Computer Networks and Distributed Systems

Introduction

Dr Fidelis Perkonigg

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Syllabus Overview

- Introduce networking concepts and terminology
  - Introduce OSI[1] and TCP/IP engineering models
  - Course loosely follows OSI Reference Model
- Describe network standards and protocols
  - Learn how design choices affect network behaviour
- Describe how networks inter-connect
- Illustrate how networks interact with applications

[1] Open Systems Interconnection

Recommended Books and Resources

- Computer Networks, Andrew S. Tanenbaum, David J. Wetherall, 4th or 5th Edition
- IEEE, IETF, ITU, OSI and W3C standards form basis of much of the material
- Distributed Systems: Concepts and Design, George Coulouris, Jean Dollimore, Tim Kindberg, Gordon Blair Addison-Wesley, 2005 (5th Edition)
- Acknowledgements: slides based on material by Dan Chalmers, Ian Harries and Peter Pietzuch

Terminology

- **Information:** Stimuli that have meaning in some context to a receiver
- **Data:** Information translated into a form that is more convenient for a computer to move or process
- **Channel:** Path through which signals can flow
- **Network:** Graph of devices interconnected by channels
- **Node:**
  - Device on network graph
  - May refer to end-point (e.g. computer) or communications device (e.g. router)

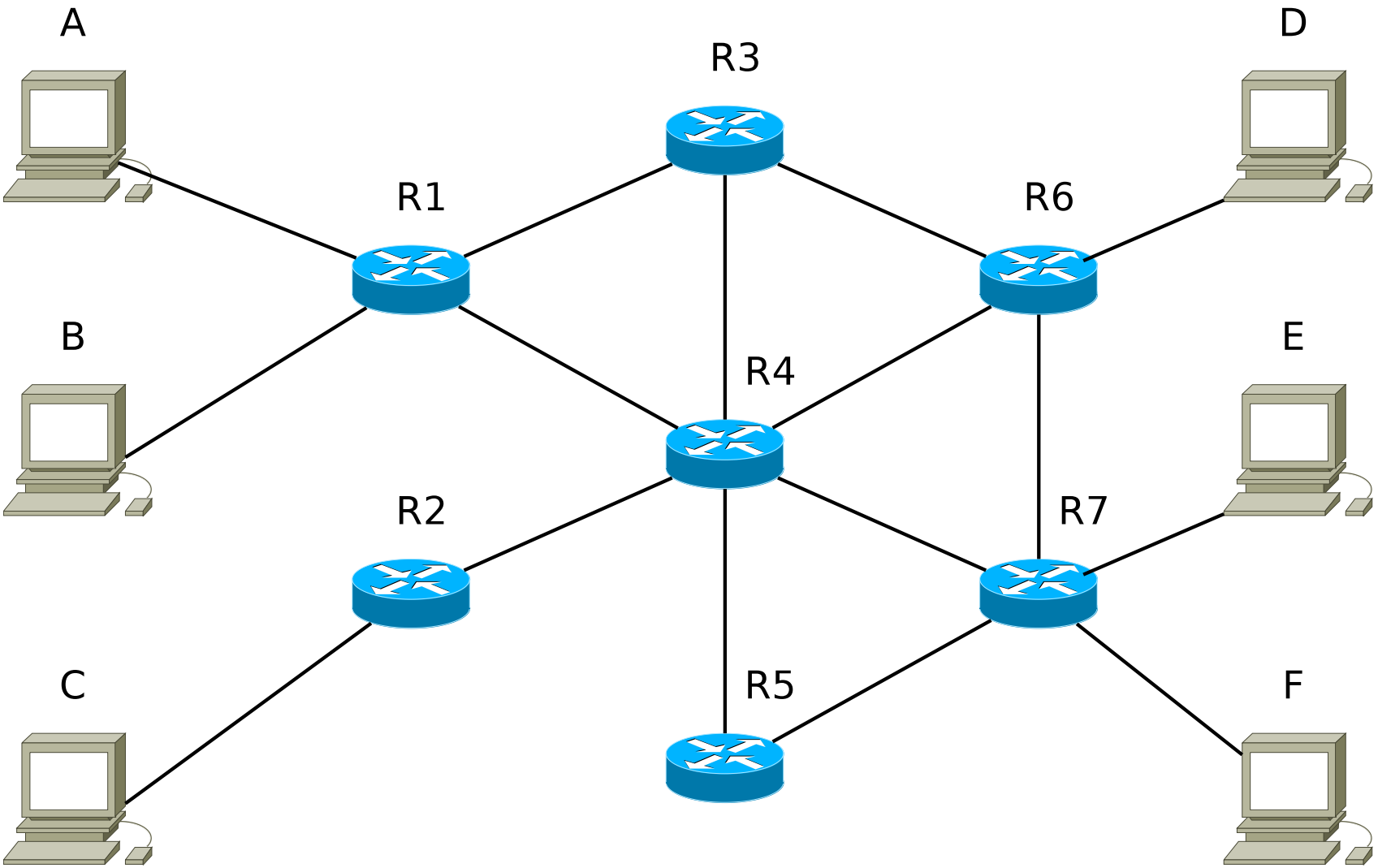
Network Metrics

- **Bandwidth:**
  - (Informally) used for channel capacity
  - Data transferred per time unit (usually bits/second)
  - How much data can be sent through a channel?
  - Refers to transmission rate (throughput) e.g. This is a high bandwidth connection
  - Bandwidth is also a technical (EE) term (measure of frequency range of analogue channel)
- **Delay or Latency:** Time a bit takes to get from source to destination (transmission, propagation, processing, queuing delay)
- **Jitter:** Variation in delay (usually percentage of delay or value)
- **Loss:** Rate of loss of units of transfer (percentage, unit depends on what is being lost)

From Connections to Networks

- Individual wires between each pair of computers $\rightarrow$ simple but clearly not scalable
- Shared wires between computers
  - Only listen to messages addressed to you
  - Connect to other networks by having switches make dynamic connections over shared pool of channels
- Types of Networks
  - Two forms of switch operation for networks: circuit switching and packet switching
  - Two types of service that networks can provide: connection less and connection oriented
  - Each valid but offer different behaviour (compare telephone network vs. computer network)

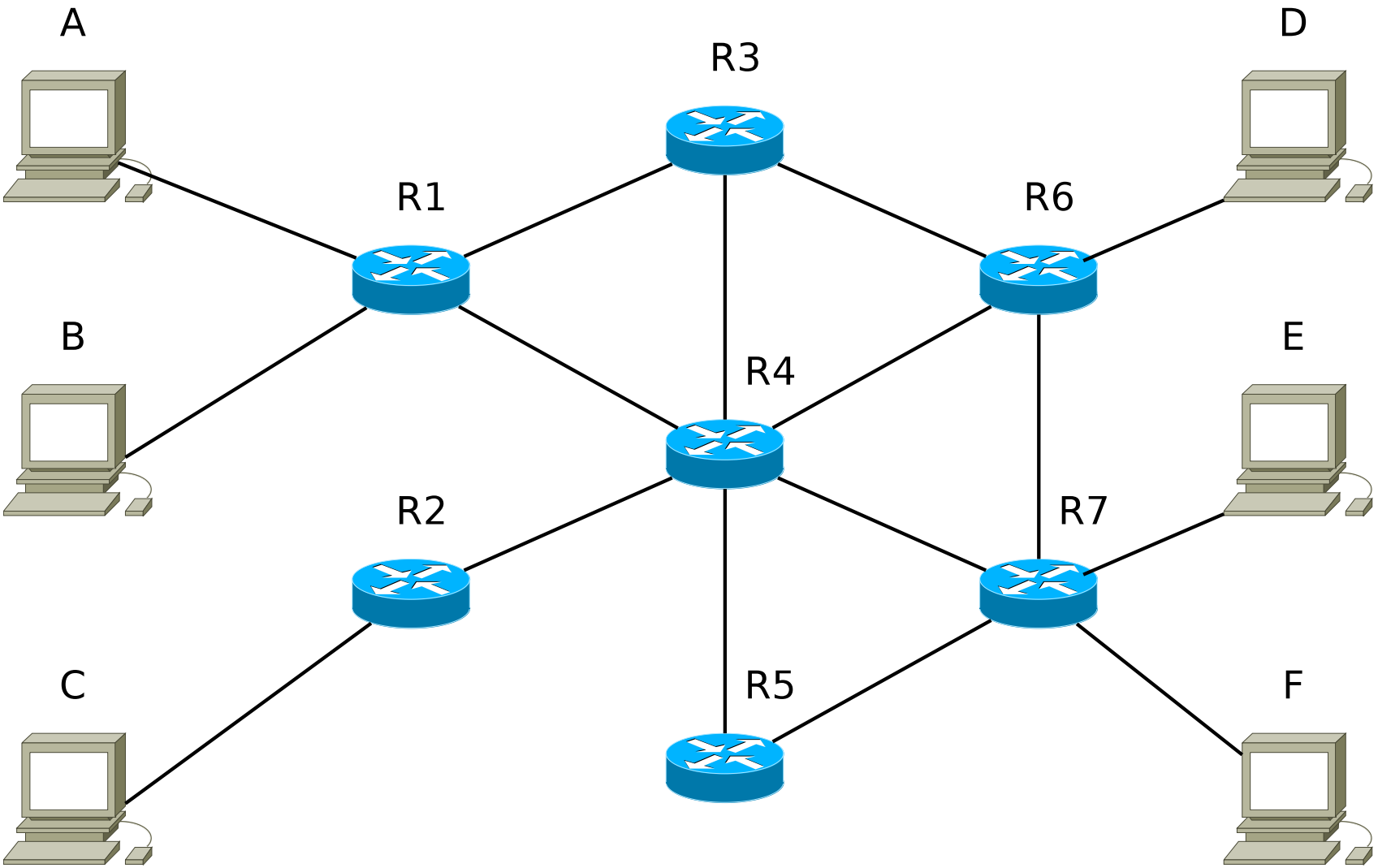
Circuit Switching (CS)



Circuit Switching (CS) Features

- One maintained path (circuit) (e.g. telephone call)
- Three phases:
  1. Circuit establishment
  2. Data transfer
  3. Circuit disconnection
- Overhead for call set-up, no overhead for use
- Provides guaranteed resources
- Connection breaks if any link or node on the route fails
- Charged typically by time

Packet Switching (PS)



Packet Switching Features

- Route calculated for each packet (e.g. postal service)
  - Packets may arrive out of order
  - Packets may be stored and forwarded, which adds delays
- All data has addressing and control overhead but no initial overhead
- Usually no guaranteed resources
  - Different routes may have different properties
  - Packets may be lost/retransmitted due to failure
- New route may be found if any link or node fails
- Charging typically by packet

Circuit Switching vs. Packet Switching

- Fixed bandwidth
- Unused bandwidth wasted
- Call set-up required
- Congestion may occur at call
- Overhead on call setup only
- In-order delivery
- Circuit fails if any link or node fails

- Variable bandwidth
- Uses only bandwidth required
- No call set-up
- Congestion may occur at any time (causing delay and reordering)
- Overhead on every packet
- Out-of-order delivery
- New route found if any link or node fails (some data may be lost)

Types of Connection Service

- Network provides connection service to programs
- May be connectionless (CL) or connection-oriented (CO)

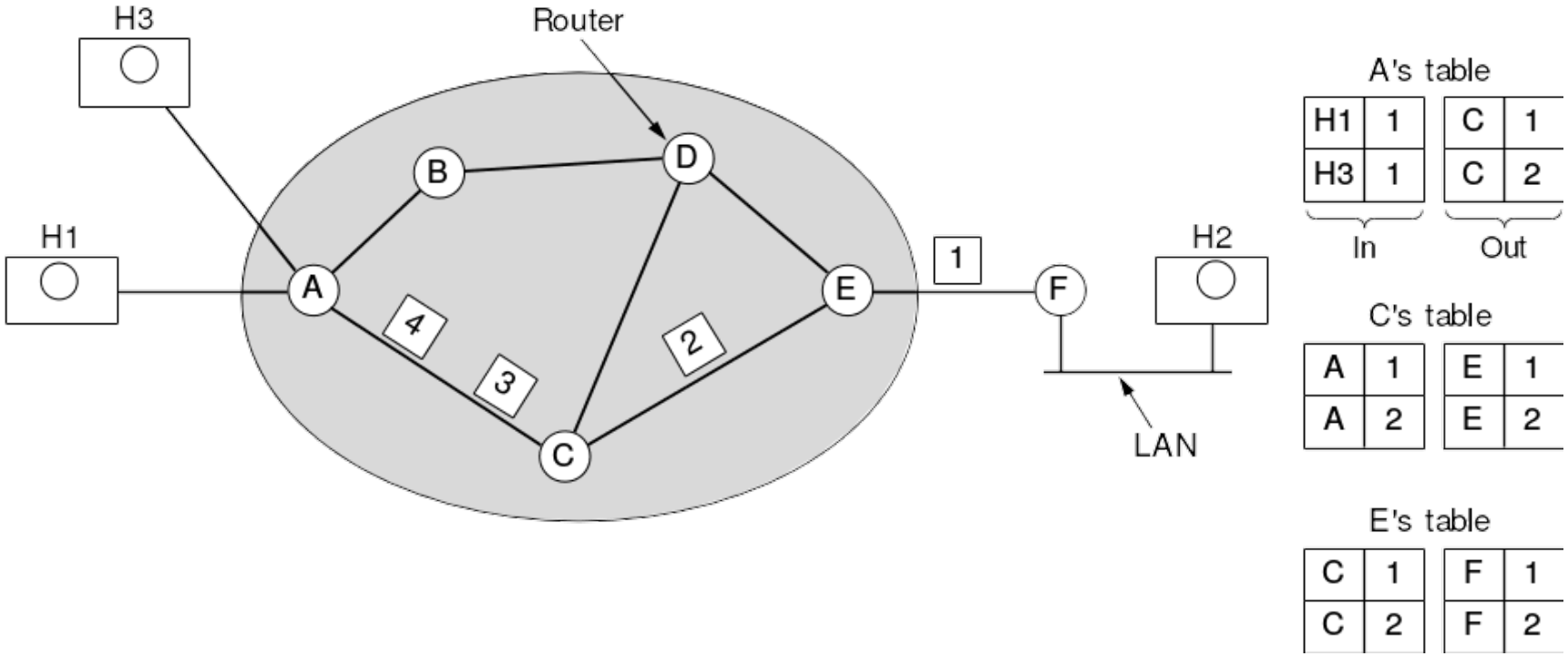
Connectionless Service (CL)

- No conceptual connection or maintained route
- Unit of connection is datagram (packet)
- No guarantee of order
- Packet switched networks provide pure CL service
  - Packets addressed by destination and routed accordingly
  - Each packet handled separately
  - No set-up/tear-down calls

Connection-Oriented Service (CO)

- Connection maintained between end-points
- Unit of connection is the circuit
- Order is preserved
- Circuit switched networks provide pure CO service (circuit defines destination and route)
- Packet switched networks can provide CO service by using virtual circuits

Virtual Circuits

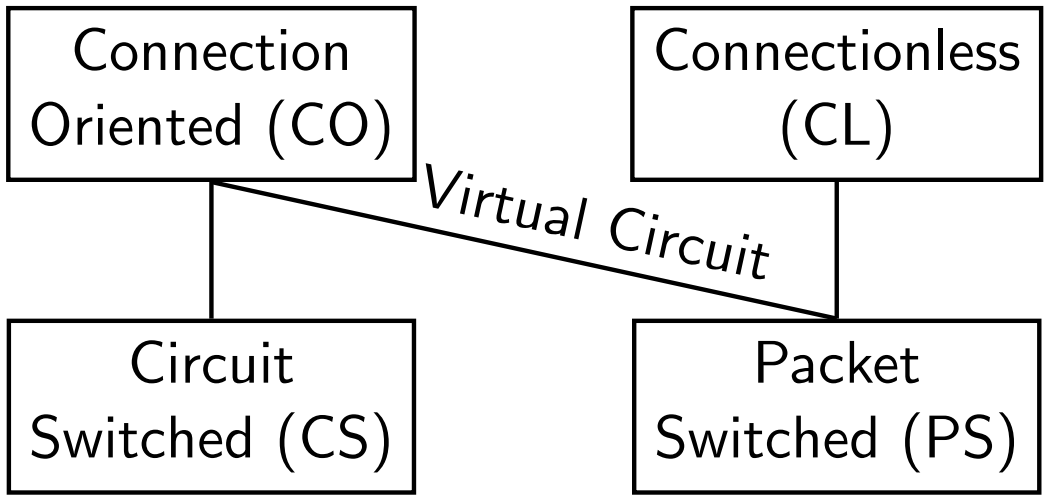


- Routes packets by circuit identifier (1 and 2 in the example above)
- Each packet includes circuit identifier in the header
- Set-up/tear-down overhead
- Switches/Routers need to maintain circuit information (tables)
- Less routing overhead compared to PS

Classes of Network Connection - Summary

Connection Service Provided

Underlying Network



Scale of Networks

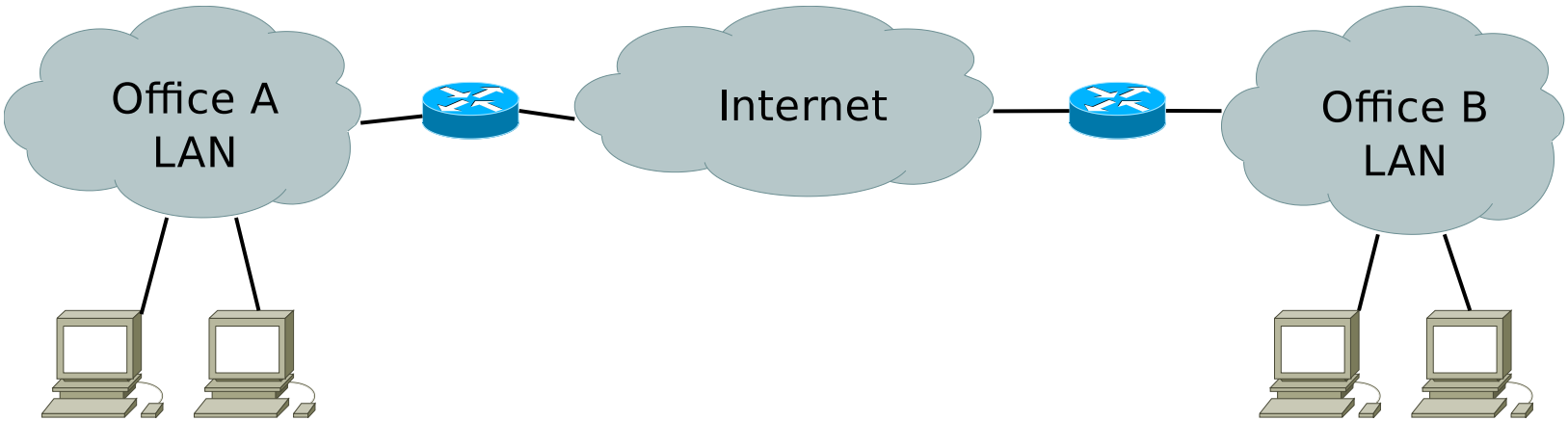
Inter-device Distance	Device Location	Connection Environment
0.1m	Circuit board	Dataflow machine
1m	System board	Multiprocessor
10m	Room	Local-Area Network
100m	Building	Local-Area Network
1km	Campus	Local-Area Network
10km	City	Local-Area Network
100km	Country	Metropolitan-Area
1000km	Continent	Metropolitan-Area
10000km	Planet	Internet

Local Area Networks (LANs)

- Connecting a variety of devices
  - Different message sizes and rates
  - Nodes may connect and disconnect, or fail
  - Systems may compete or co-operate
- Typically under single admin domain

Metropolitan, Wide-Area, Inter-nets

- Formed from interconnected LANs
  - Longer distances
  - Costs of long cables, satellite links
  - Delay and bandwidth restrictions due to distance
- Politics of shared ownership and international connections



Network Abstractions

- General-purpose networks are complex
  - Different networking technologies
  - Equipment provided by multiple manufacturers
  - Managed by different people
- How do we describe a complete network architecture?
- How do we define intended behaviour?
- Answer: standards, network stack model, and protocols

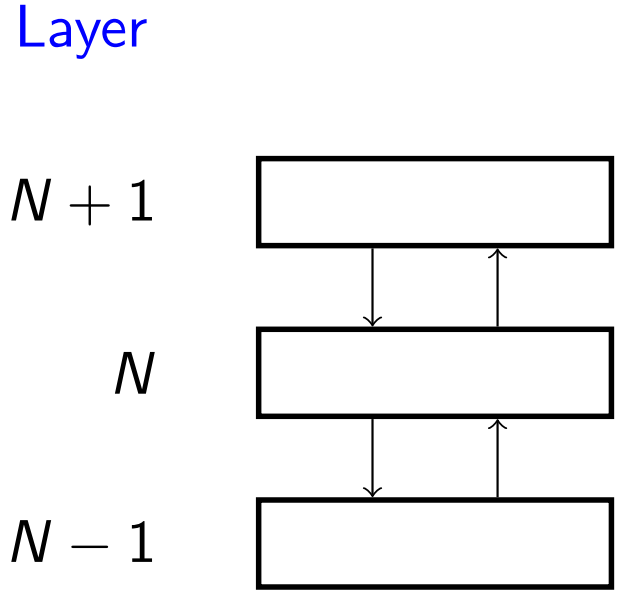
Applications view network as black box service; details of the network are hidden from the application.

Standards

- Standardised ways of connecting systems
  - Hardware and software (protocol) standards
  - Require backwards compatibility
  - Do not prescribe implementation
- Many standard bodies exist, e.g. ISO, ITU, IEEE, IETF, W3C
- Different types of standards
  - Open (published, free) vs. proprietary standards
  - Industry provides de-facto standards

Network Stack Model

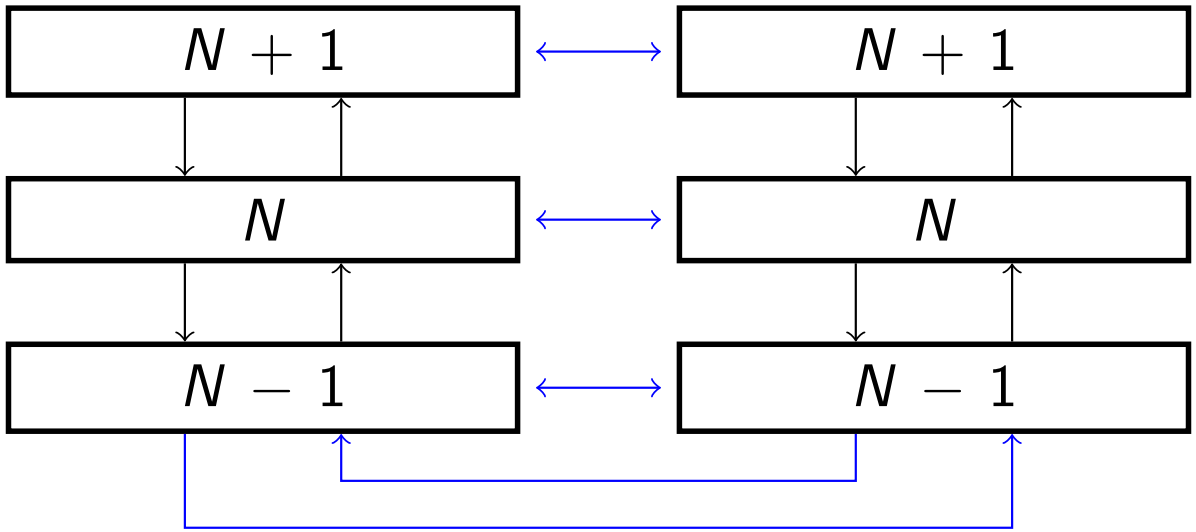
- Model network as layered stack
  - Layer N provides well-defined service to Layer N+1
  - Layer N uses Layer N-1 for communication
- Layering provides modularity
  - Layers do not process data from higher layers
  - May replace implementation of layers
- But too many layers lead to inefficiency



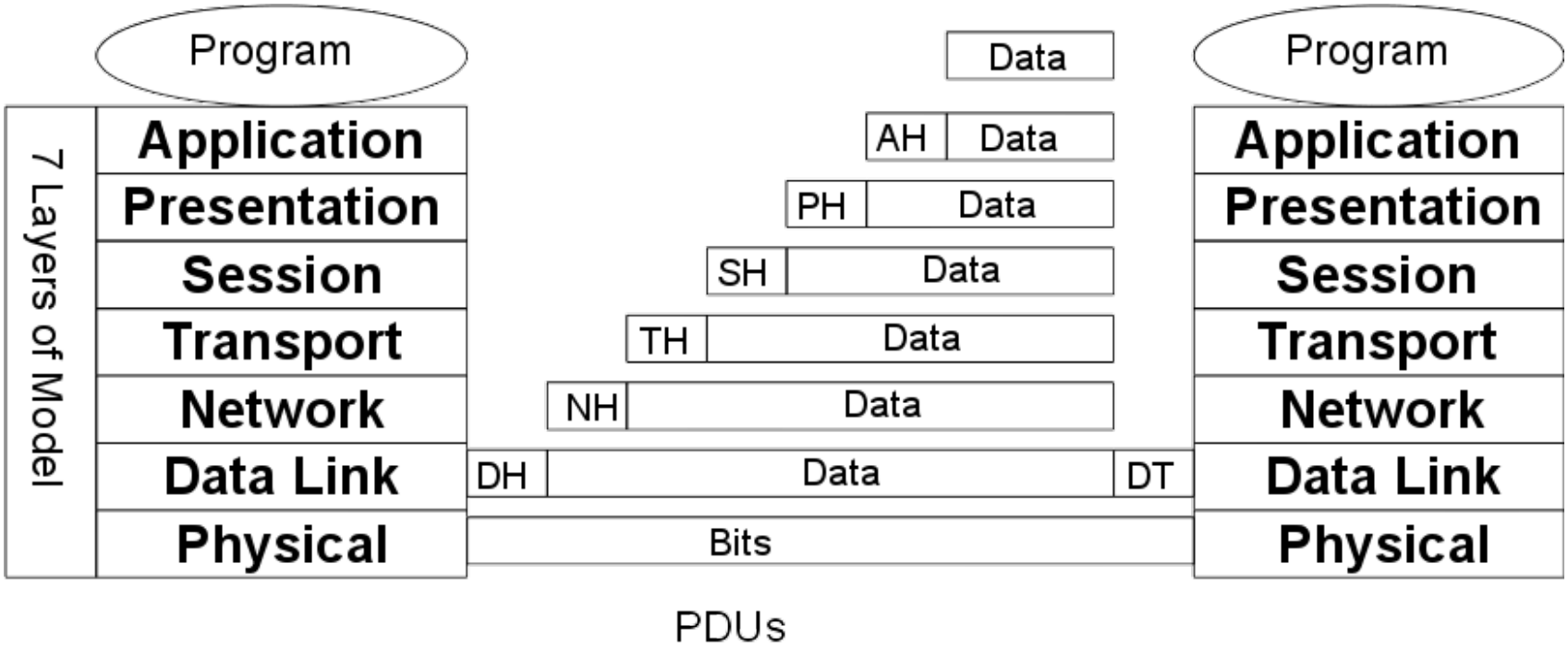
Protocols

The agreed rules and conventions used in the communication between parties are known as a protocol.

- Defines message formats, relationships between messages, etc
- Entity at one host exchanges protocol data units (PDU) with peer entity at another host
- Actual connection only at lowest layer



OSI Reference Model



OSI - Physical and Data Link Layers

Physical Layer

- Transmission of bit-stream over medium (provides communication path between nodes)
- Encodes data according to signalling standards
- Connectors and cables defined

Data Link Layer

- Arranges data into bit stream for sending over physical link
- Data encoded in transmission frames
- Low-level flow and error control for single hop
- Possible services to network layer: Unacknowledged CL, Acknowledged CL, Acknowledged CO

OSI Network and Transport Layers

Network Layer

- Provides end-to-end transmission of data
- Uses data link layer to provide transmission over single hops
- Global addressing and routing
- Hides differences in underlying networks

Transport Layer

- Provides transparent transfer service
- End-to-end flow control and error recovery
- Can be more reliable than underlying network

OSI Session and Presentation Layers

Session Layer

- Enhances transport for sessions with special services
- e.g. dialogue synchronisation, exception handling, etc

Presentation Layer

- Manages syntax and semantics of data exchanged
- e.g. data encryption, authentication, and compression
- e.g. data marshalling, byte ordering, etc

We do not look at session and presentation layers much in this course

OSI Application Layer

- Provides interface to application but but does not include the application
- Most users only have contact with application layer
- Protocols for common application interactions are for example: file transfer, e-mail, web, IM, video telephony

TCP/IP Model

OSI	TCP/IP
Application	Application
Presentation	Not present
Session	Not present
Transport	Transport
Network	Internet
Data Link	Link
Physical	Not present

- Developed by DoD for ARPANET[2]
- Presentation and session functions not seen as necessary
- Link layer is an interface between hosts and transmission links

[2] Advanced Research Projects Agency Network

OSI vs TCP/IP Model

- Central concepts: services, interfaces, protocols
- Devised before protocols (no bias)
- Sometimes challenging to make protocols fit model
- Can be complex, not all layers always used
- The standard model

- Concepts lack generality
- Rather a description of existing protocols
- Some layers largely undefined (link layer and physical layer)
- TCP/IP protocol most widely used

This course tends to use OSI model but Internet protocols