Imperial College London

Computer Networks and Distributed Systems

Computer Networks – Introduction

Course 527 – Spring Term 2014-2015

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Aims and Assumptions

- Course covers basic principles of networking through examples of real technology
- Networks enable distributed systems
  - Understanding networks helps analyse, design, implement distributed systems
- Assumptions
  - Familiarity with basic concepts of computer architecture
  - We're all network users
- *Acknowledgements: based on material by Dan Chalmers, Ian Harries and Peter Pietzuch*

Recommended Books (for CN)

- “Computer Networks”, Andrew S. Tanenbaum, Prentice Hall, 2005 (4th Edition)
  - Main reference and worth reading

- “Distributed Systems: Concepts and Design”, George Coulouris, Jean Dollimore, Tim Kindberg, Gordon Blair Addison-Wesley, 2005 (5th Edition)

- IEEE, IETF, ITU, OSI and W3C standards form basis of much of the material, but not designed as tutorials

Syllabus Overview

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

Terminology

- Information
  - Stimuli that have meaning in some context for receiver
- Data
  - Information translated into form more convenient to move or process by computer
- 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

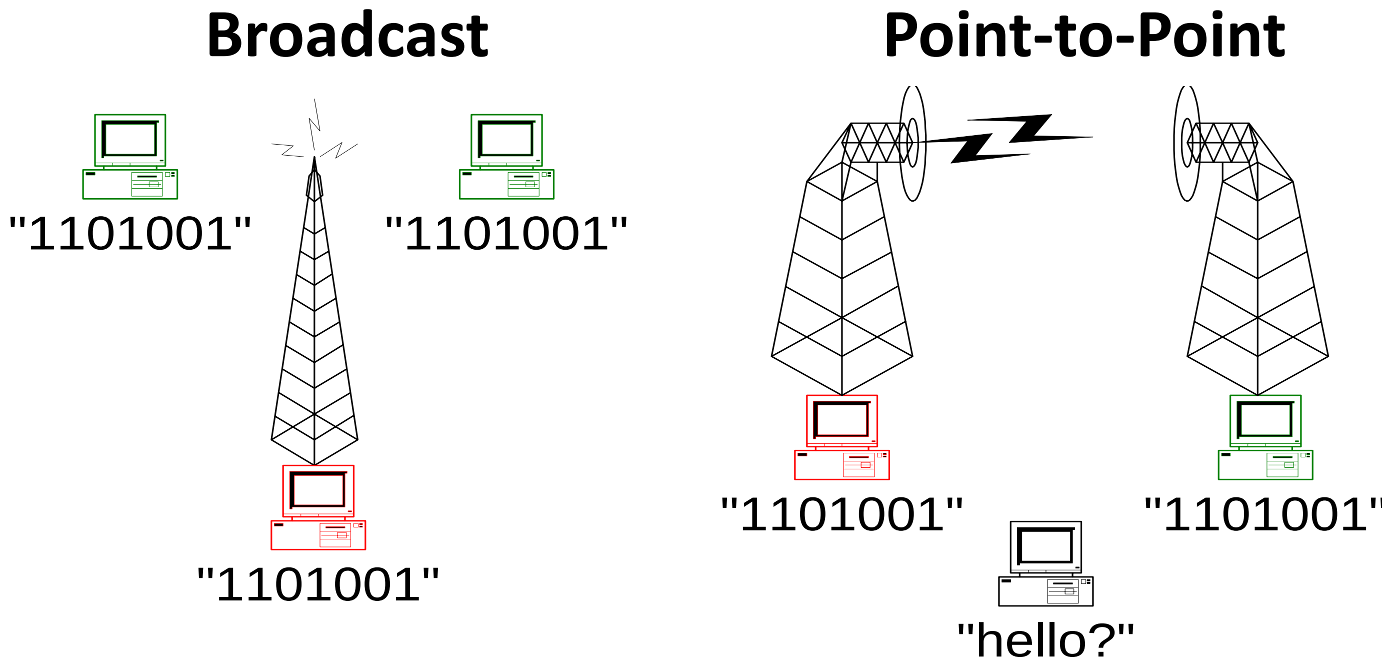
- Bandwidth
  - (Informally) used for **channel capacity**
  - Data transferred per unit time (usually bits/second)
  - How much data can be sent through a channel?
  - Refers to **transmission rate** (throughput) e.g. “This is a high bandwidth connection”
  - Careful! Bandwidth also technical (EE) term → measure of frequency range of analogue channel

- Delay or Latency
  - Time a bit takes to get from source to destination (seconds)
- Jitter
  - Variation in delay (usually % of delay or value +/- seconds)
- Loss
  - Rate of loss of units of transfer (percentage, unit depends on what is being lost)

Classes of Communication

- Many ways to describe a network
  - Wires (or media) that form channels
  - Behaviour of channels
  - Range in physical and organisational terms
  - Needs and capabilities of nodes

☛ We need models to describe diverse networks



From Connections to Networks

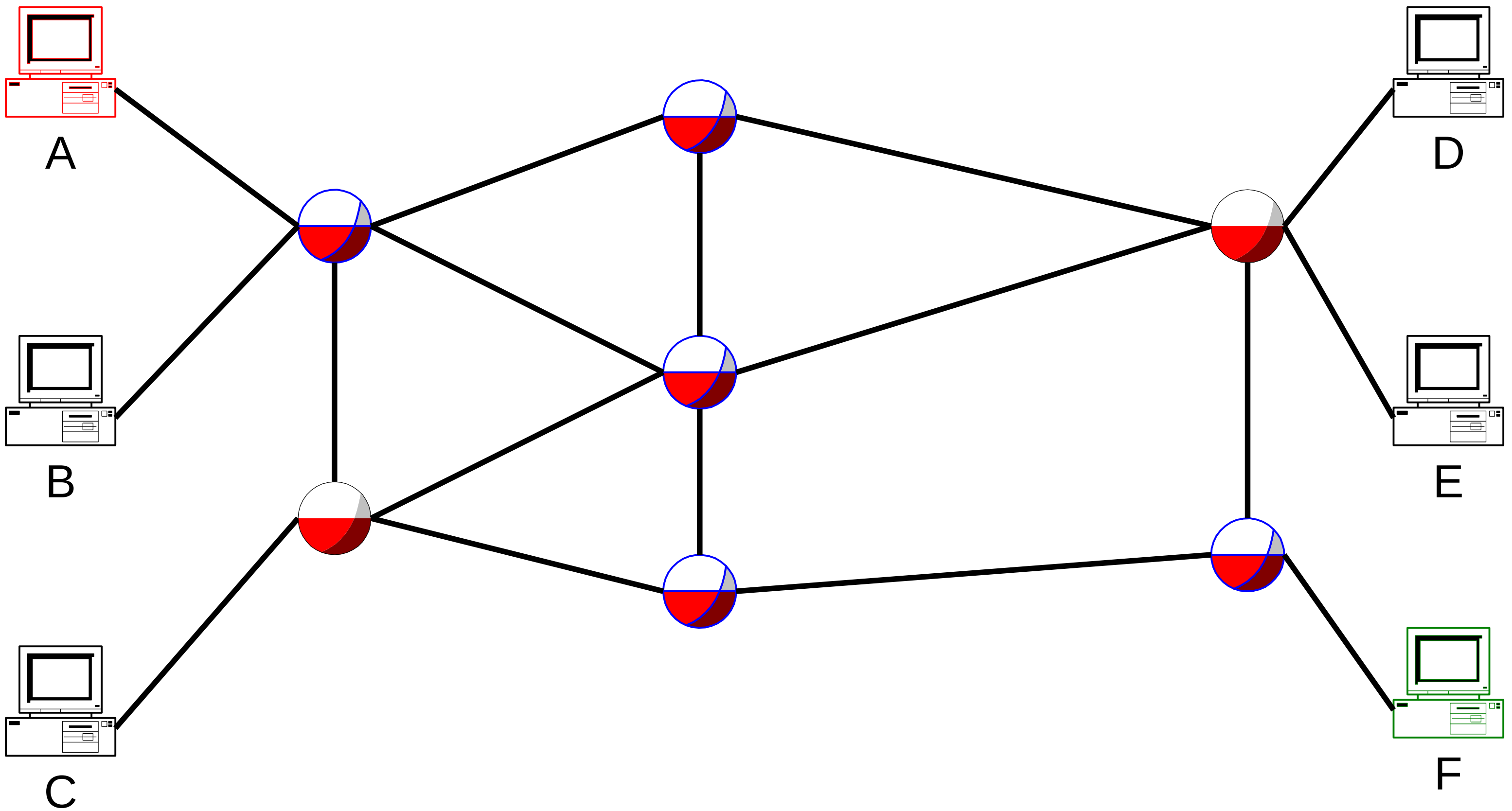
- Most networks have >2 devices that connect dynamically

- Individual wires between each pair of computers
  - Simple but clearly not scalable

- Shared wires between computers
  - Only listen to messages addressed to you
  - Larger networks by having switches make dynamic connections over shared pool of channels

- Types of Networks
  - Two forms of switch operation for networks
  - Two types of service that networks can provide
  - Each valid but offer different behaviour → compare *telephone network* vs. *computer network*

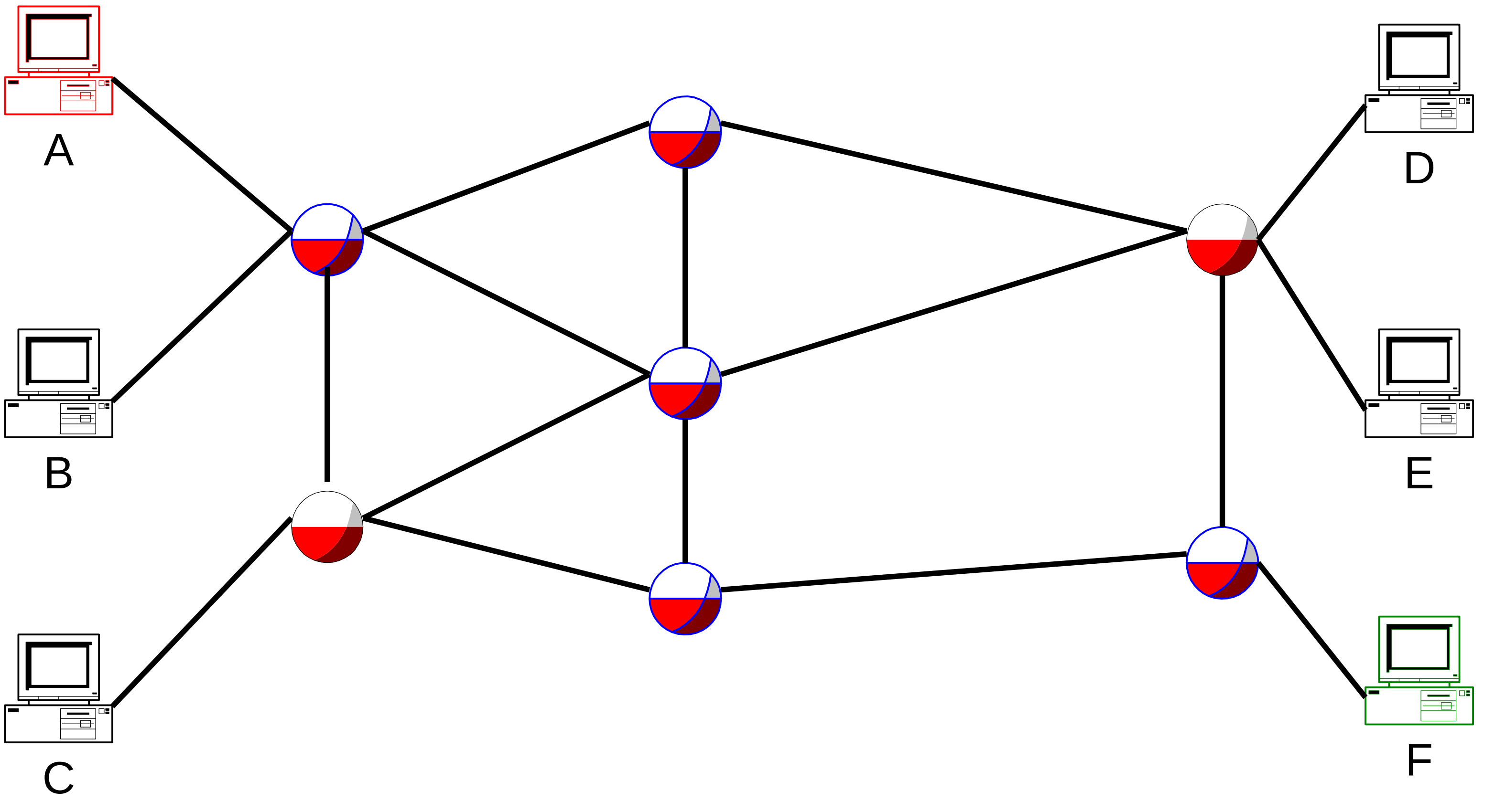
Circuit Switching (CS)



Circuit Switching 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 switch on route fails
- Charging typically by time

Packet Switching (PS)



Packet Switching Features

- Route calculated for each packet (e.g. postal service)
  - Packets may arrive out of order
  - Switches may store and forward packets
- All data has addressing and control overhead
  - But no initial overhead
- Usually no guaranteed resources
- Failures accommodated transparently
  - Different routes may have different properties
  - Packets may be lost/retransmitted due to failure
- Charging typically by packet

Circuit Switching vs. Packet Switching

- **Circuit Switching**
  - Fixed bandwidth
  - Unused bandwidth wasted
  - Call set-up required
  - Congestion may occur at call set-up (arrival rate = transmission rate)
  - Overhead on call setup only
  - In-order delivery
  - Circuit fails if any link or switch fails
- **Packet Switching**
  - Variable bandwidth
  - Uses only bandwidth required
  - No call set-up
  - Congestion may occur on any packet (causing delay and reordering)
  - Overhead on every packet
  - Out-of-order delivery
  - New route found if any link or switch fails (some data may be lost)

Types of Connection Service

- Network provides connection service to programs
  - May be connectionless or connection-oriented

- Uses underlying network to achieve this
  - Network may be PS or CS
  - Network doesn't determine service type provided
    - Software can add behaviour

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 state at switches or 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

Scale of Networks

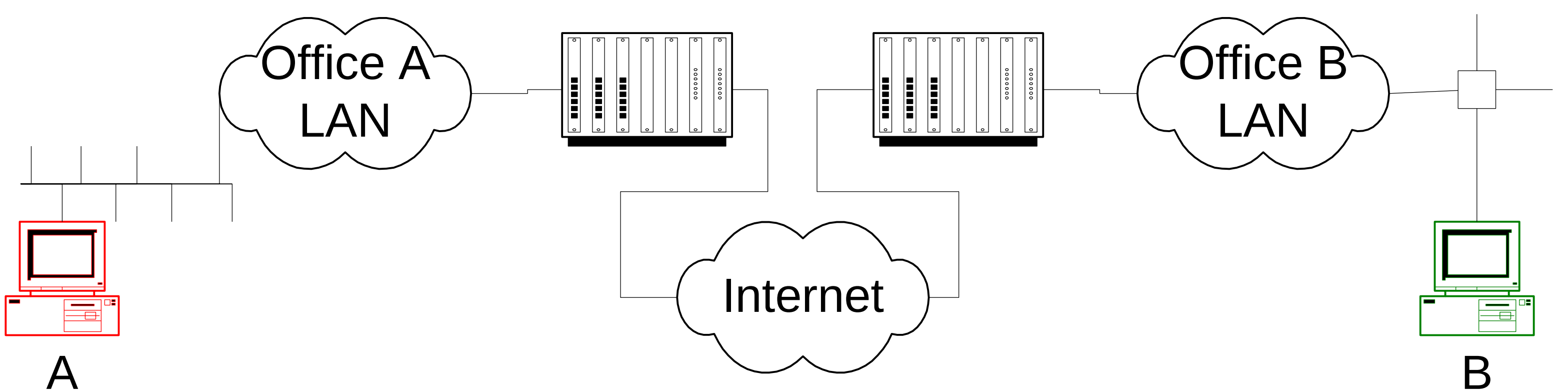
Inter-device distance	Devices located in same	Connection environment
0.1m	Circuit board	Dataflow machine
1m	System board	Multiprocessor
10m	Room	Local-Area Network
100m	Building	
1km	Campus	
10km	City	Metropolitan-Area
100km	Country	Wide-Area Network
1000km	Continent	
10000km	Planet	Internet

Local Area Networks (LANs)

- Transmission through buildings
  - Typically 80% of communications are local
- Many and varied 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

- Applications view network as black box service
  - Hide the details of the network
  - Many parameters are orthogonal

☛ How do we describe a complete network architecture?

- General-purpose networks are complex
  - Different networking technologies
  - Equipment provided by multiple manufacturers
  - Managed by different people

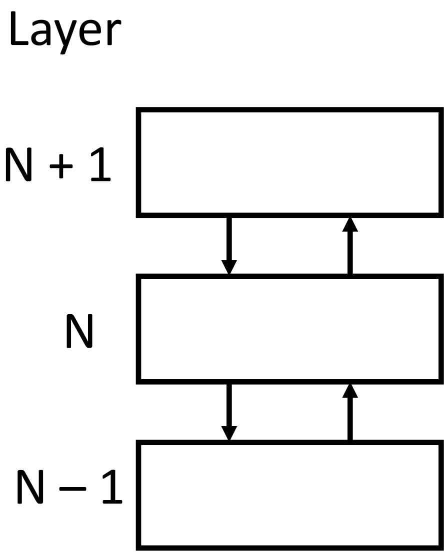
☛ How do we define intended behaviour?

Standards

- Standardised ways of connecting systems
  - Hardware and software (protocol) standards
  - Freeze technology and 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
  - e.g. 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



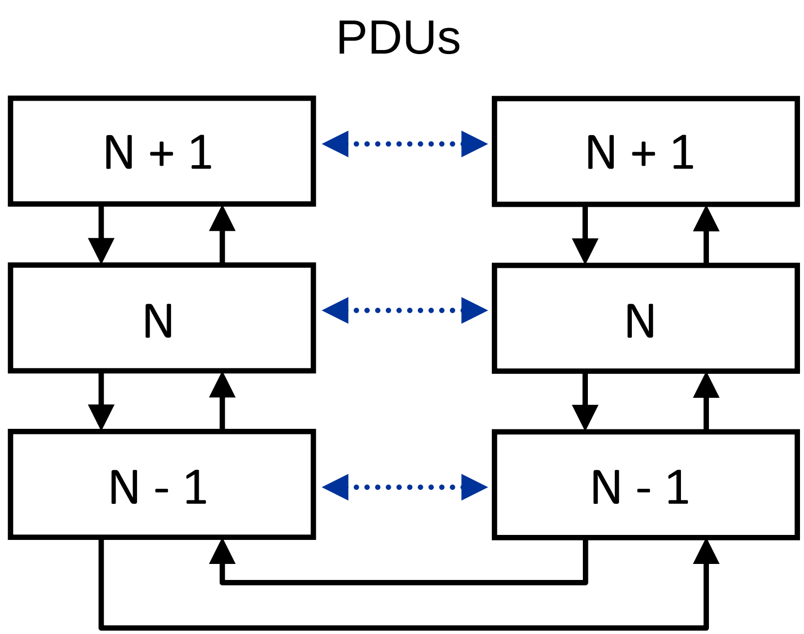
- Layering provides modularity
  - Layers do not process data from higher layers
  - May replace implementation of layers

- But too many layers lead to inefficiency

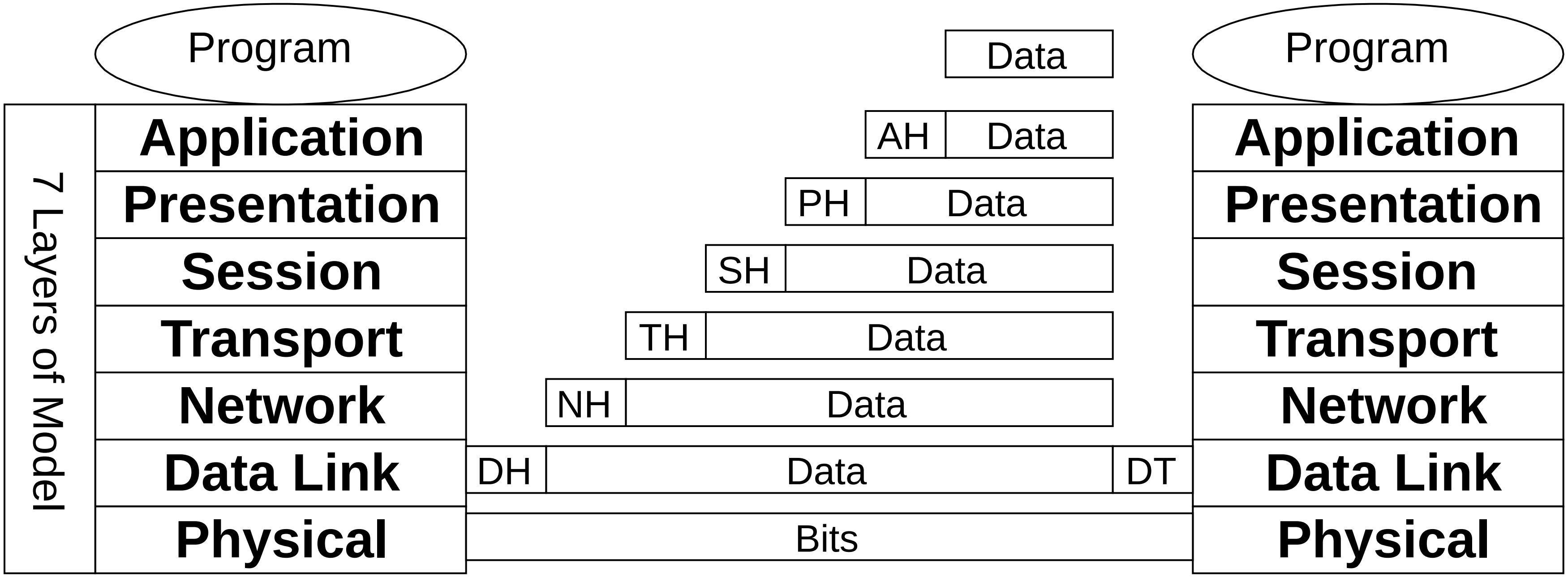
Protocols

- Protocol → "an agreement between parties on how communication is to proceed"
  - Defines msg formats, relationships between msgs, …
  - Reuse protocol implementations across apps

- Entity at one host exchanges **protocol data units (PDU)** with peer entity at another host
  - Actual connection only at lowest layer



OSI Reference Model



PDUs

OSI – Physical and Data Link Layers

- Physical Layer
  - Transmission of bit-stream over medium
  - 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
    - Set-up and termination of connections (CO)
    - Global addressing and routing (CL)
    - Hides differences in underlying networks
  - Uses data link layer to provide transmission over single hops

- 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

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

☛ We don’t look at session and presentation layers much in this course

OSI – Application Layer

- Provides interface to application
  - But does not include the application!
  - Network functionality specific to given application
  - Most users only have contact with app layer

- Protocols for common application interactions
  - e.g. file transfer, e-mail, web

TCP/IP Model

OSI	TCP/IP
Application	Application
Presentation	Not present
Session	
Transport	Transport
Network	Internet
Data Link	Host-to-host network
Physical	

- Developed by DoD for ARPANET
  - Still used in Internet
  - Designed to be resilient to failures
- Presentation and session functions not seen as necessary
- Host-to-host network largely undefined

Internet Layer

- Packet-switched (PS), connectionless (CL), inter-networking layer
- Delivery to destination
  - Routing, congestion control
  - Hides different physical networks
- IP protocol realises layer
  - Defines packet format

Transport and Application Layers

- Transport Layer
  - End-to-end connections
    - Flow control
    - Error recovery
  - TCP and UDP realise layer
- Application Layer
  - Protocols for application interaction
    - HTTP (web), SMTP (e-mail), DNS (host naming), FTP (file transfer), NNTP (usenet news)

Comparing Reference Models

OSI Model

- The standard model
- Can be complex, not all layers always used
- OSI protocols unpopular and poor implementation

TCP/IP Model

- Concepts lack generality
- Host-network layer poorly defined
- TCP/IP protocol most widely used

☛ Computing (and this course) tends to use OSI model but Internet protocols