COSC264
Introduction to Computer Networks and the Internet

Introduction to Routing

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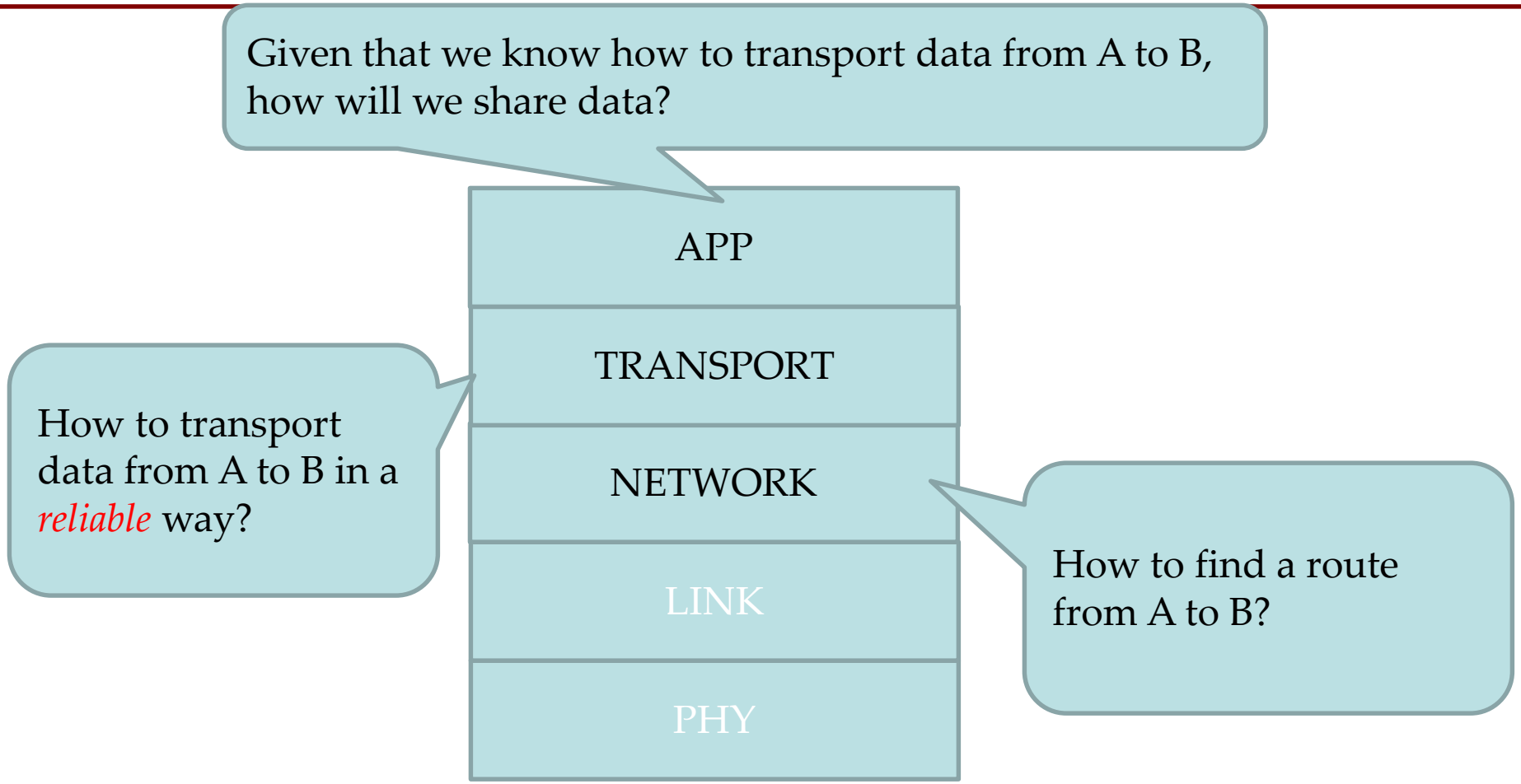
An overview for this term



Outline

- Network layer overview
- Routing overview
- Link-state routing (Dijkstra's algorithm)
- Distance-vector routing (Bellman-Ford)
- Summary

Outline - today

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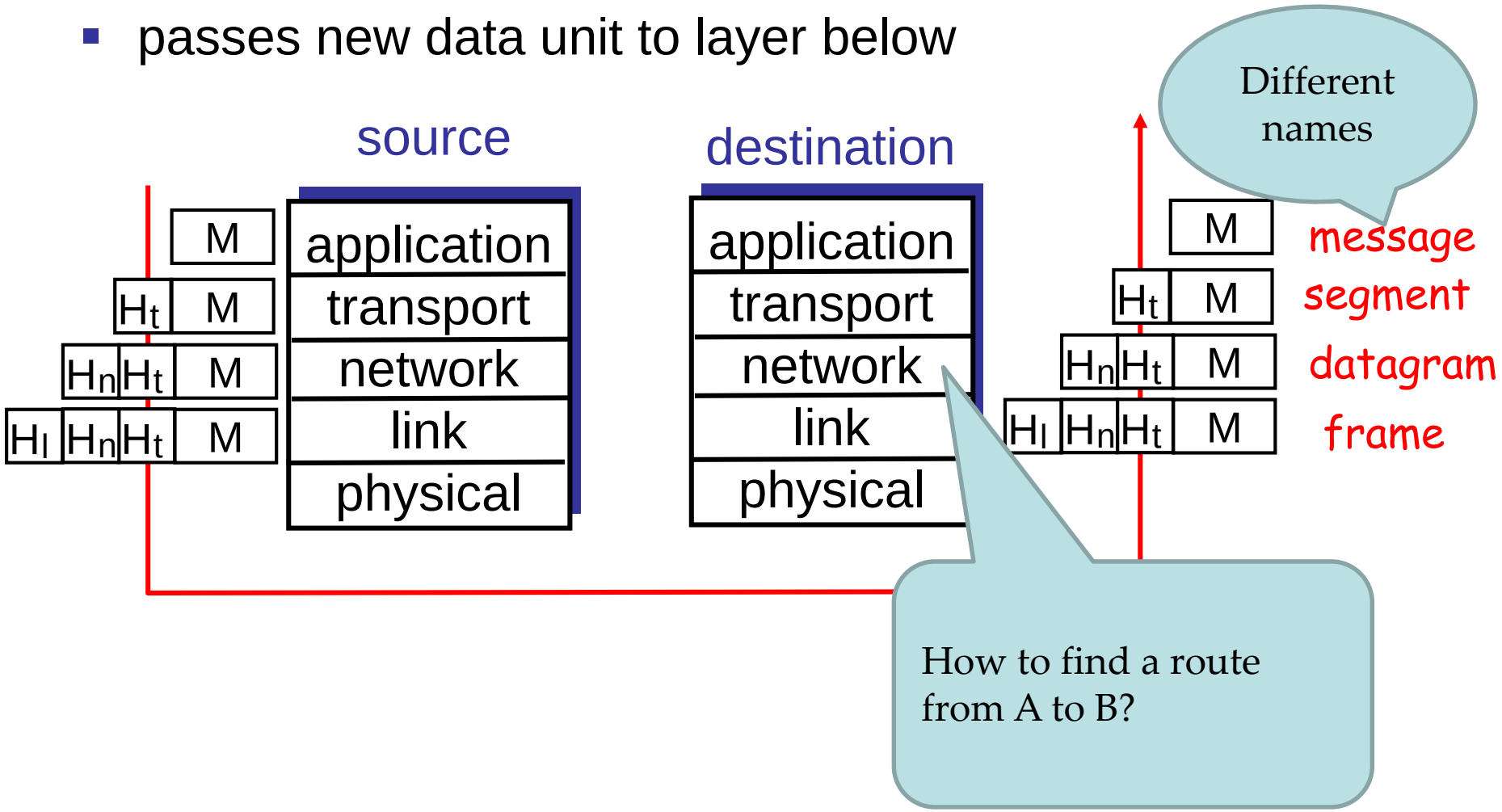
Protocol layering and data

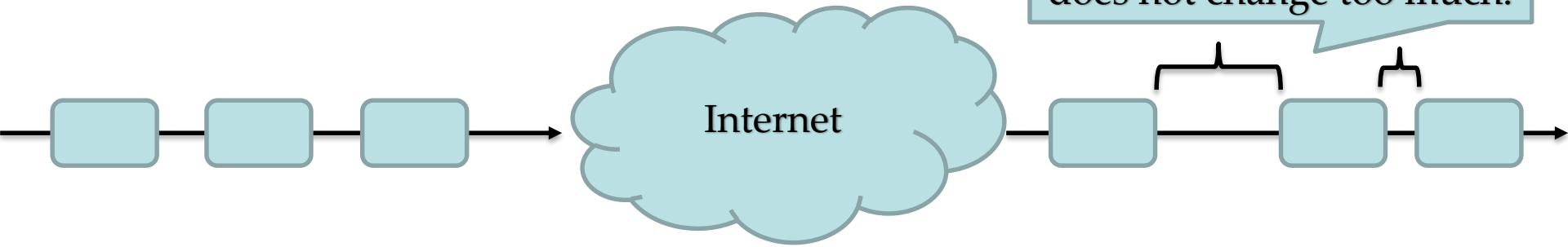
Each layer takes data from above

- adds header information to create new data unit
- passes new data unit to layer below



Possible services of general network layer

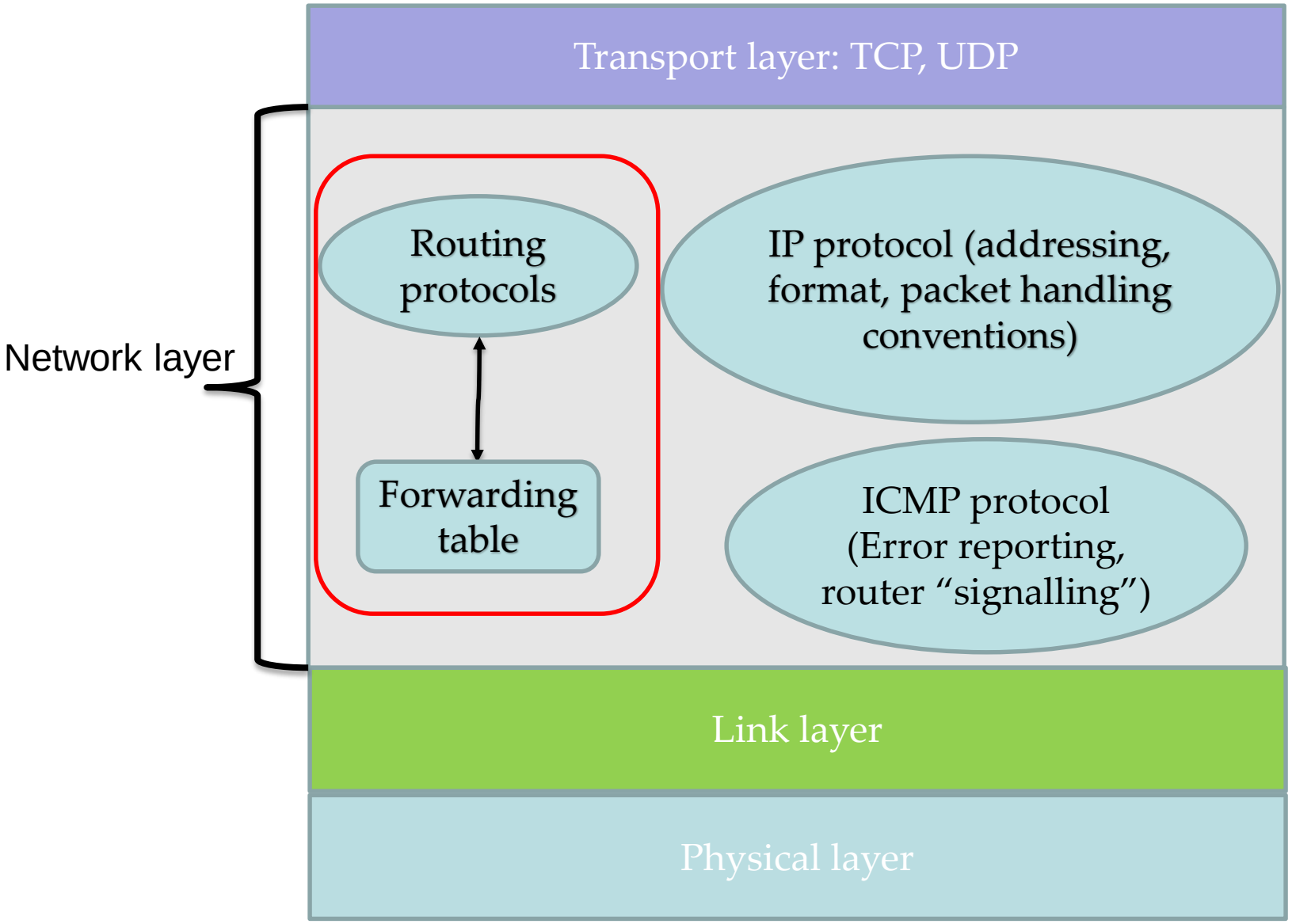
- Possible ones:
  - Guaranteed delivery (/with bounded delay);
  - In-order delivery;
  - Guaranteed minimal bandwidth;
  - Guaranteed maximum jitter;



Service of the Internet network layer

- Best-effort service (*No guarantee at all*!);
- There are other networks (ATM-*asynchronous transfer mode* -network) providing certain guarantees but they are not heard now.

A look inside the Internet's network layer



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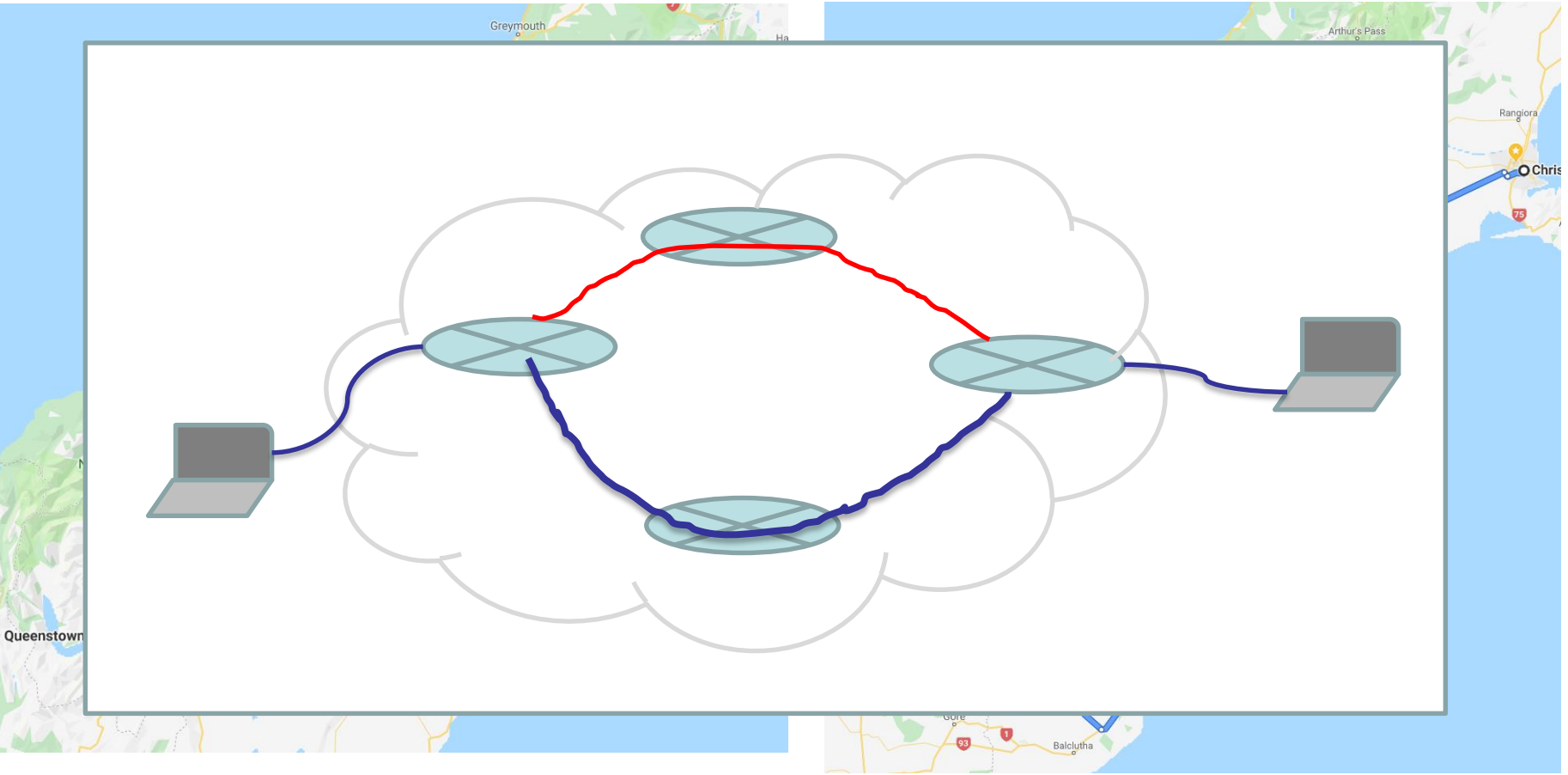
What is routing?

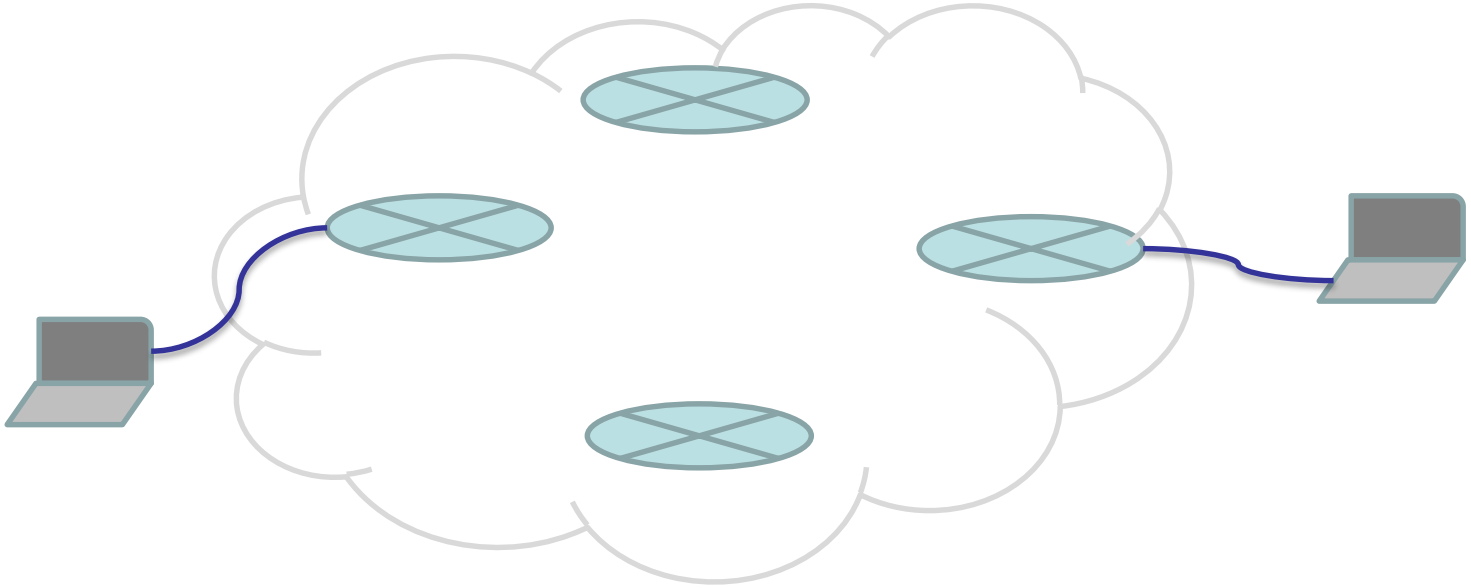
- Routing refers to the network-wide process that determines the end-to-end paths that packets take from source to destination.



Source: Google maps

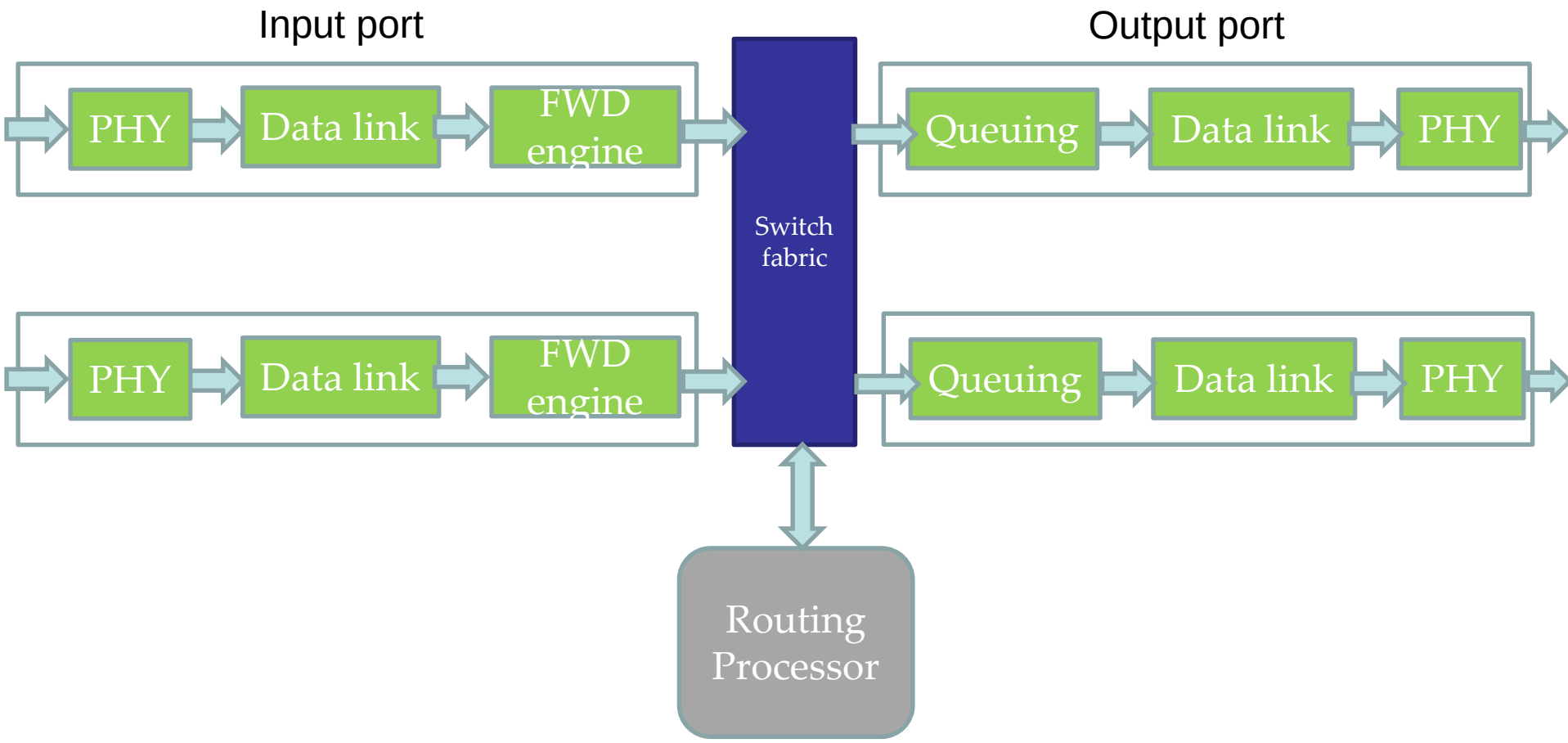
Why does routing matter?

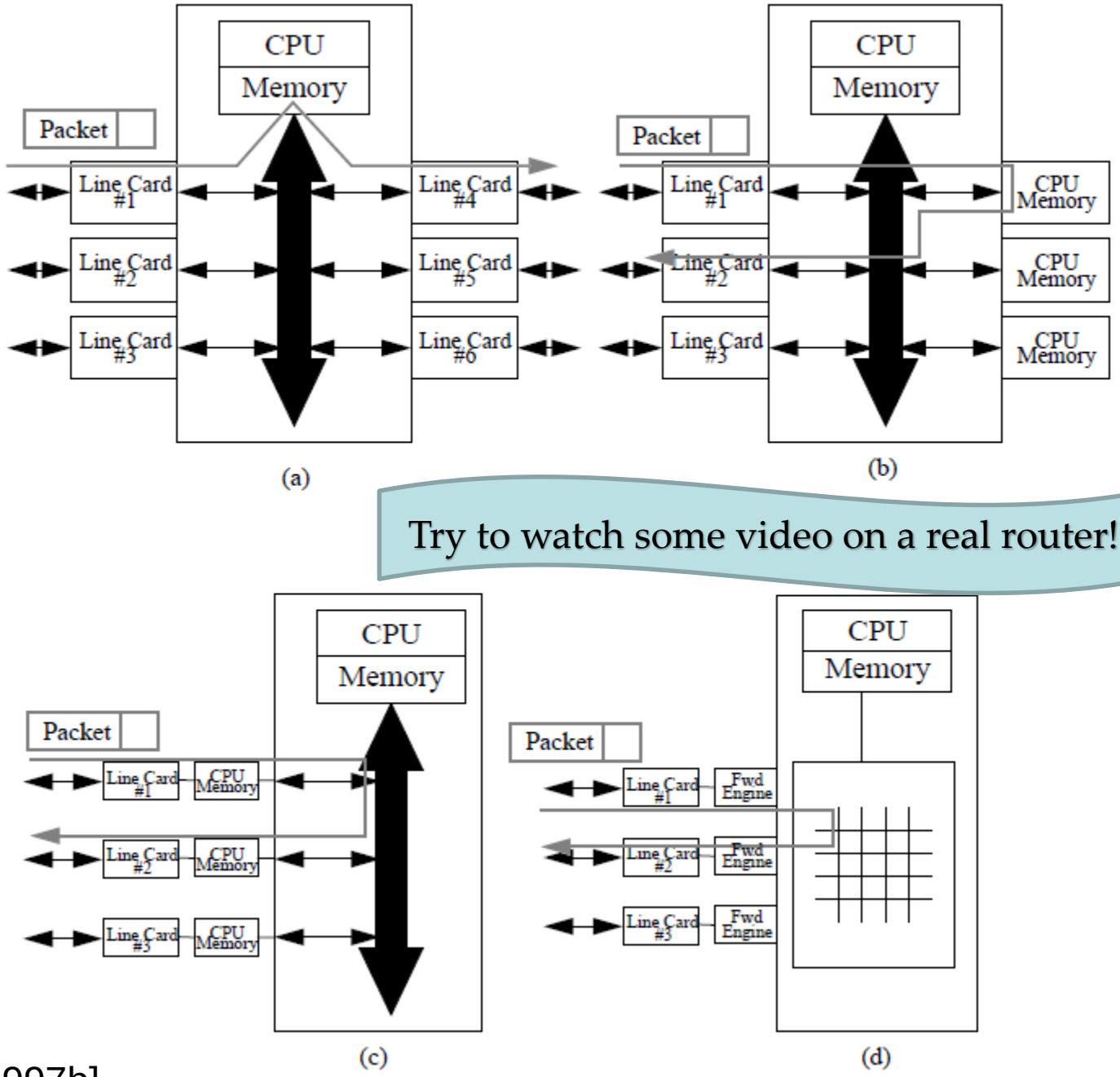
- The network needs to work out the path from the sender to the receiver *automatically*;
- More precisely, from the sending *router* to the receiving *router*!!



Where does routing happen?

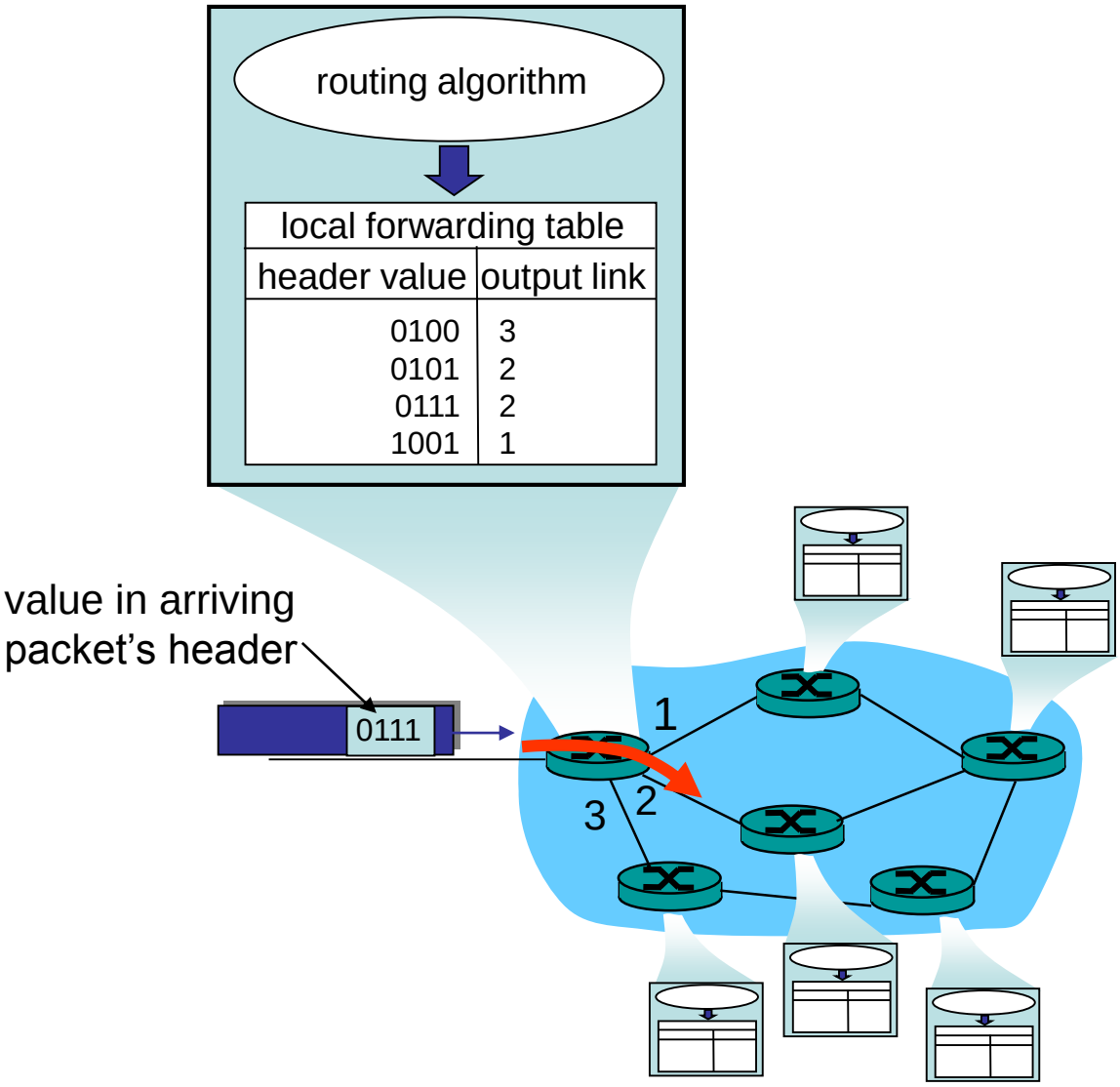
- In the routers!





[McKeown1997b] "A fast switched backplane for a gigabit switched router"

How does routing happen



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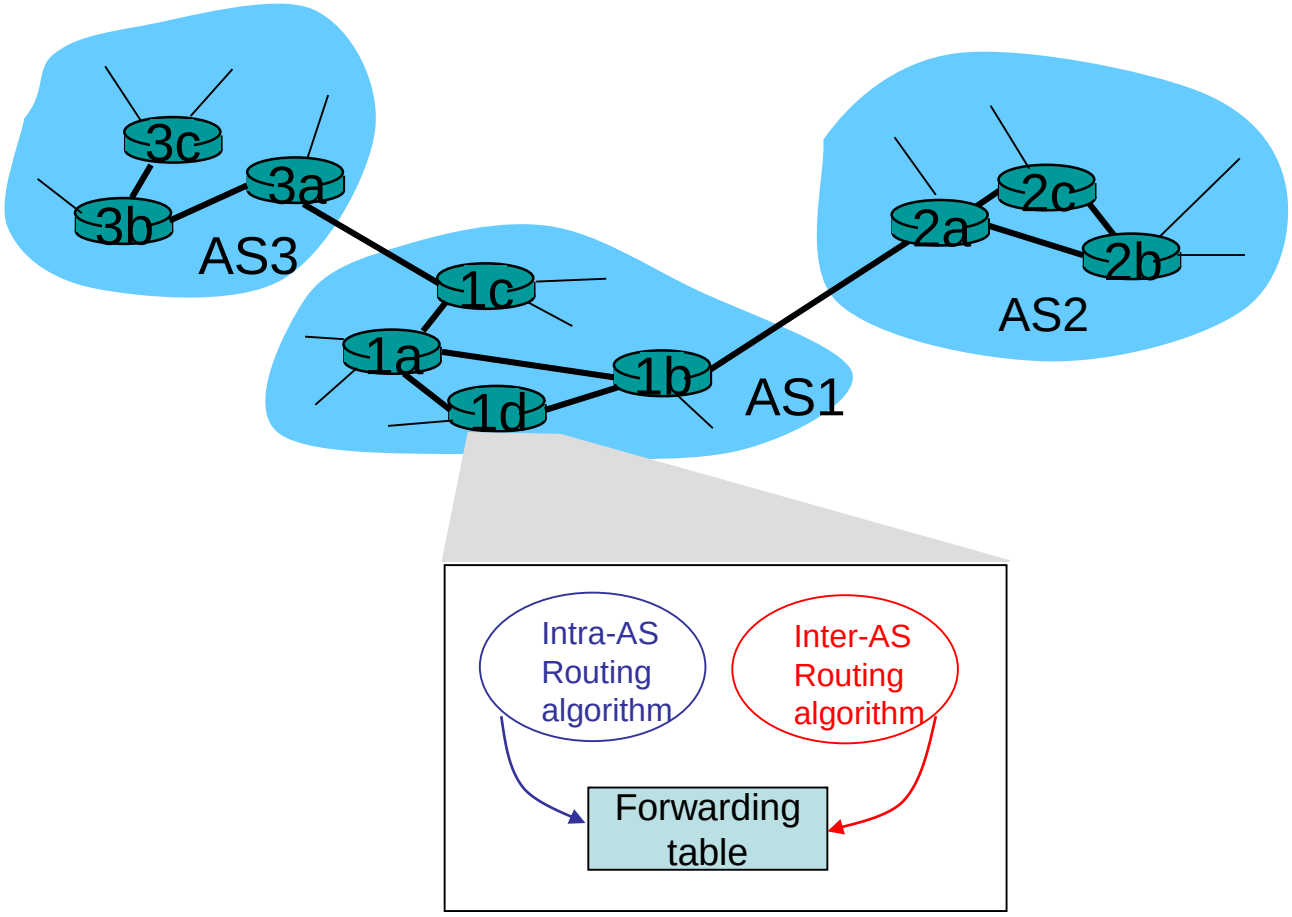
The scale of the Internet

- According to Cisco, 500 billion devices are expected to be connected to the Internet by 2030.

Hierarchical routing in the Internet



Autonomous System (AS)

- Each Internet Service Provider (ISP) is an AS
  - e.g., Google has an AS number (ASN): 15169,
    Facebook: 32934, Vodafone: 9500
  - Other AS examples: corporations, universities
- Exhibits the following characteristics:
  - is a set of routers and networks managed by a *single* organization;
  - consists of a group of routers exchanging information via a *common* routing protocol;
  - is connected;

An example

asn:university of canterbury

asn

Total amount of IPs for this ASN: **66,048**

As Number	9432
As Name	University of Canterbury
CIDR Range	132.181.0.0/16
	Monitor this
As Number	9432
As Name	University of Canterbury
CIDR Range	202.36.178.0/23
	Monitor this

Source: MXtoolbox

```
C:\Users\xwu25>ping www.canterbury.ac.nz

Pinging www.canterbury.ac.nz [132.181.106.9] with 32 bytes of data:
Reply from 132.181.106.9: bytes=32 time=1ms TTL=252
Reply from 132.181.106.9: bytes=32 time=1ms TTL=252
Reply from 132.181.106.9: bytes=32 time=1ms TTL=252
Reply from 132.181.106.9: bytes=32 time=1ms TTL=252
```

WHOIS IP Lookup Tool

The IPWHOIS Lookup tool finds contact information for the owner of a specified IP address.

Enter a host name or an IP address:

202.36.178.0 Go »

Related Tools: DNS Traversal Traceroute Vector Trace Ping WHOIS Lookup

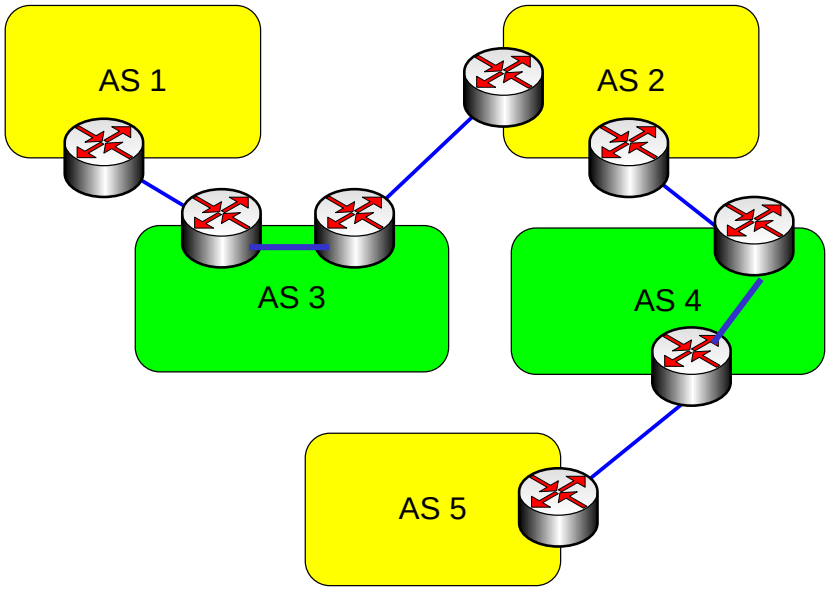
```
            Source: whois.apnic.net
        IP Address: 202.36.178.0

% [whois.apnic.net]
% Whois data copyright terms    http://www.apnic.net/db/dbcopyright.html

% Information related to '202.36.178.0 - 202.36.179.255'

% No abuse contact registered for 202.36.178.0 - 202.36.179.255

inetnum:        202.36.178.0 - 202.36.179.255
netname:        CCOE-NZ
descr:          Christchurch College of Education
descr:          PO Box 31-065
descr:          Christchurch
country:        NZ
admin-c:        AB175-AP
tech-c:         AB175-AP
status:         ASSIGNED PORTABLE
remarks:
```

Source: Ultratools.com

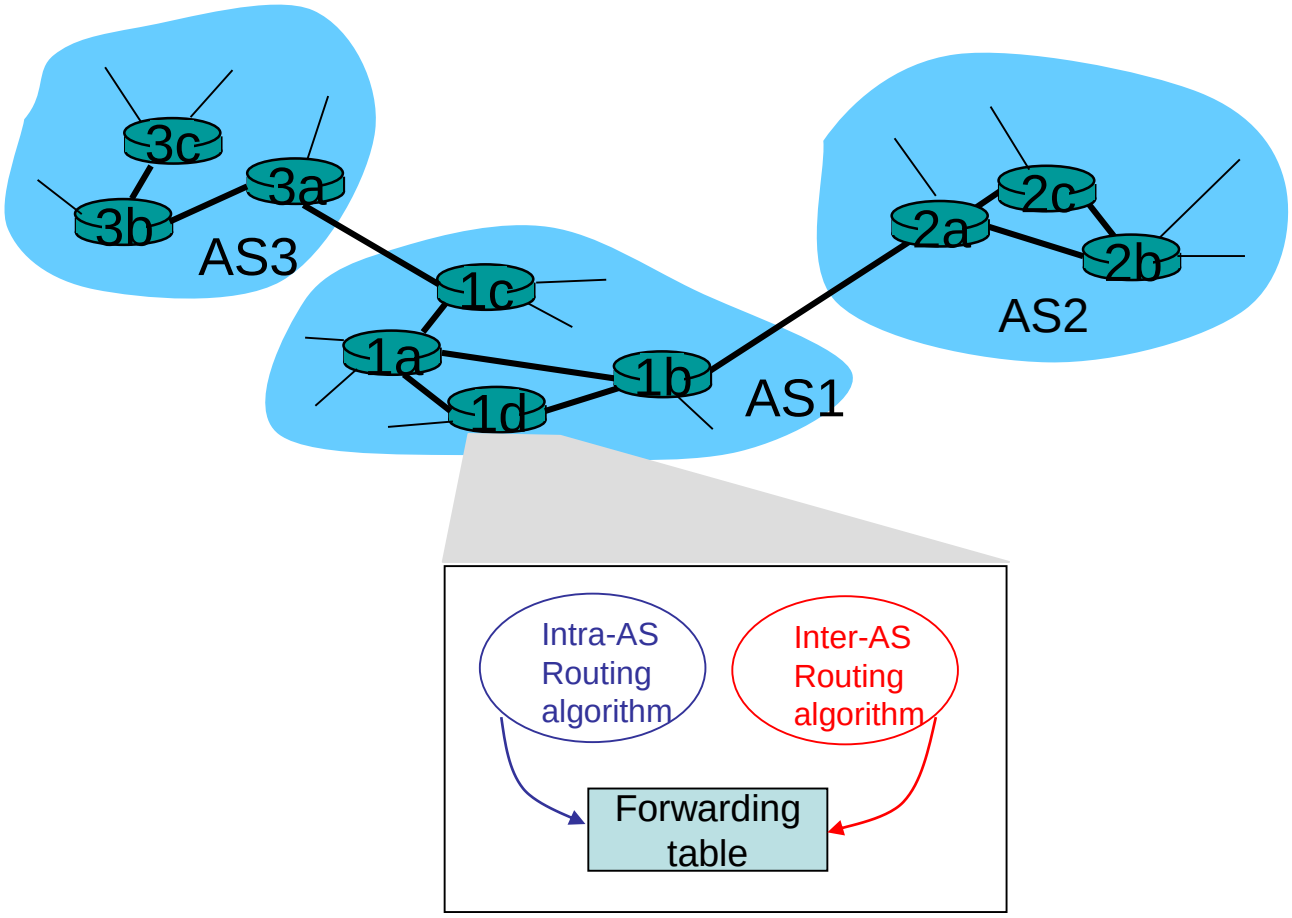
Three different types of AS

ASs are categorized according to the way they are connected each other ASs (not by their size).

- Stub AS
  - has only one connection to another AS
  - e.g., AS1, AS5
- Multi-homed AS
  - has more than one connection to other ASs, but does not allow traffic pass through
  - e.g., AS2
- Transit AS
  - is connected more than one AS and also allows the traffic to pass through
  - e.g., AS3, AS4



Hierarchical Routing in the Internet



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Forward vs Routing

- Routing determines the **path** to take
  - [analogy: planning trip from source to destination]
  - Routing is (general) not done per packet
  - Forwarding table entries populated by routing
  - Routing algorithm independent of forwarding
- Forwarding transfers packets hop-by-hop
  - [analogy: determining which exits to take on a drive]
  - Forwarding is per packet decision
  - Each switch (router) makes decision on **which link** to send

Routing vs. Forwarding (2)

- Routing: Computing ***paths*** the packets will follow
  - routers talking amongst themselves
    - normally only between routers
  - **non-**real time: latency up to 2 minutes
  - Jointly *creating* ***forwarding tables***

- Forwarding:
  - Directing every data packet to an outgoing link
  - Done in **real time;** may be implemented in specialised **hardware**
  - Individual router *using* a ***forwarding table***

Forwarding Table

- The forwarding table:
  - results from the execution of the **routing protocol** (dynamic routing), or static / preconfigured (static routing)
  - is consulted for every packet
  - is changed on relatively large timescales, e.g. upon topology changes, load changes or changes in metrics

- A *forwarding table* within a router maps to each destination address:
  - an outgoing interface (next-hop)

[NZTA]

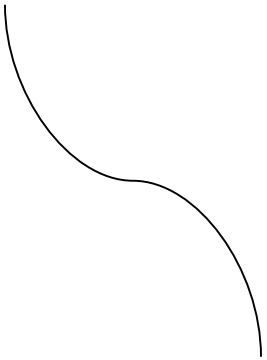
A forwarding table- a toy example

Destination address	Interface	
200.23.16.0	0	
200.23.16.1	0	
200.23.16.2	0	
…		
200.23.16.255	0	
200.23.17.0	1	

Another forwarding table

Destination address range	Interface	
range1	0	
range2	1	
range3	2	

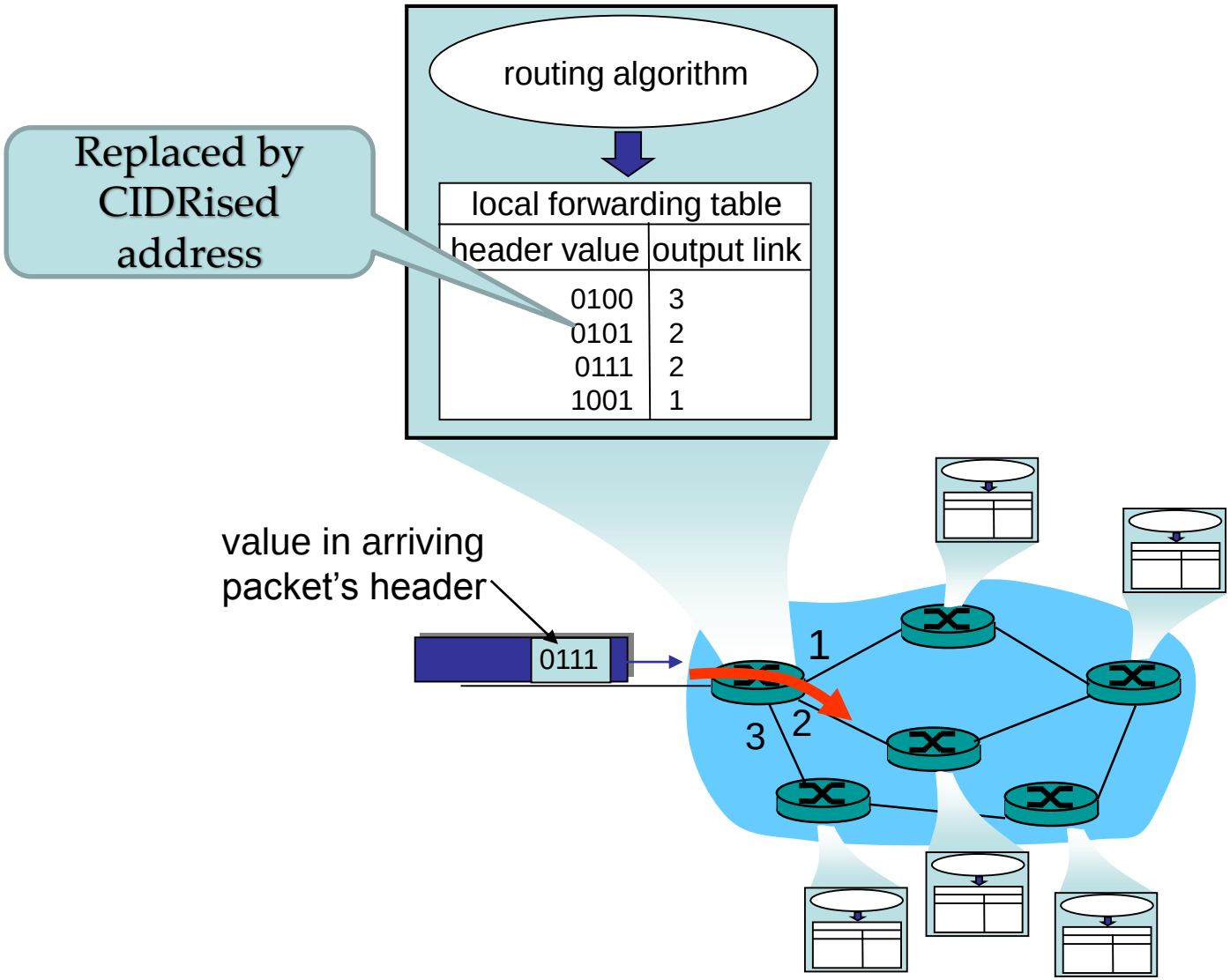
e.g., range1 – 200.23.16.0/24; CIDRised address
11001000 00010111 00010000 00000000



11001000 00010111 00010000 11111111

Apply *longest prefix match* when there are overlaps among range values.

Routing and Forwarding



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Q. What is the difference between routing algorithms and routing protocols?

Routing Algorithms and Routing Protocols

- A ***routing algorithm*** solves a routing problem with ideal assumptions.
- A ***routing protocol***
  - embeds a *routing algorithm* into a real networking context:
    - It operates in a distributed environment
    - It incorporates explicit information exchange among nodes
    - Information exchange takes time and might fail, the protocol must consider these possibilities

Routing Algorithms and Routing Protocols

Routing Protocols	Routing Algorithms
RIP	Bellman-Ford (Distance-vector) Algorithm
OSFP	Dijkstra's Algorithm
BGP	Bellman-Ford (Distance-vector) Algorithm

Routing algorithms classification

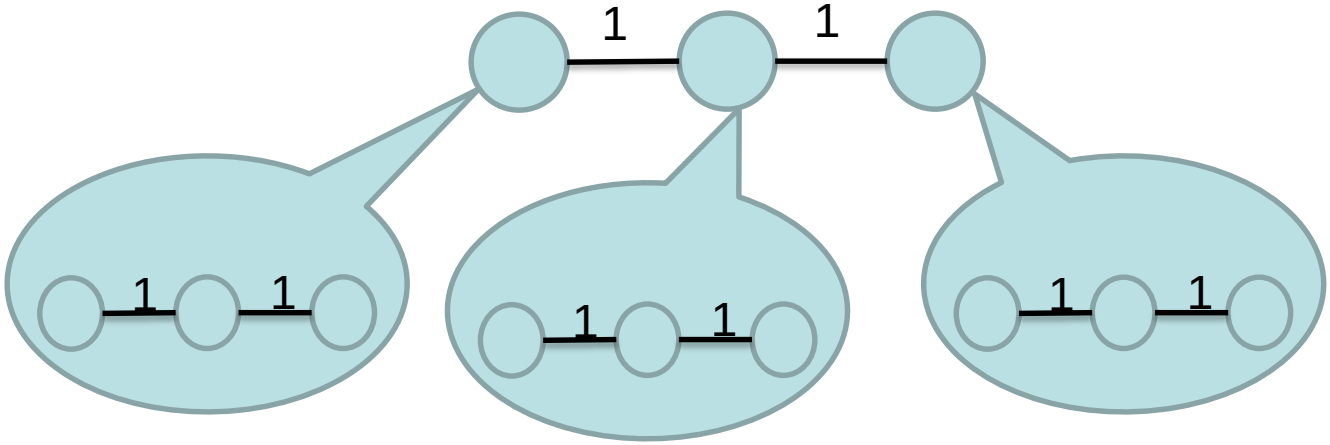
- Static or dynamic
- Global or decentralised
- Load-sensitive or load-insensitive

Static or dynamic

- Static
  - Routes change very slowly over time, often as a result of human intervention;
- Dynamic (adaptive)
  - Algorithm re-compute routes in response to topology or traffic change;
  - Route computation may occur
    - Periodically
    - In direct response to changes in topology and traffic
  - More responsive to changes;
    - Routing loops and oscillation in routes

Global or decentralised

- State (topology and link costs)
- Global
  - Each node (router) has global knowledge (state) of the network;
  - Example: Dijkstra's algorithm;
- Decentralised
  - No node (router) has complete information (state) about the network;
  - Exchange information with its neighbours;
  - Example: Bellman-Ford algorithm;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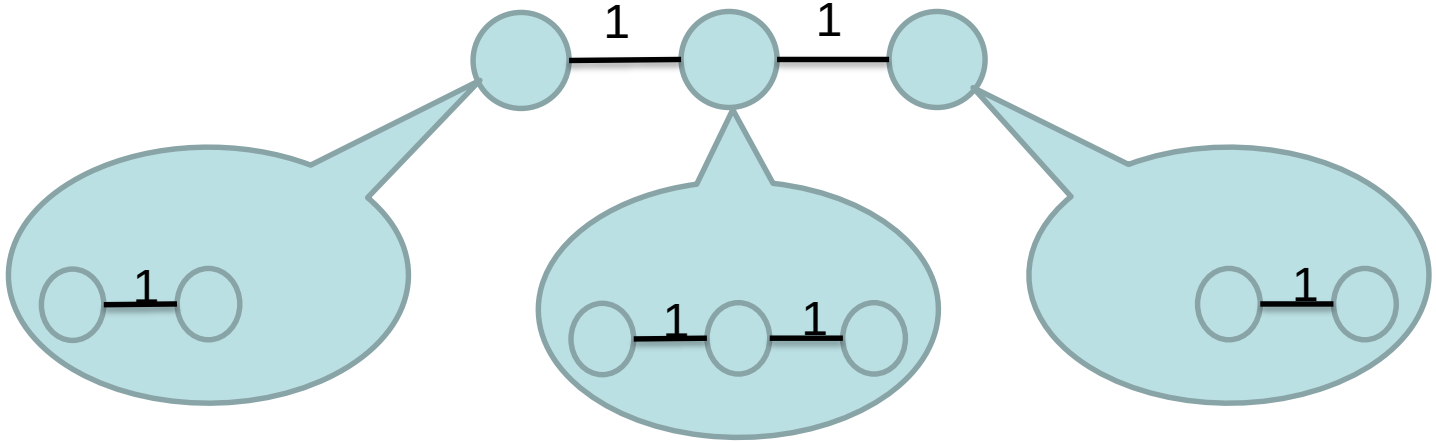
1
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1

Load-sensitive or load-insensitive

- Load-sensitive:
  - Link costs vary dynamically to reflect the current level of congestion in the link;
- Load-insensitive

The Internet routing protocols (RIP, OSPF, and BGP) are ***load-insensitive***.

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References

- [KR3] James F. Kurose, Keith W. Ross, *Computer networking: a top-down approach featuring the Internet*, 3rd edition.
- [PD5] Larry L. Peterson, Bruce S. Davie, *Computer networks: a systems approach*, 5th edition
- [TW5] Andrew S. Tanenbaum, David J. Wetherall, *Computer network*, 5th edition
- [LHBi]Y-D. Lin, R-H. Hwang, F. Baker, *Computer network: an open source approach*, International edition

Acknowledgements

- All slides are developed based on slides from the following two sources:
  - Dr DongSeong Kim's slides for COSC264, University of Canterbury;
  - Prof Aleksandar Kuzmanovic's lecture notes for CS340,Northwestern University, https://users.cs.northwestern.edu/~akuzma/classes/CS340-w05/lecture_notes.htm