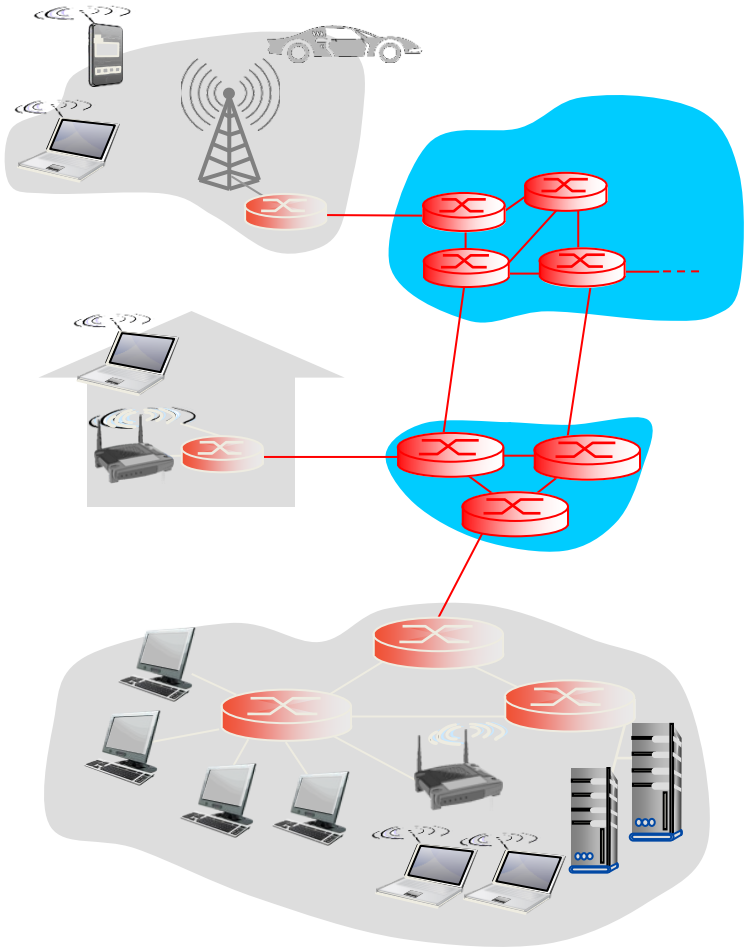
1. packet-switching

   - hosts break application-layer messages into *packets*
   - forward packets from one router to the next, across links on path from source to destination

2. circuit-switching

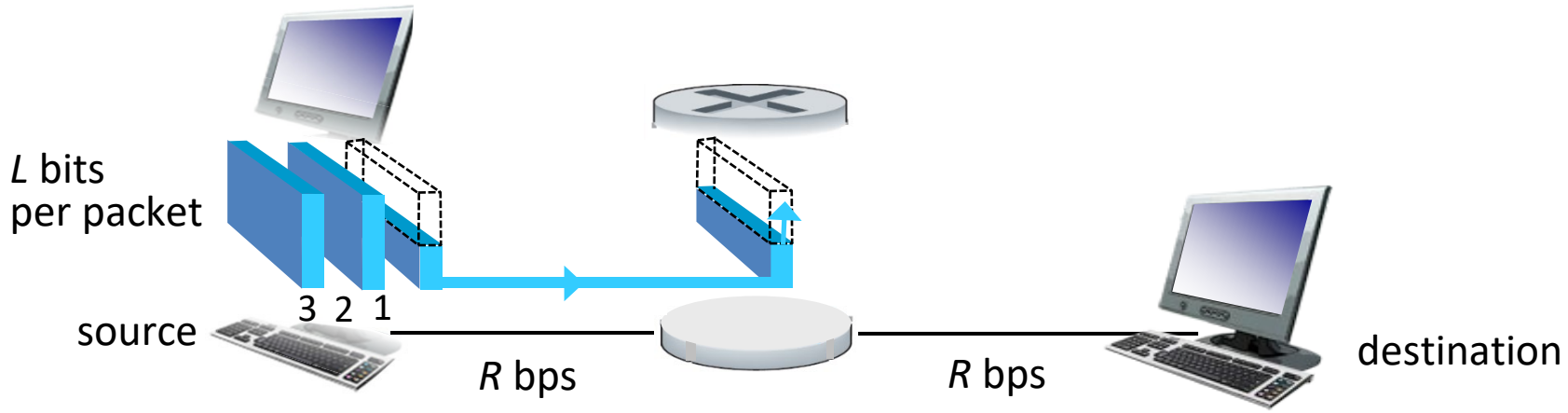
   - end-end resources allocated to, reserved for "call" between source & dest
   - circuit segment idle if not used by call (no sharing)

Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?



Packet switching

Store-and-forward



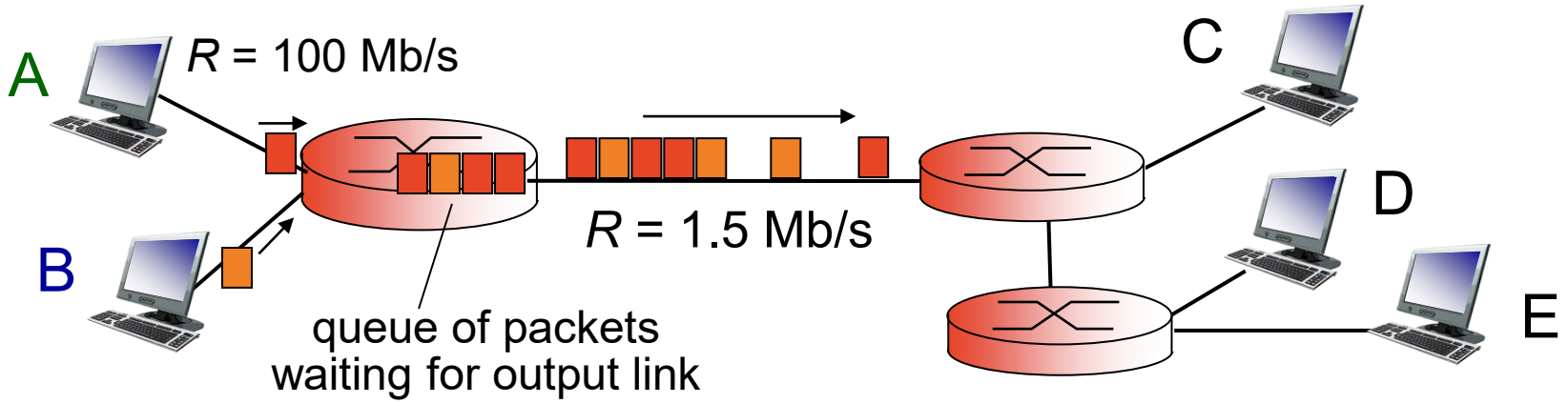
- takes *L*/*R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- *end-end delay:* 2 *L*/*R* (assuming no other delays)

- *one-hop numerical example:*
  - *L* = 7.5 Mbits
  - *R* = 1.5 Mbps
  - delay = 5 sec

more on delay shortly …

Packet switching (con't)

Queueing delay, loss



Queueing and loss:

› if arrival rate (in bits) to link exceeds transmission rate of link for a period of time:

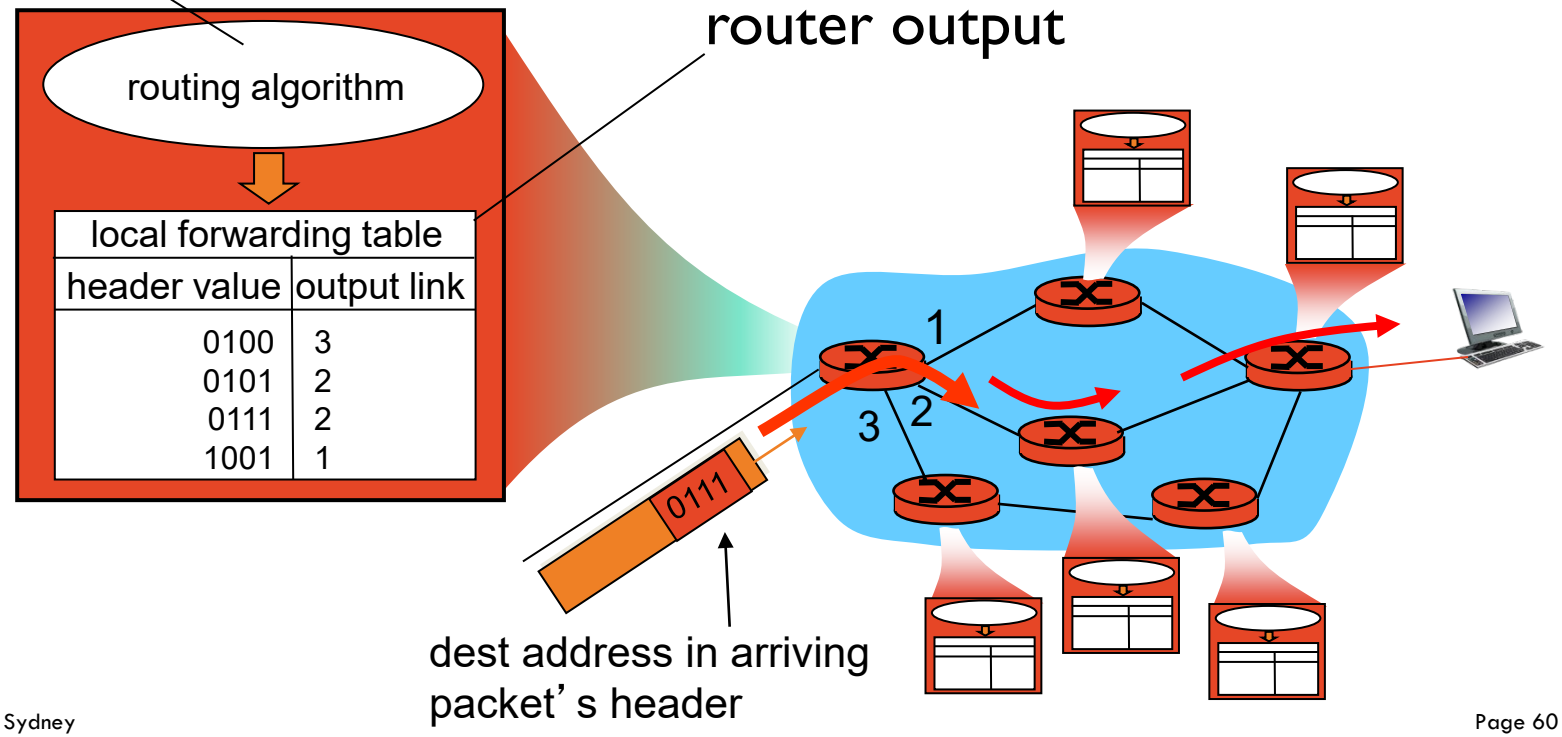
- packets will queue, wait to be transmitted on link
- packets can be dropped (lost) if memory (buffer) fills up

Packet switching (con't)

Two key network-core functions

routing: determines source-destination route taken by packets

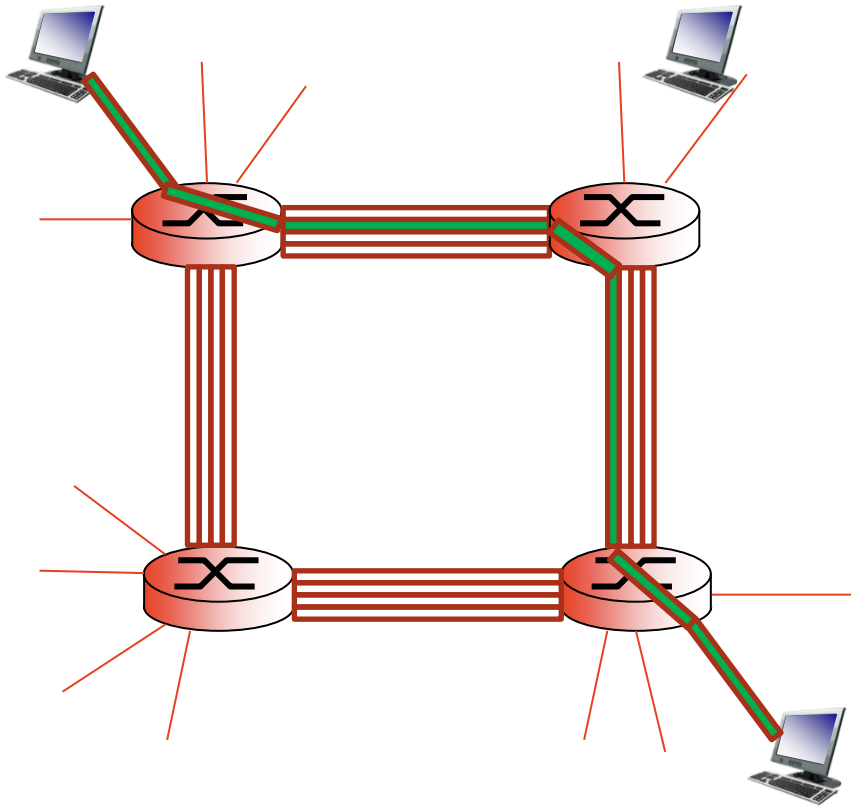
forwarding: move packets from router's input to appropriate router output



Circuit switching

end-end resources allocated to, reserved for "call" between source & dest:

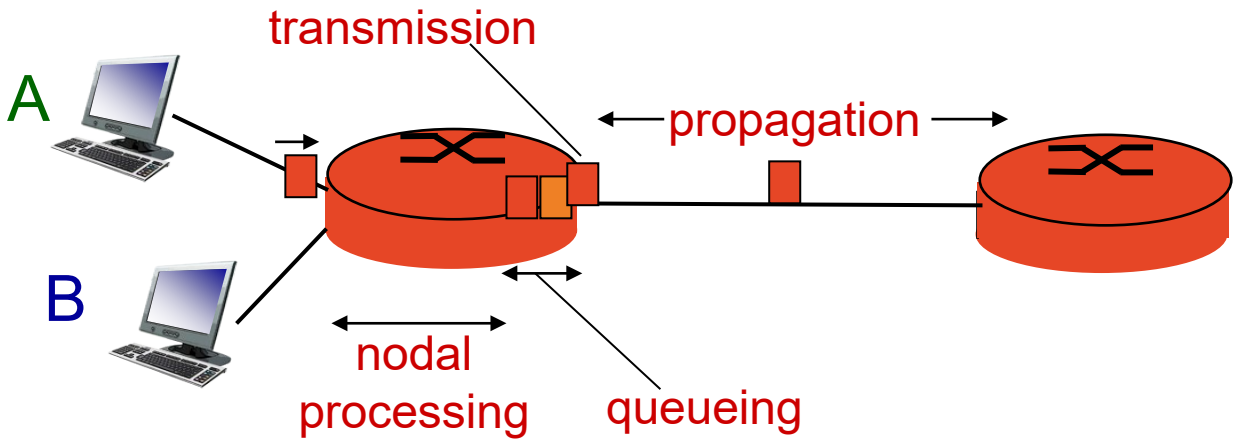
- In diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- commonly used in traditional telephone networks



Network Delays

Delay

Four sources of packet delay



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{proc}: nodal processing

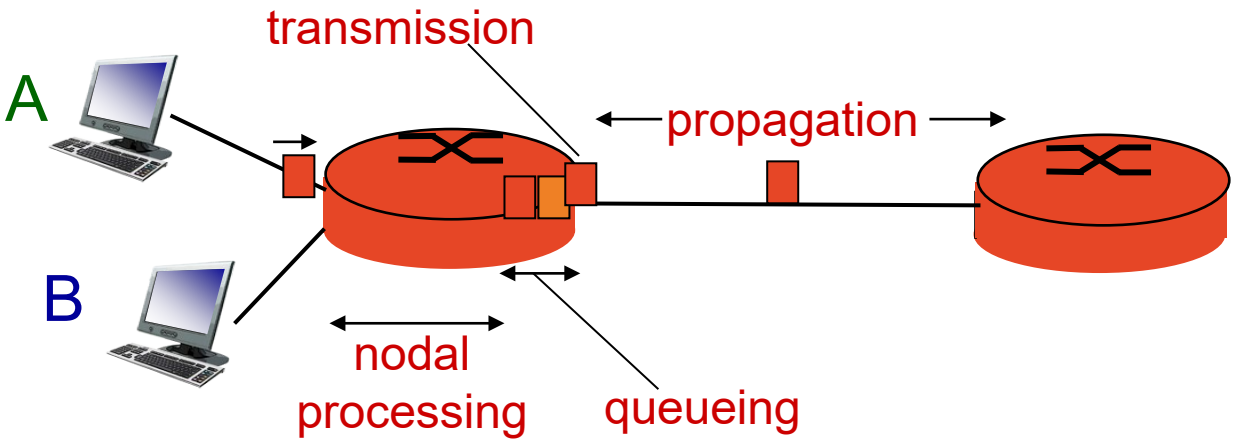
- check bit errors
- determine output link
- typically < msec

d_{queue}: queueing delay

- time waiting at output link for transmission
- depends on congestion level of router

Delay

Four sources of packet delay



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{trans}: transmission delay:

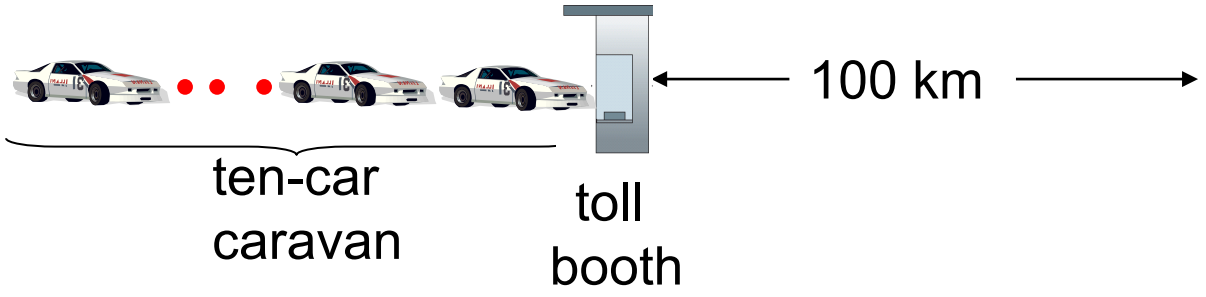
- L: packet length (bits)
- R: link *bandwidth (bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay:

- d: length of physical link
- s: propagation speed in medium (~2×10^8 m/sec)
- $d_{prop} = d/s$

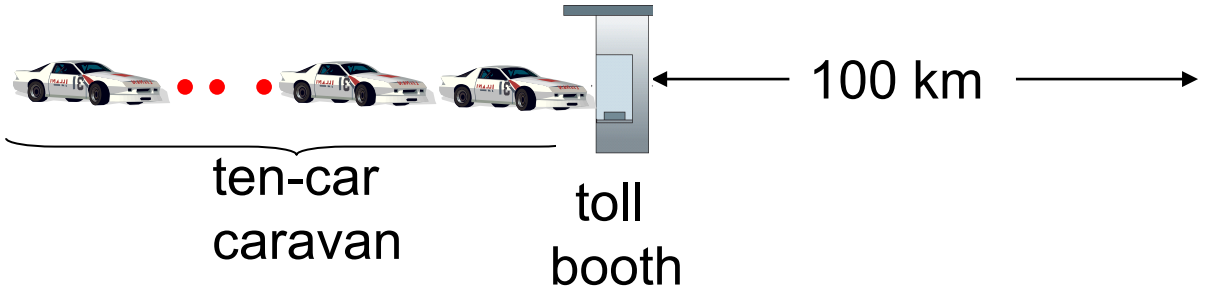
d_{trans} and d_{prop} *very* different

Caravan analogy



- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (bit transmission time)
- car ~ bit; caravan ~ packet
- *Q:* How long until caravan arrives the destination?

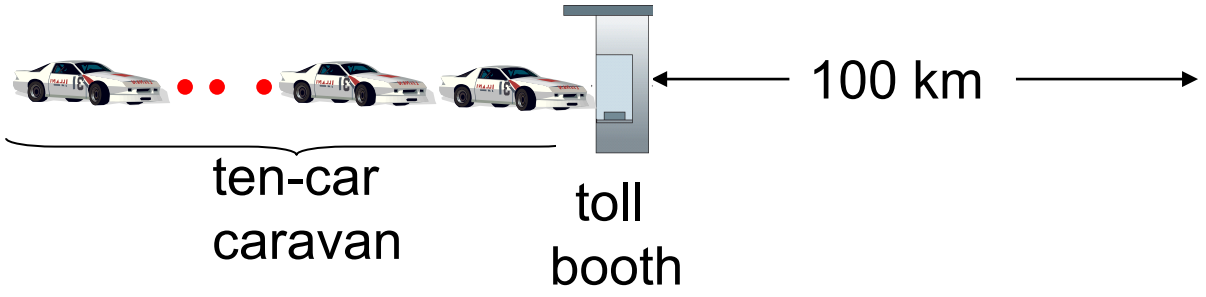
Caravan analogy

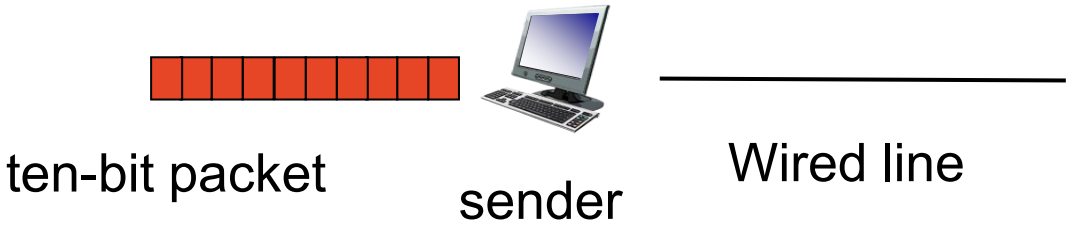


- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (bit transmission time)
- car ~ bit; caravan ~ packet
- *Q:* How long until caravan arrives the destination?

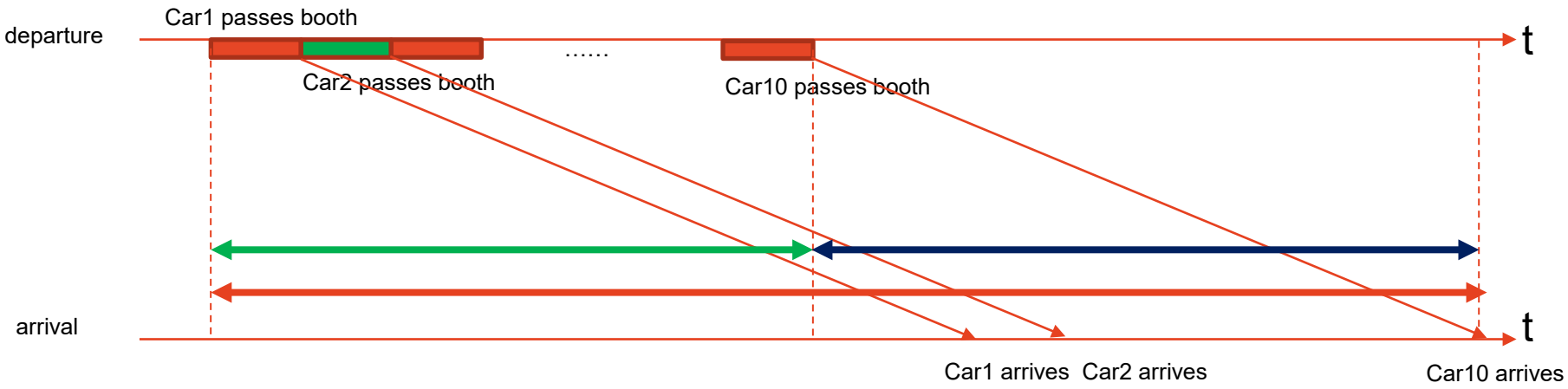
- time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec
- time for last car to propagate from booth to destination is 100km/(100km/hr)= 1 hr
- *A:* 62 minutes

Caravan analogy

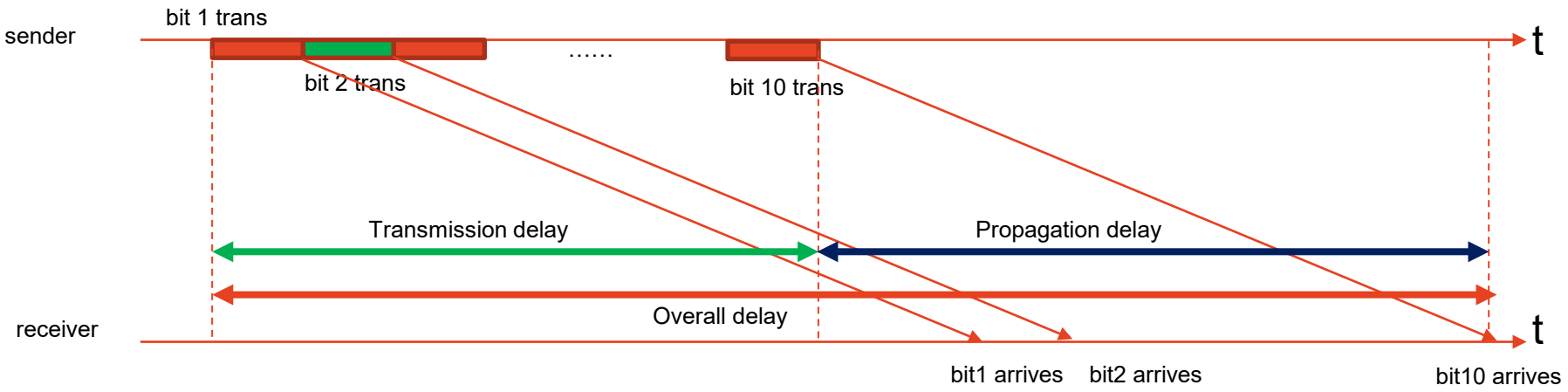




Caravan analogy

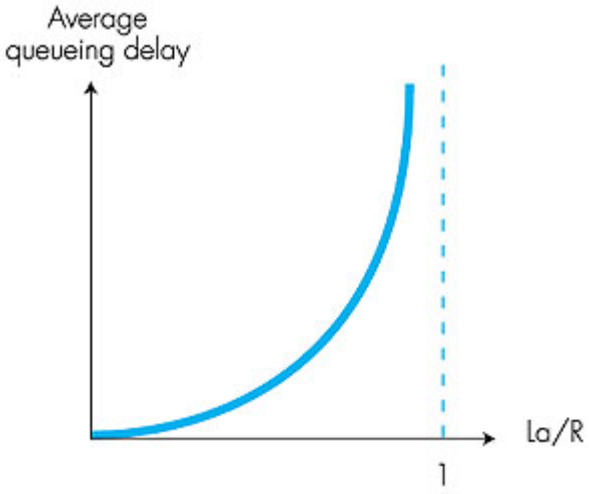


Caravan analogy



Queueing delay

- *R:* link bandwidth (bps)
- *L:* packet length (bits)
- a: average packet arrival rate



traffic intensity = La/R

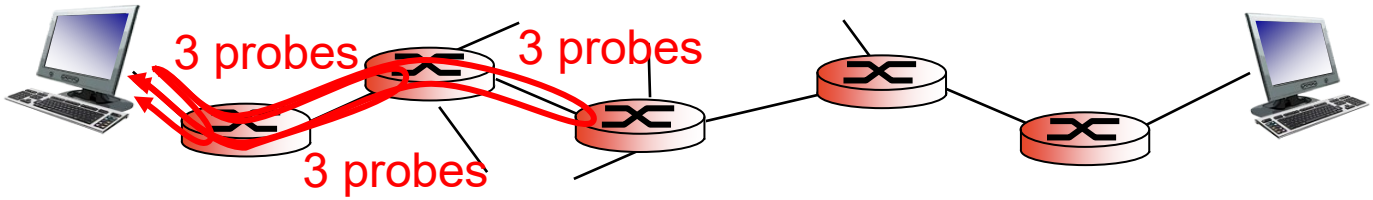
- *La/R* ~ 0: avg. queueing delay small
- *La/R* ~< 1: avg. queueing delay large
- *La/R* > 1: more "work" arriving than can be serviced, average delay infinite!

La/R ~ 0

La/R <~ 1

“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
  - router *i* will return packets to sender
  - sender times 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
```

trans-oceanic link

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