Computer Networks I

Introduction and Overview

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Overview

1 History

18th century	Mechanics Industrial Revolution 1791: Semaphoric Telegraph (Chappe)
19th century	Steam Engine Electricity 1837: Telegraph with coded signals (Morse) 1861: Telephone (Reis) 1877: First (manually switched) phone exchange USA 1881: Also installed in Berlin with 8 participants
20th century	Electronics Radio, TV, telephone, automobiles, airplanes, data processing, analog to digital, digital networks, worldwide & local
21st century	Information, knowledge mobility ubiquitous (hidden) NETWORKED COMPUTERS

History

1950 Main memory 64 K
Single user operation
Peripherals: punched tape

1960 Main memory 64 K (magnetic cores)
Batch operating systems
Peripherals: magnetic drum, (hard-)disk, & tape, punch card

1970 Main memory 256 K (semiconductor & magnetic components) Time-sharing operating system
Virtual memory (paging)
Terminals for system programmers
1969: COMPUTER NETWORK ARPANET WITH 4 NODES (USA)

1980 Main memory 1 MB (semiconductor)
Time-sharing, Interactive program development at terminal
Online transaction processing at the terminal
Terminal networks over dedicated lines

NETWORK ARCHITECTURES (INTERNET, OSI, MANUFACTURER SPECIFIC)

1982: PC
1986: first ISDN private branch exchanges
1989: precursor broadband network VBN

➔ WORLD WIDE ACCESS

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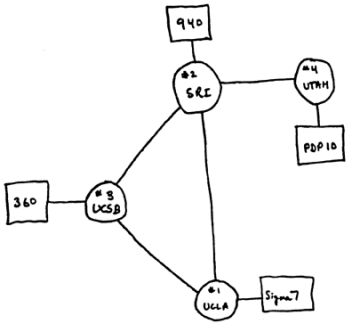

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➔ WORLD WIDE ACCESS

History

1990 workstations, PCs: main memory from 8 to 100 MB,
Department systems, Supercomputers, large processing center,
Computer networks (LAN, WAN, MAN), distributed systems
1991: mobile telephone network in Germany

➔ WORLD WIDE WEB

2000 PC adapted to workstation performance
Broadband - wide-area networks: 2,4 GBit ATM
High-speed LANs: Gigabit-Ethernet
Wireless LANs,IP-telephony

Markets and industries merge:
communication systems + computers + media + entertainment electronics

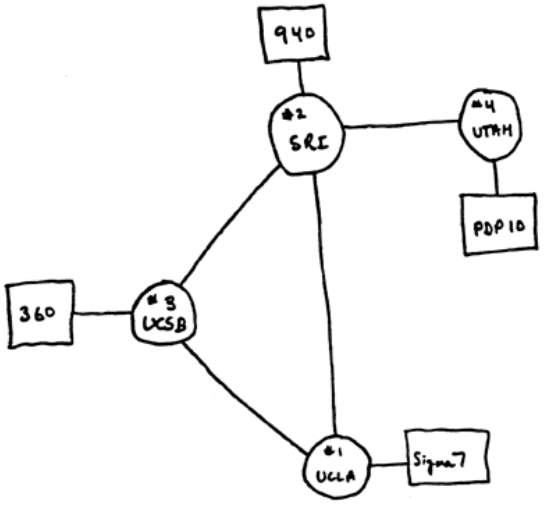
➔ WORLD WIDE PEER-TO-PEER

2010 & 2020 Mobility
ubiquitous computing (& hidden communicating)
Various wireless networks, Photonic switching
Sensor Networks, Internet of Things, Body Area Networks

➔ WORLD WIDE SEAMLESS COMMUNICATIONS (really …?)

Internet Development

From just 4 nodes in 1969



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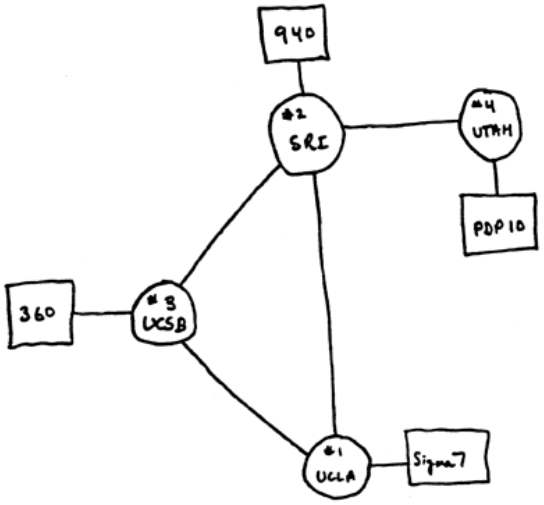
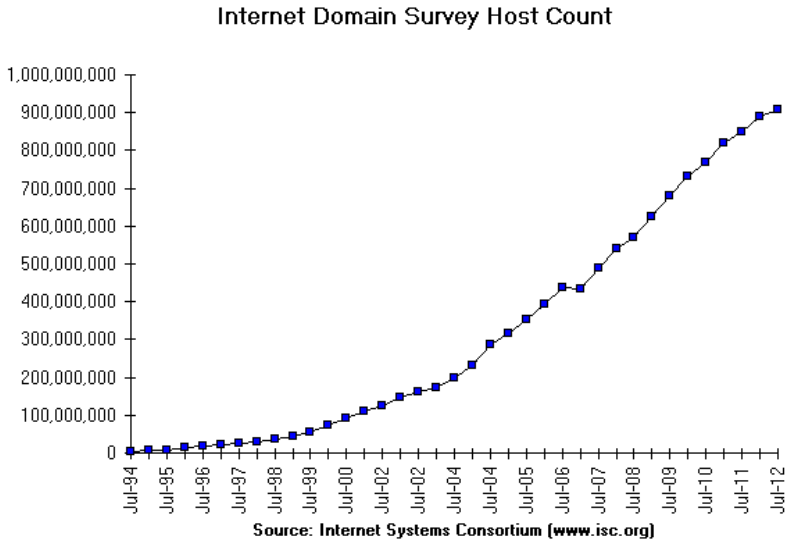


To a very large network



Approx. 1000000000 nodes in 2012

2 Implications on Society

Change, change, change …

Huge impact in various ways

Just some examples:

- New economic aspects
- New business models
- New media
- Changes in human behavior and relationships
- Access to knowledge (and education)
- …

...

Implications on Society

Open communication
- Who, when with whom about what
- increased communication among many people across the globe
- consequences:
  - information flood
  - cultures melt
  - monitoring of communication between "entities" can become possible
  - risk of lots of fake news
- Network neutrality !?

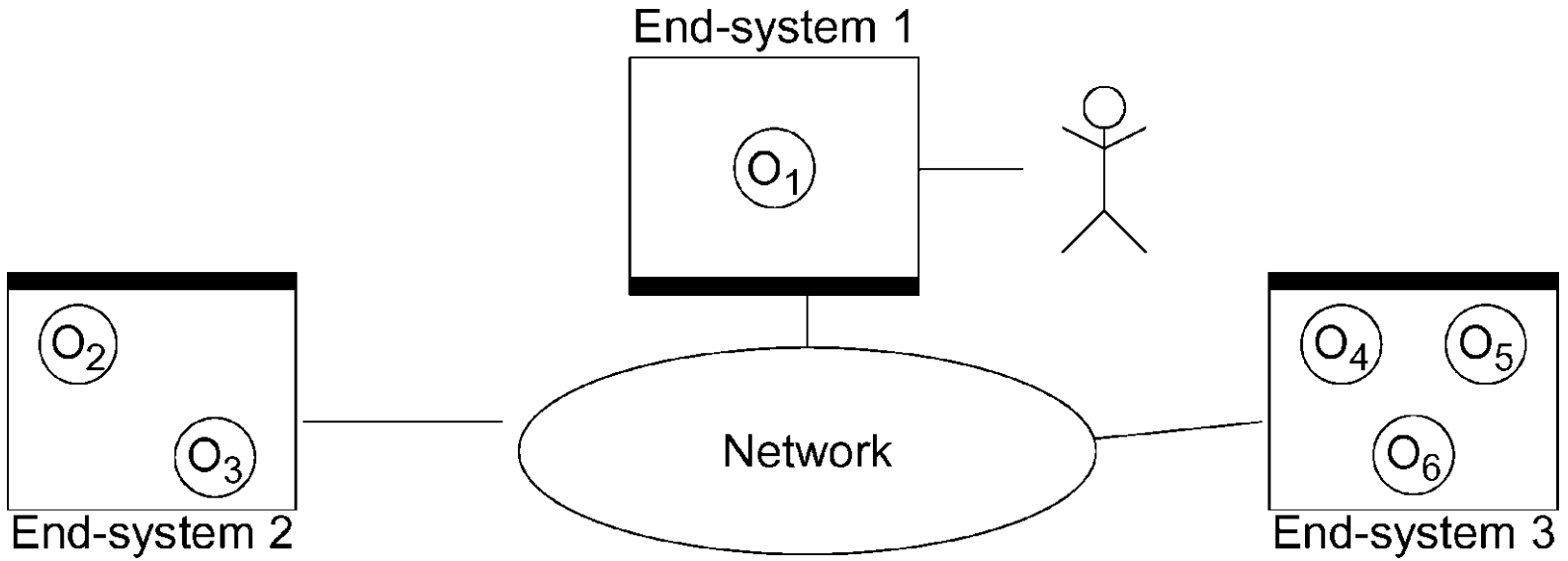
Speed
- fast distribution of information
- meaning: democracy, efficiency, ...

Legal issues
- copyright
- validity of electronic contracts (signature)

Contents
- besides technology also politics, religion and sex
- multitude of media, stored and live
- responsibility? (network carriers: hardly possible)

➔ security & privacy in networks, etc.

3 Computer Network



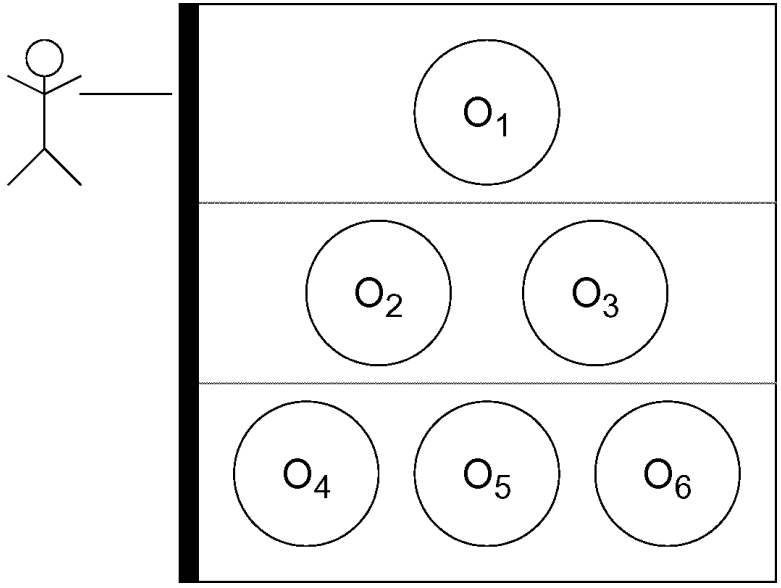
Computer Network

- several autonomous computers/end-systems interconnected
- with the aim to exchange data
- but, no distribution transparency

Distributed System

Distributed system

- is executed by several independent CPUs/systems
- user perspective:
  - centralized system (i.e. for example no explicit "login")
- the existence of single objects/units/systems is not visible



➔goal: distribution transparency

Computer networks used as basis to enable such distributed systems

4 Objectives

Shared usage of resources (programs, data, devices)
- share load, data, operation, …

Increased reliability
- e.g., use another server if one fails or needs maintenance

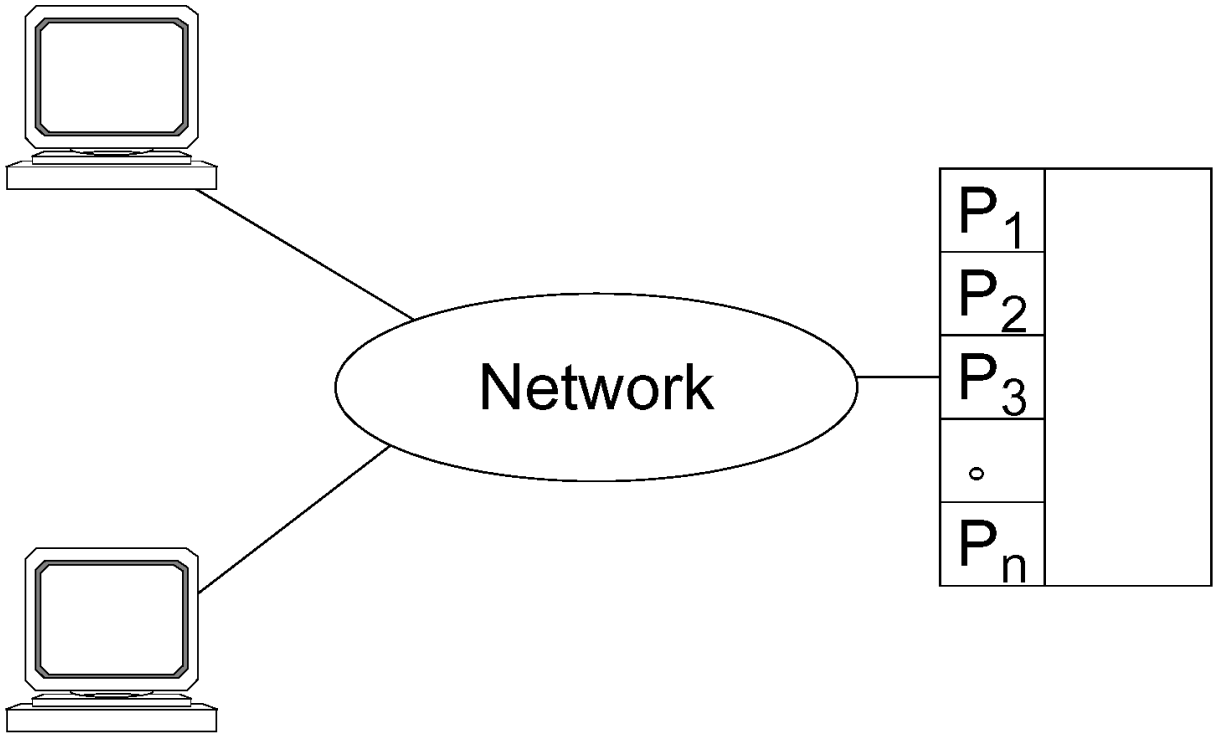
Reduced costs
- e.g., shared usage of a data server

Extensibility
- e.g., additional server

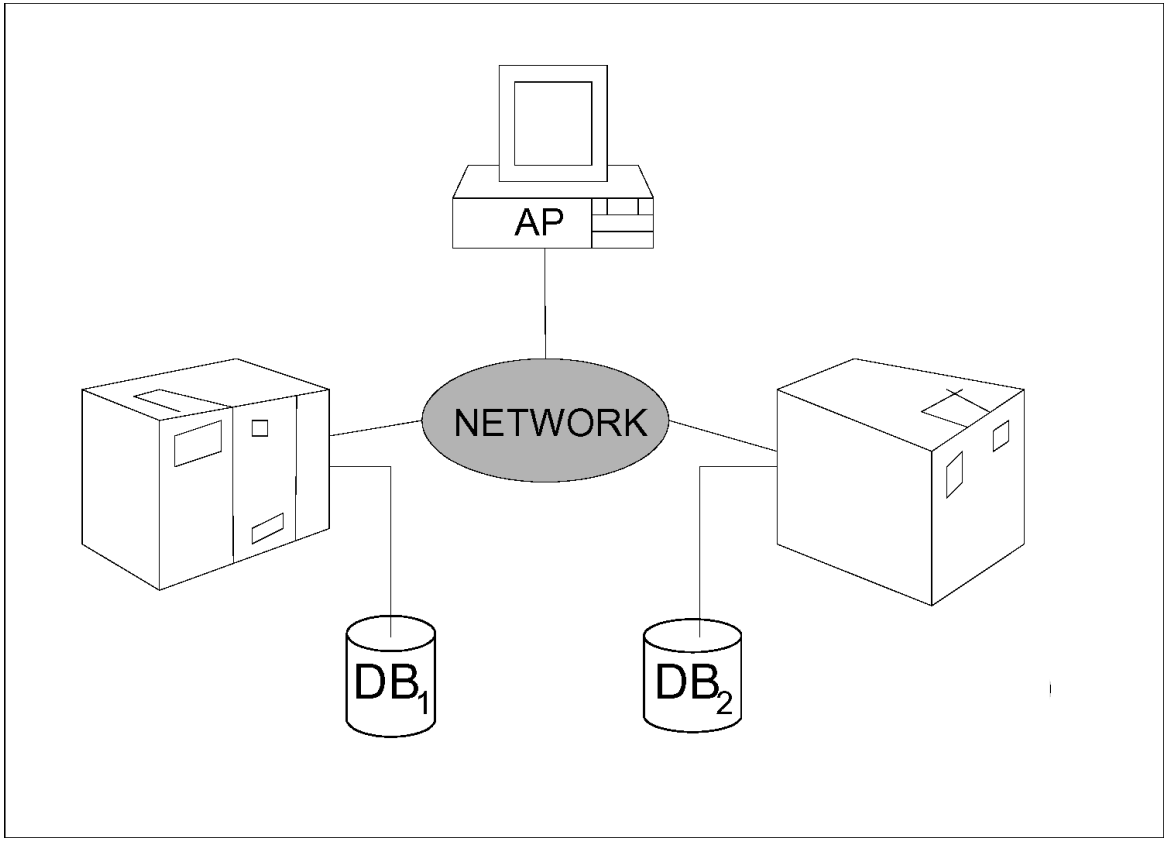
High-performance communication media
- person to person (e.g., social networks, messenger, email, interactively)
- person to machine (e.g. data bases, WWW, video server)
- machine to machine (e.g. often Peer-to-Peer)

5 Applications: Access to Remote Programs

- e.g. also GRID computing, Cloud computing, access to supercomputers
  www.rechenkraft.de www.gridforum.org
  www.ggf.org/ogsi-wg



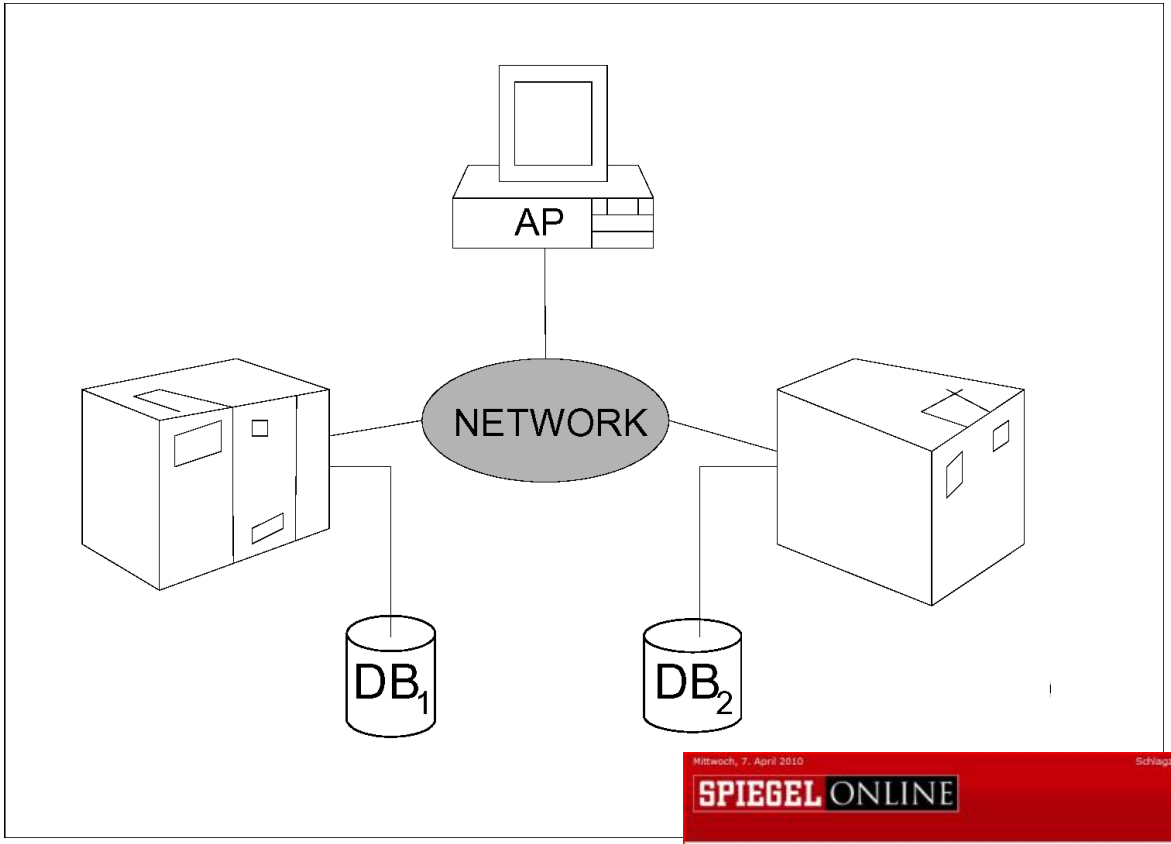
Applications: Access to Remote Data



e. g.

- reservation systems
- home banking
- electronic newspaper
- library
- ...
- peer-to-peer: shared audio/video data

Applications: Access to Remote Data



e. g.

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- home banking
- electronic newspaper
- library
- ...
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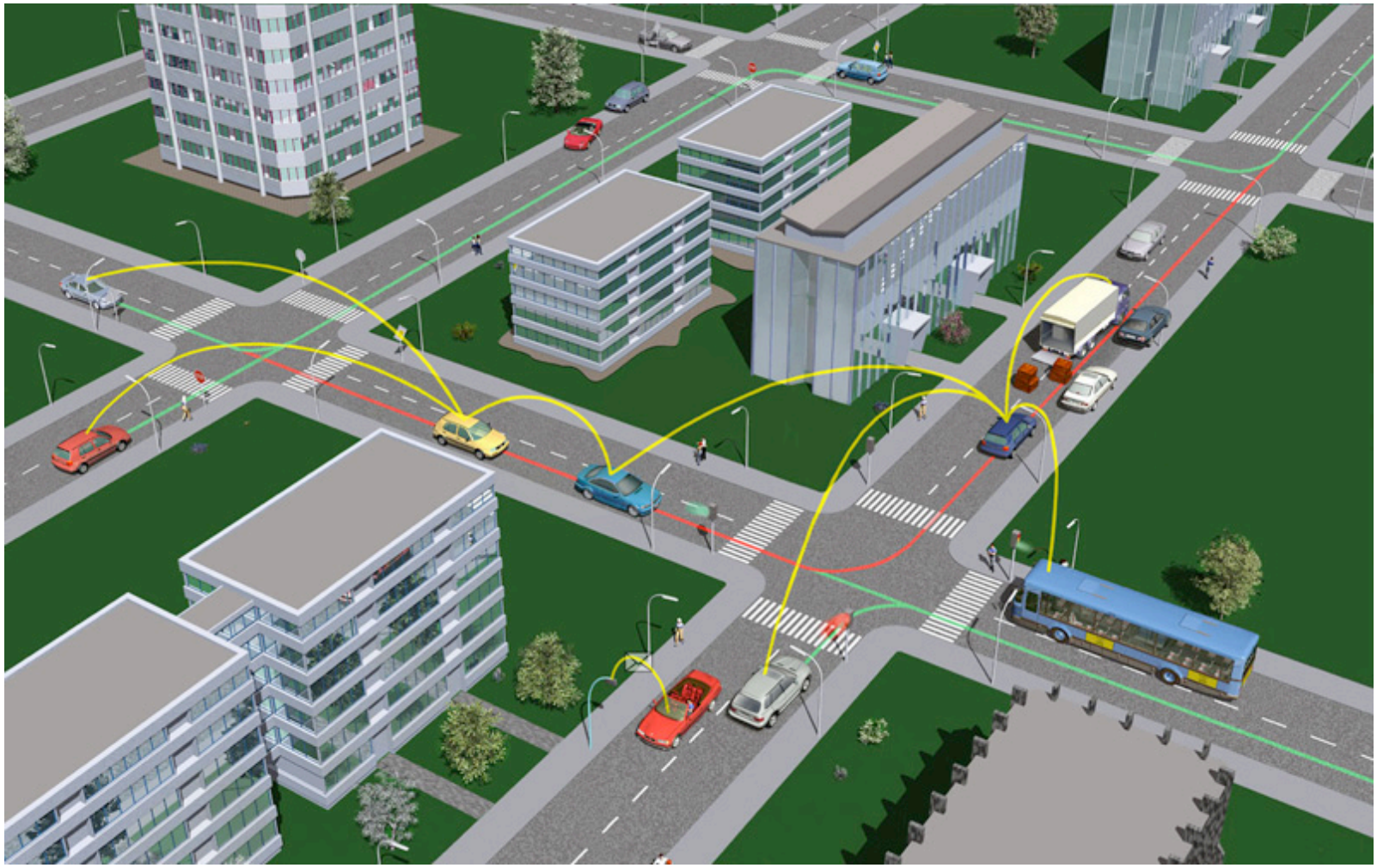
Applications: Network as a Communication Medium

e.g.

- electronic mail
- social networks
- bulletin boards
- voice & video communication

Applications: Communication for Road Scenarios



Communication system support for (road) traffic participants, e.g.,

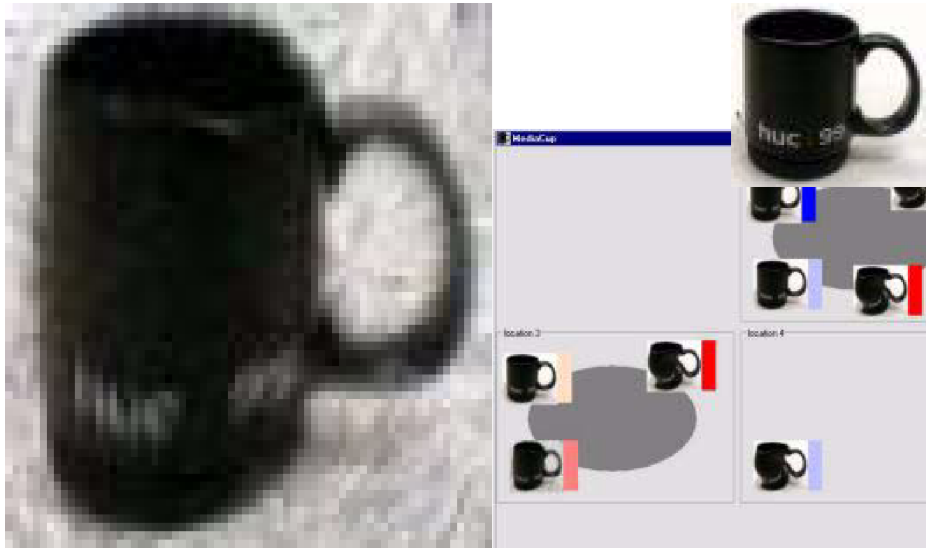
- safety (emergency warnings)
- traffic flow information (congestion)
- marketing (special offer for fuel at next station)

Applications: Ubiquitous Computing

Example furniture

Example coffee cup http://www.teco.uni-karlsruhe.de/

- sensors, processing and communication capabilities
- collect information and use it within the respective context



Applications: Interaction with Physical / Real World

Various similar areas

- Wireless Sensor (and Actuator) Networks
- Cyber-Physical Systems
- Internet of Things

Source: http://www.princeton.edu/eeb/gradinitiative/decisionmaking/

Approach:

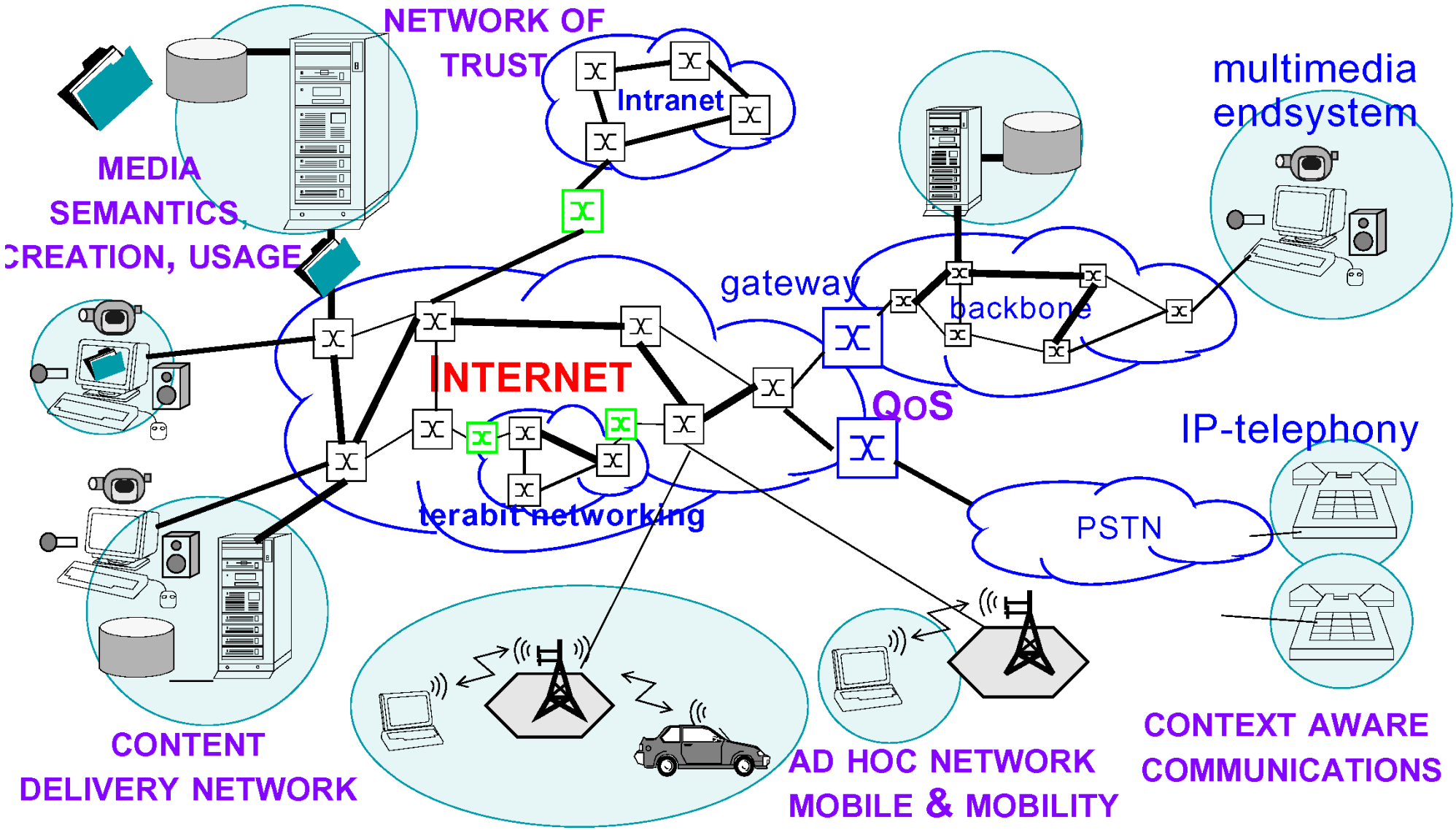
- Monitor environment by sensors
- Manipulate the physical entities via actuators
  - Valves, doors, toys, …

6 Network Structures, Types and Components

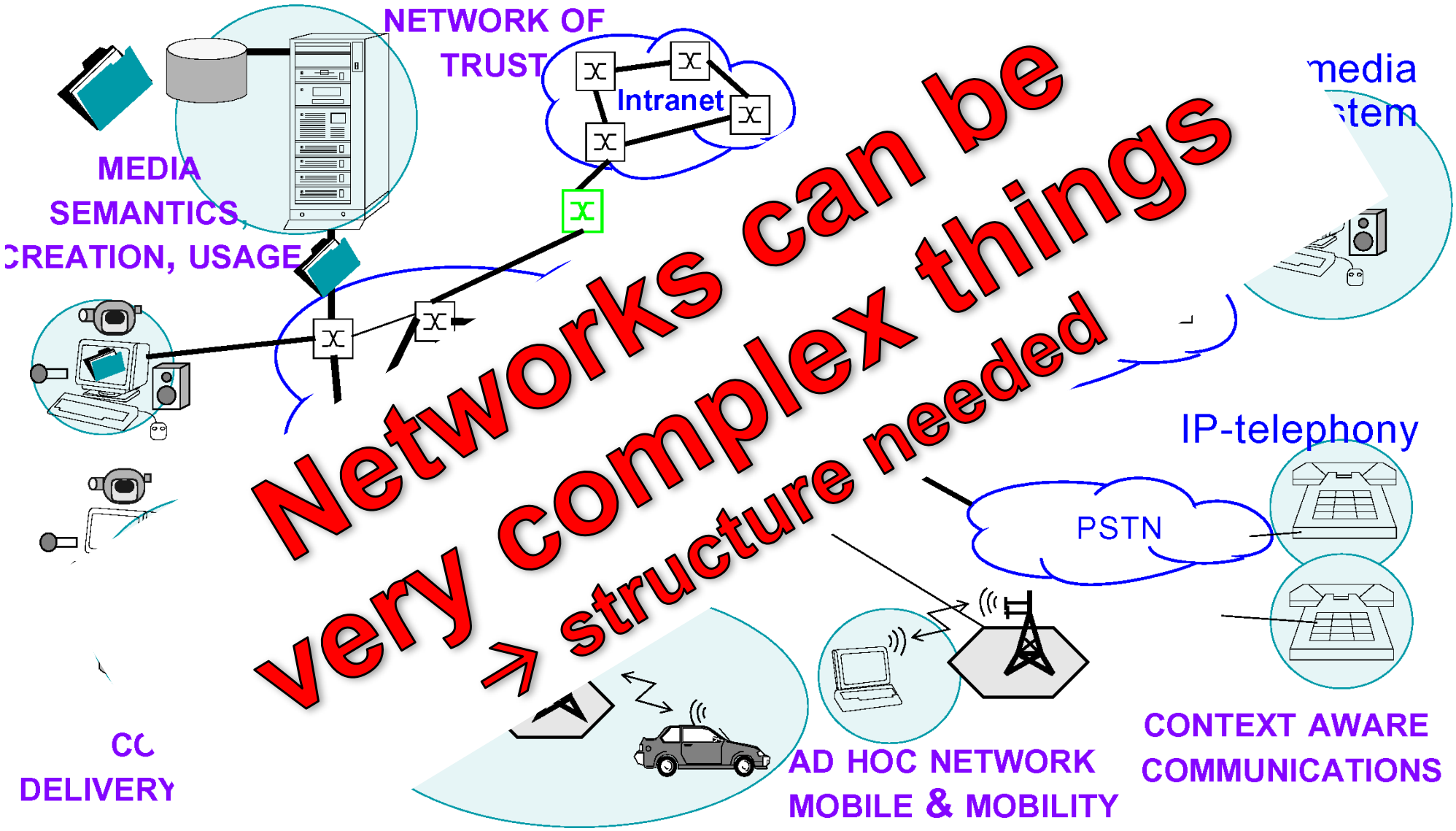
Networks are very **complex** and **large** entities

Need for
→Structuring approaches
→Classifications
→Separation of concerns

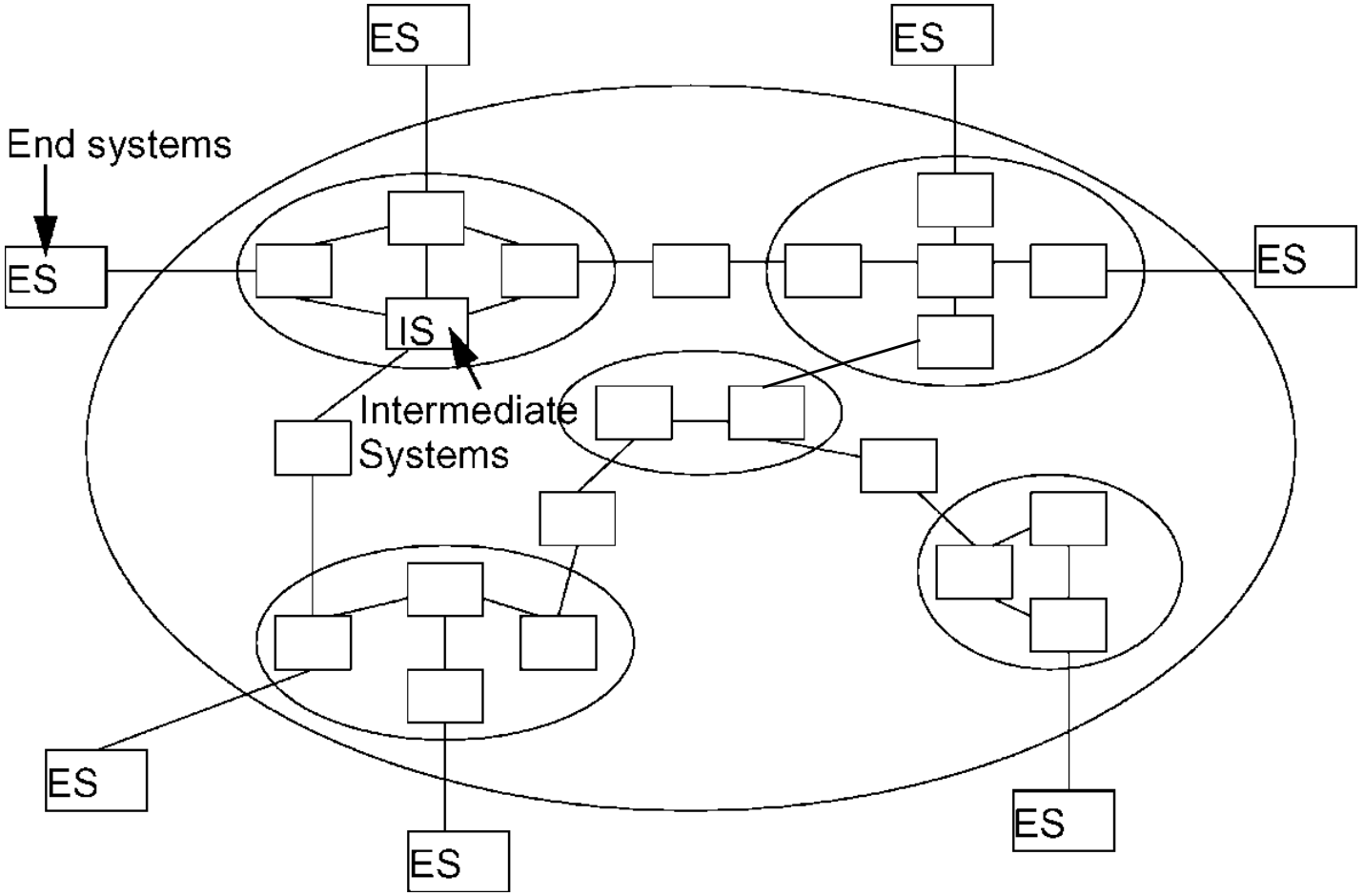
Network Structures, Types and Components



Network Structures, Types and Components



Network Components



Data transfer

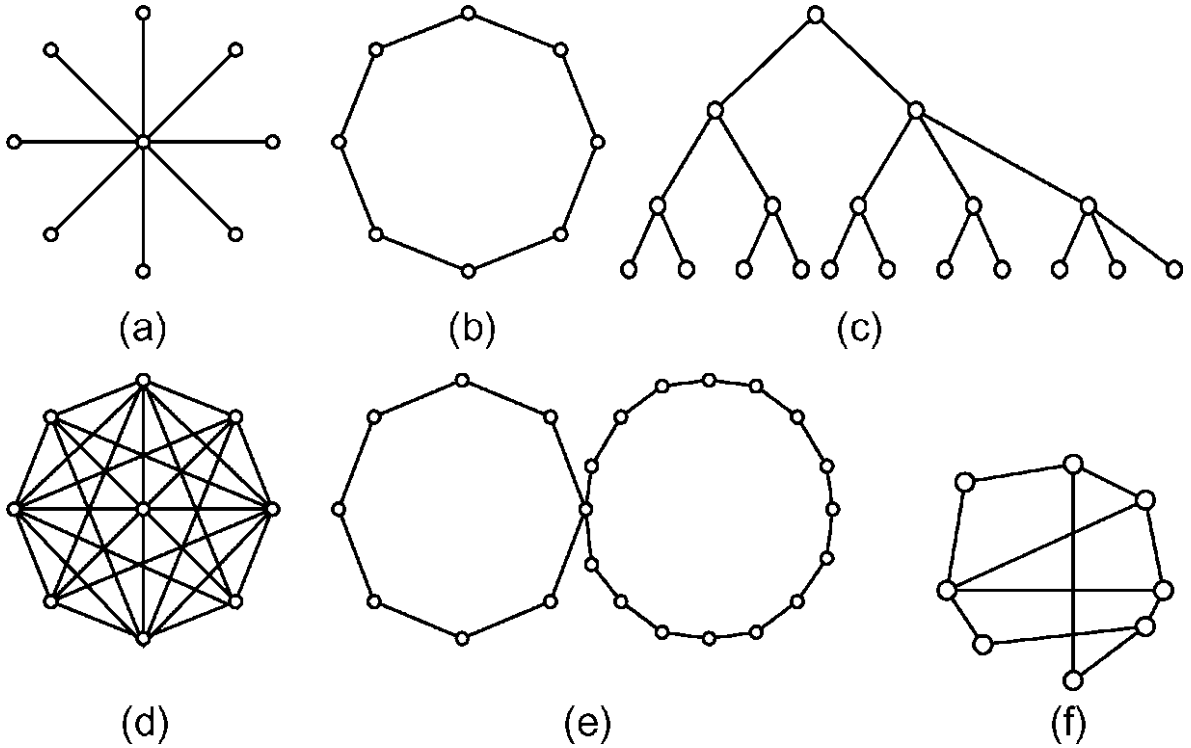
- from **end system** to **end system**
- via **intermediate systems**
- using **links** between adjacent stations

Network Structures

Point-to-point channels

- cable always connects two nodes

Topologies:



Network Structures

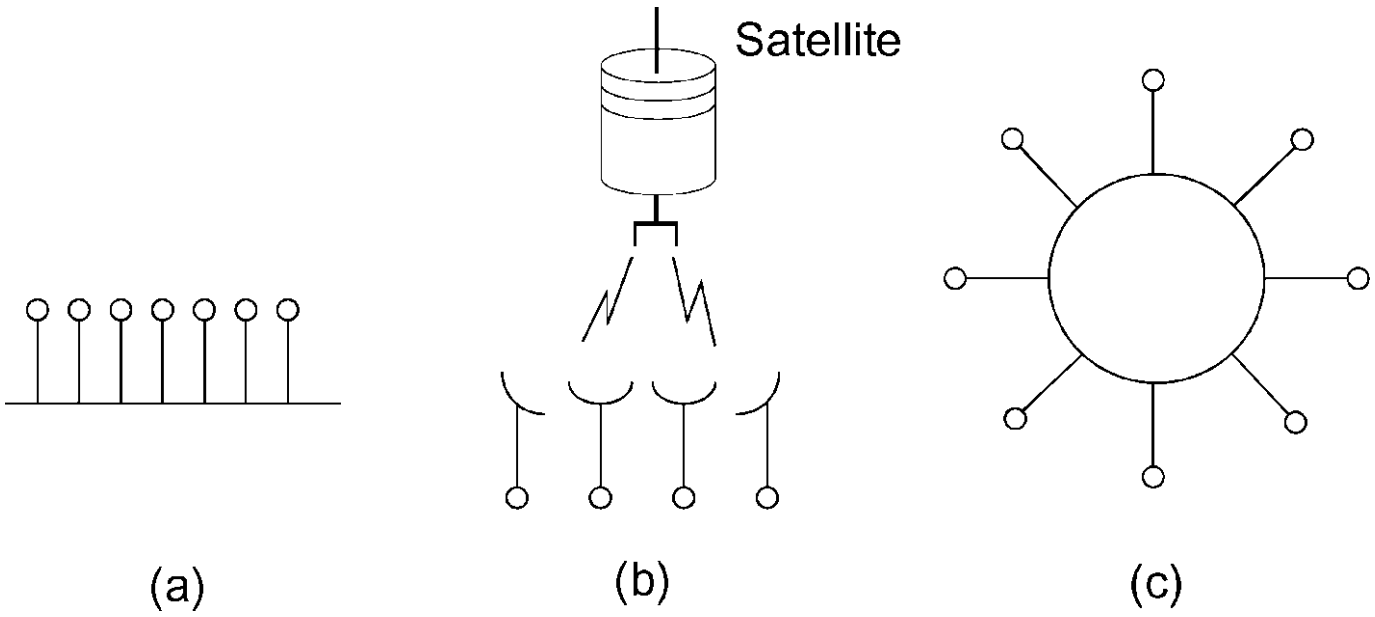
Broadcasting channels

- systems share one communication channel
- one sends, all others listen

Used for

- wide area: radio, TV, computer communication
- local area: (wireless) local networks

Topologies:



Network Types

A typical approach is to classify networks by their physical expansion

- Personal Area Network (PAN)
  - E.g., Bluetooth
- Local Area Network (LAN)
  - e.g. Ethernet, WLAN/WiFi
- Metropolitan Area Network (MAN)
  - e.g., DSL
- Wide Area Network (WAN)
  - e.g. ISP networks

- Inter-Planetary Internet: http://www.ipnsig.org/

- also others: body, desk, storage, ... area networks

Network Types

Distance betw. Processors	CPUs jointly located on/in..	Example
<= 0,1 m	Boards	multi-core processors usually tightly coupled multi-proc. sys.
1 m	Systems	e.g. body area network e.g. sensor area network e.g. storage area network
10 m	Rooms	LAN
100 m	Buildings	
1 km	Campuses	
10 km	Cities	MAN
100 km	Countries (national)	WAN
1.000 km	Continents (international)	
>= 10.000 km	Planets	

Examples: ARPANET

- initiated and financed by ARPA (Advanced Research Projects Agency of the U.S. Department of Defense (DoD))

Objective:

- originally: network to survive a nuclear war
- later: connecting scientific and military institutions

1969:

- experimental network with 4 nodes, followed by rapid growth, BBN first contractor

Development of the INTERNET

- standardized protocols for the communication between networks: TCP/IP (1983)
- linking military sub-networks (MILNET, MINET)
- linking satellite networks (SATNET, WIDEBAND)
- linking universities' LANs
- TCP/IP technology as part of UNIX spreads fast → ARPANET growing rapidly (1987: 15% per month)

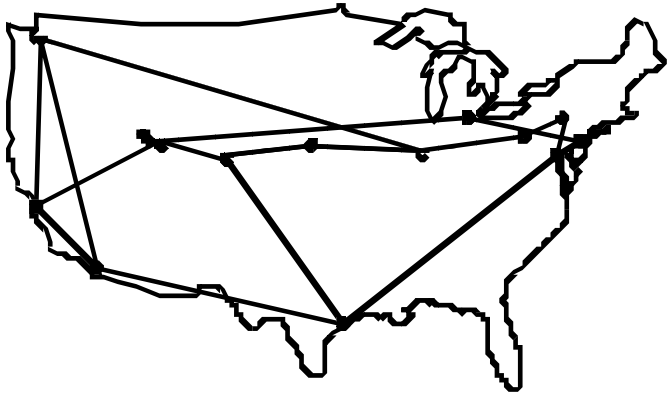
1987: 20.000 computers, more than 100.000 users

1990: ARPANET has been replaced

Services:

- E-mail, file transfer, remote login, WWW. . .

Examples: NSFNET



1988: NSF Supercomputer centers
and
NSF Mid-level network

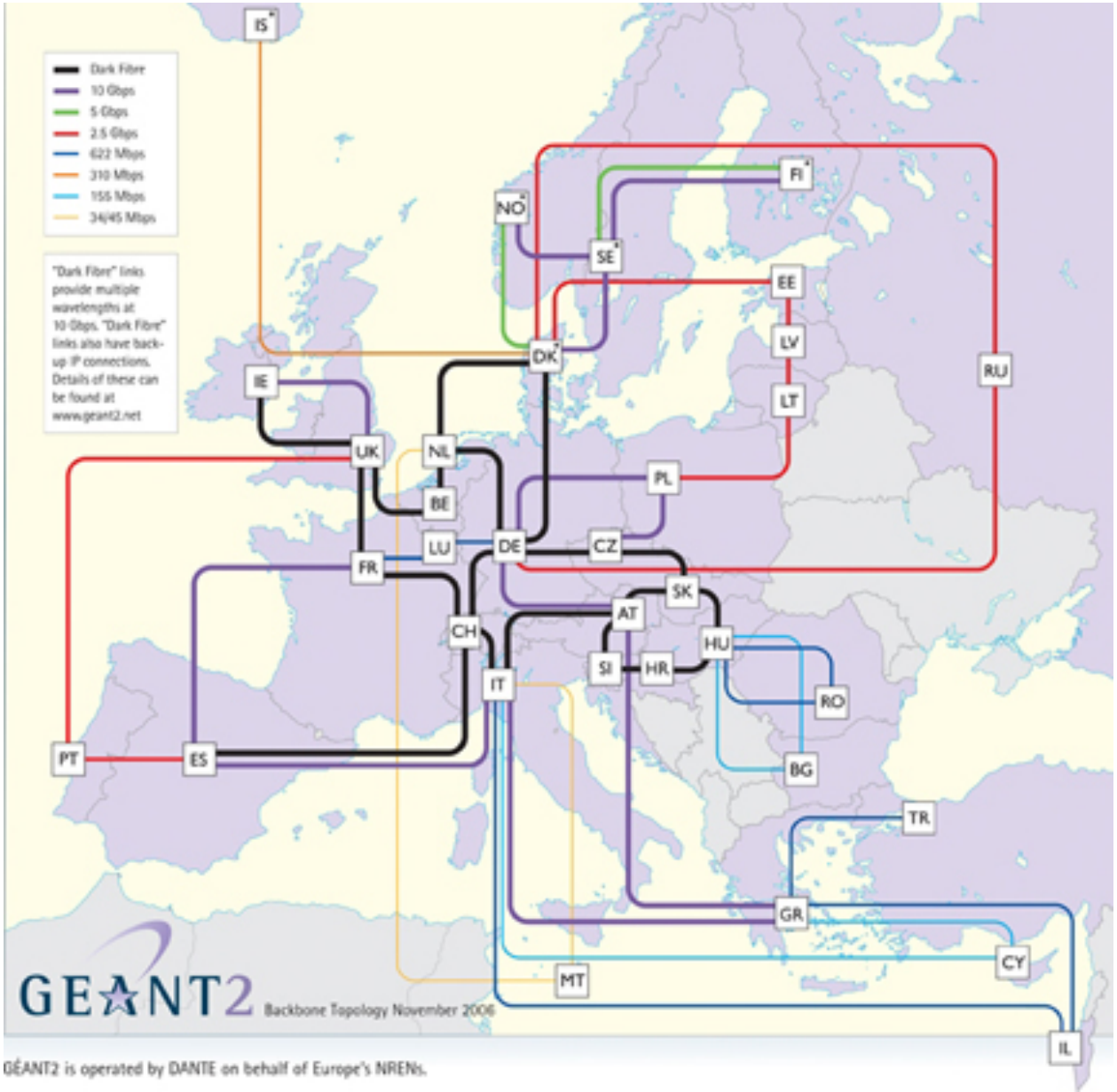
- financed by the NSF (National Science Foundation)

Objective: backbone network to connect supercomputer centers, and attach universities to the Internet
– “early” backbone of the Internet
  - 1984: 56 kbps, later 1,5 Mbps,
  - 1990: 45 Mbps

Services: E-mail, file transfer, remote login
  - ARPANET protocols (TCP/IP)

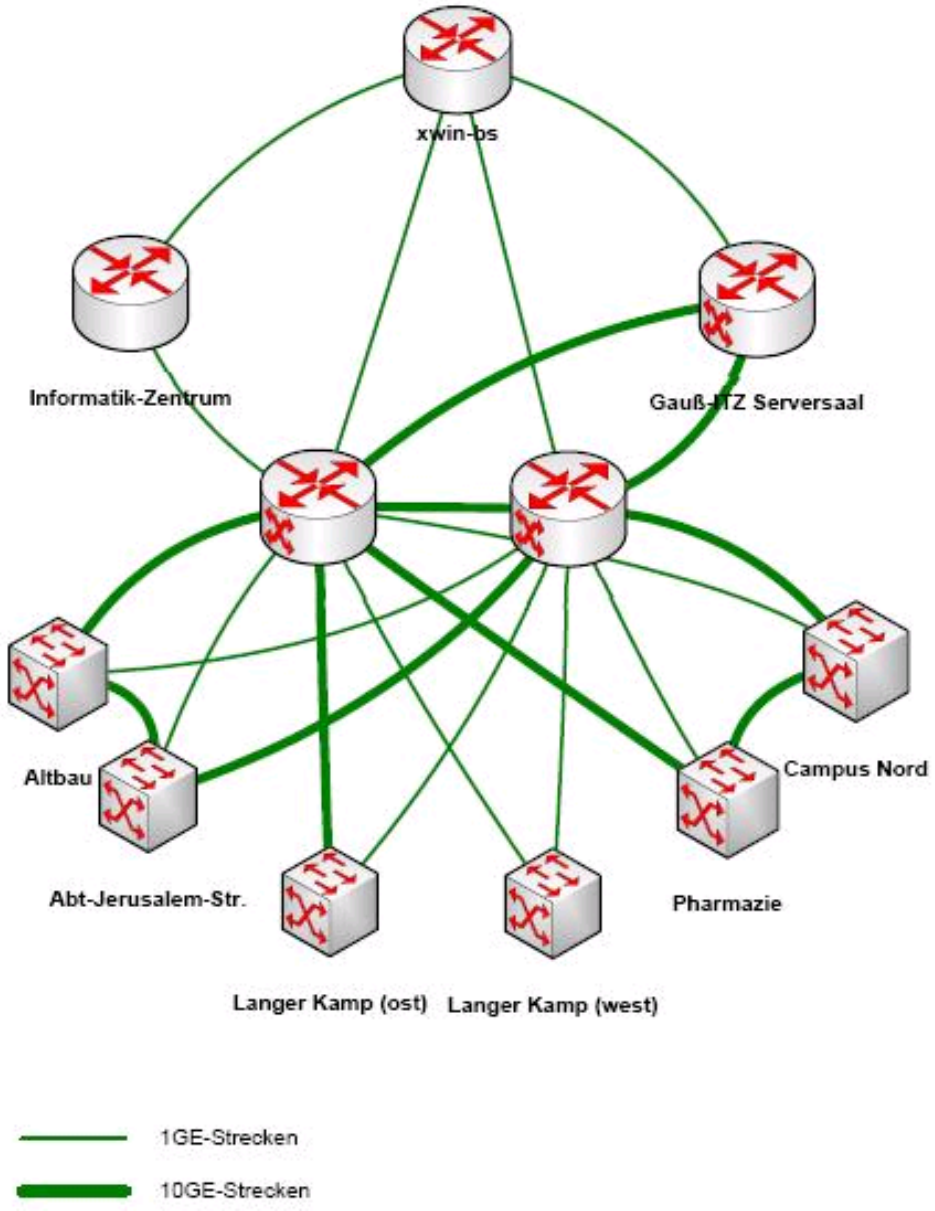
Examples: GÉANT

pan-European Gigabit Research Network
URL: http://www.dante.net/geant/



Examples: TU Braunschweig

(not today‘s structure, figure originally from http://www.tu-braunschweig.de/it/services/netz/datennetz)



7 Structuring

Problem: networking means

- many and partially complex tasks
- interaction of different systems and components

→ Modularity is needed

- manage complexity
- allow for reuse
- support exchange of components

Idea:

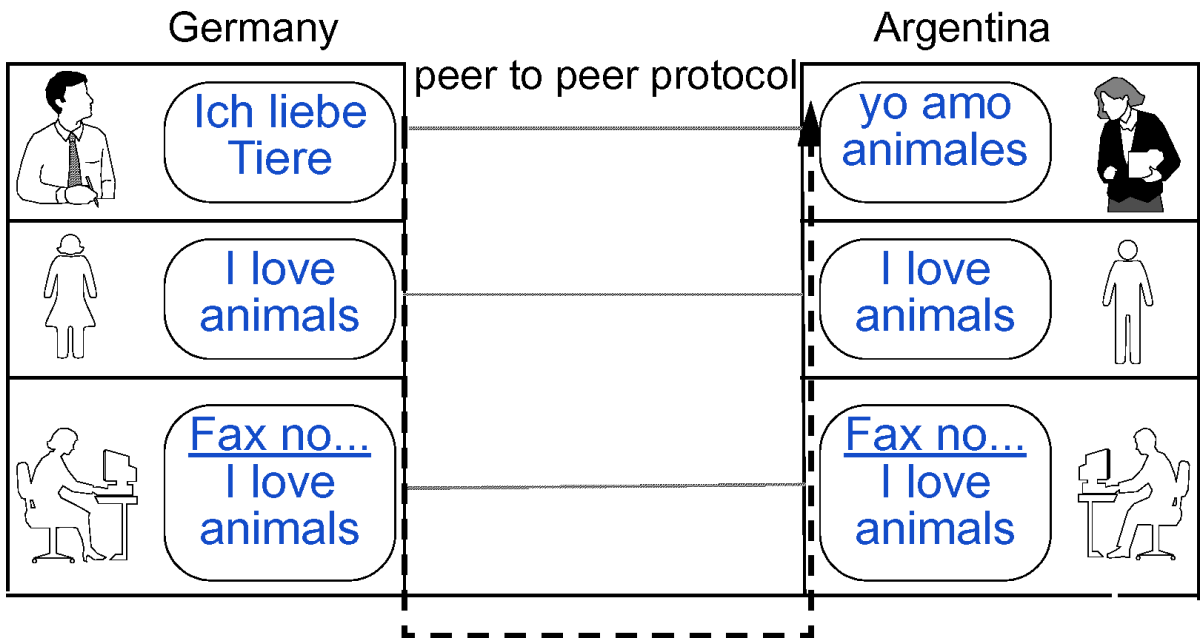
- introduce abstraction levels of varying functionalities
- in general kind of “module”
- preferably, due to simplicity: layer

Structuring

Layers are common in many places

Example:

- Biologists (X) with translator (Y) and FAX-office (Z)



Network structuring using a layered model:

- in this section we use the ISO-OSI reference model
- later we use a 5-layer model

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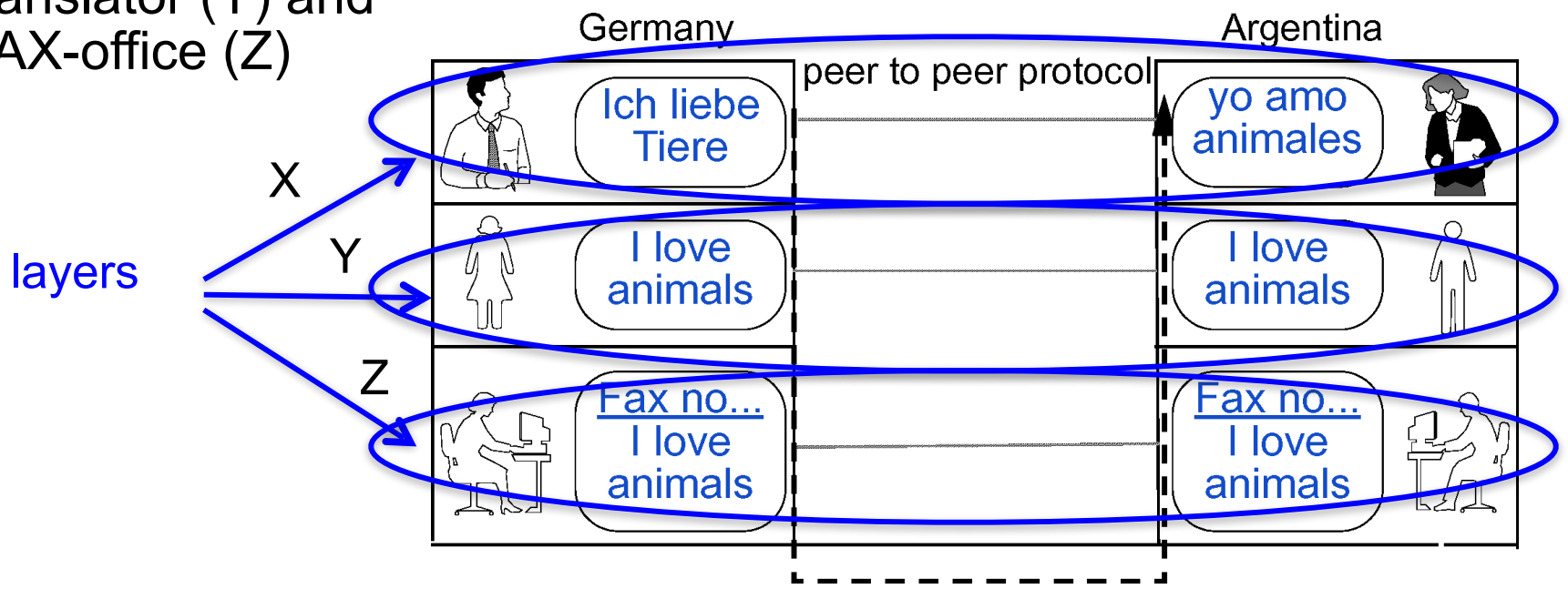

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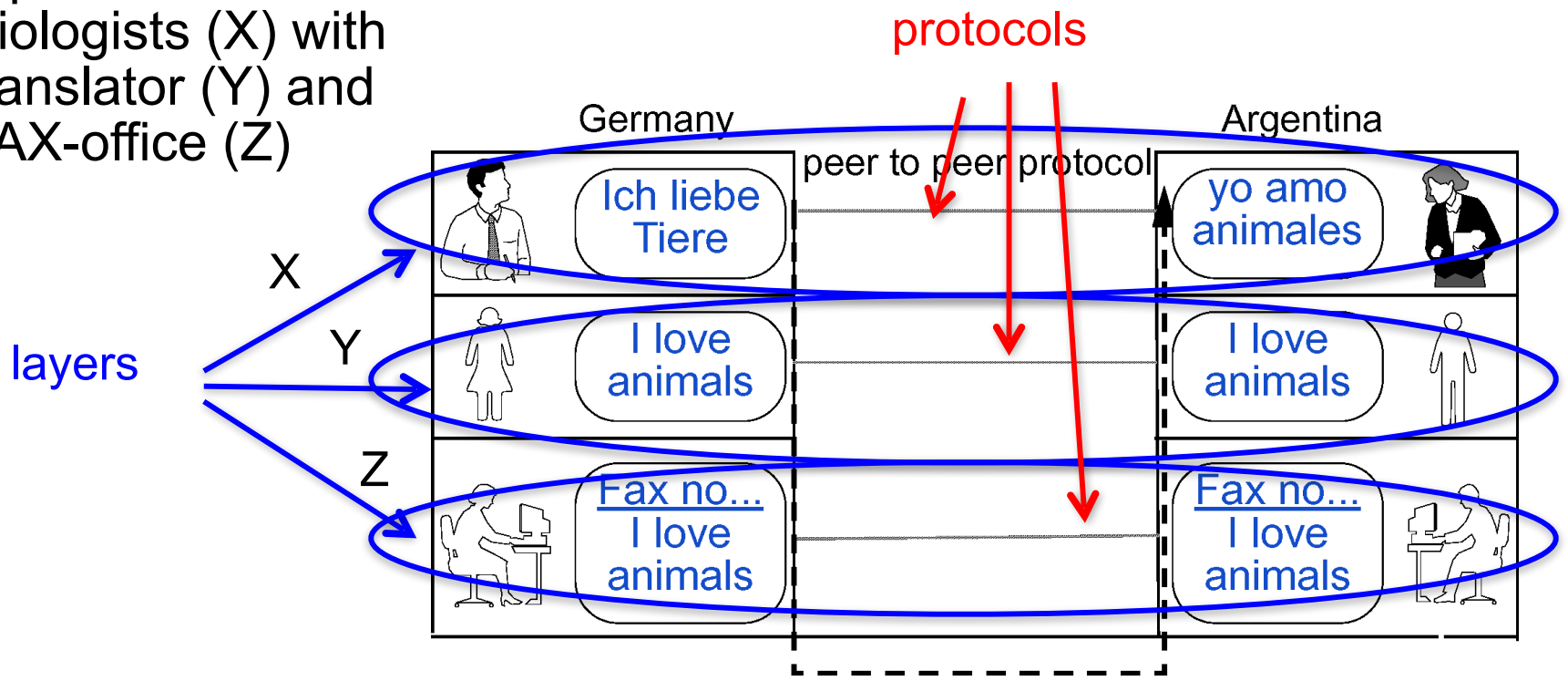


Network structuring using a layered model:

- in this section we use the ISO-OSI reference model
- later we use a 5-layer model

Reference Model for Open Systems Interconnection

ISO OSI Reference Model

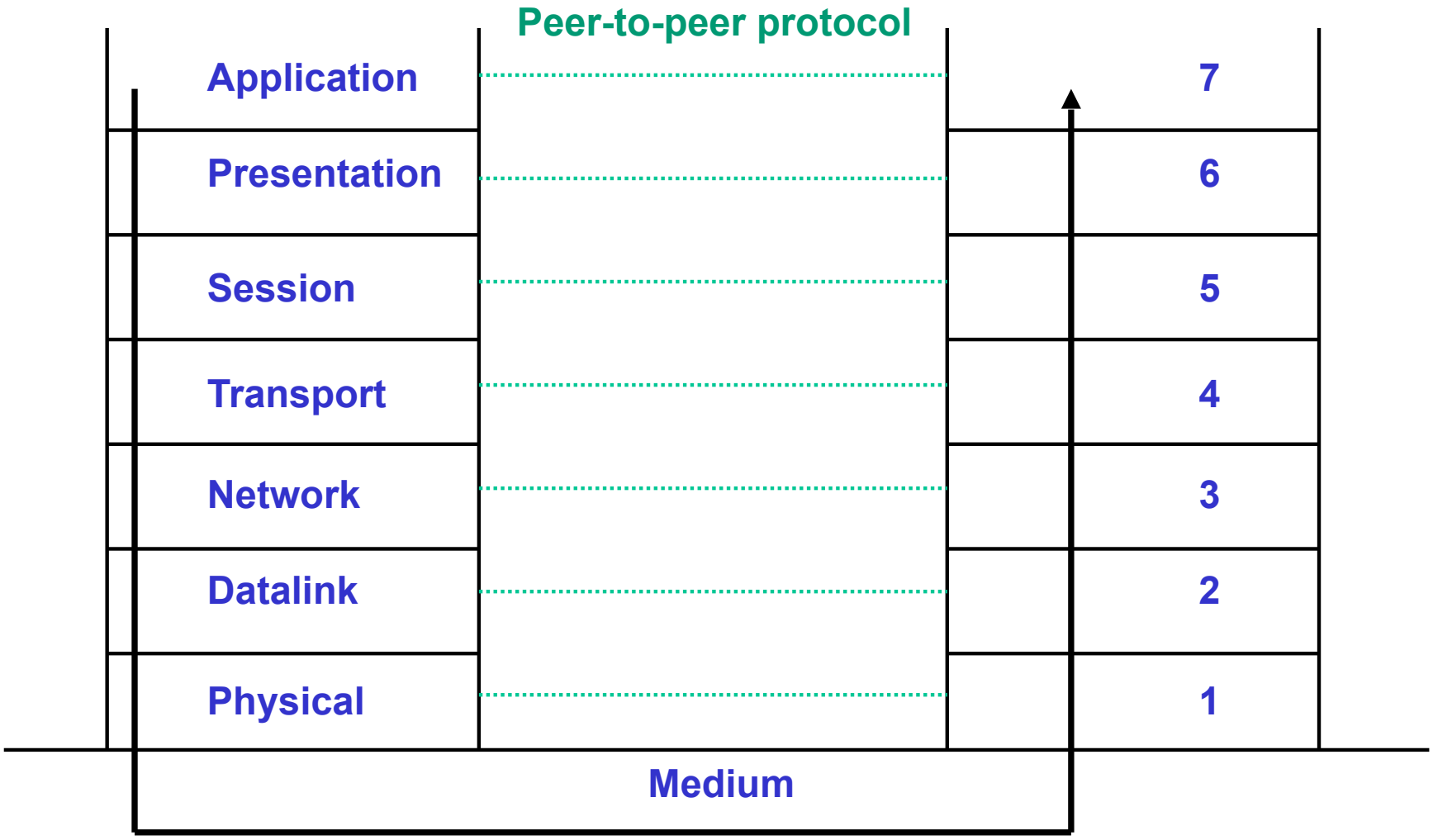
- ISO: International Organization for Standardization
- OSI: Open Systems Interconnection

- **model** for **layered communication systems**
- defines fundamental **concepts** and **terminology**
- defines **7 layers** and their functionalities

7	Application Layer
6	Presentation Layer
5	Session Layer
4	Transport Layer
3	Network Layer
2	Data Link Layer
1	Physical Layer

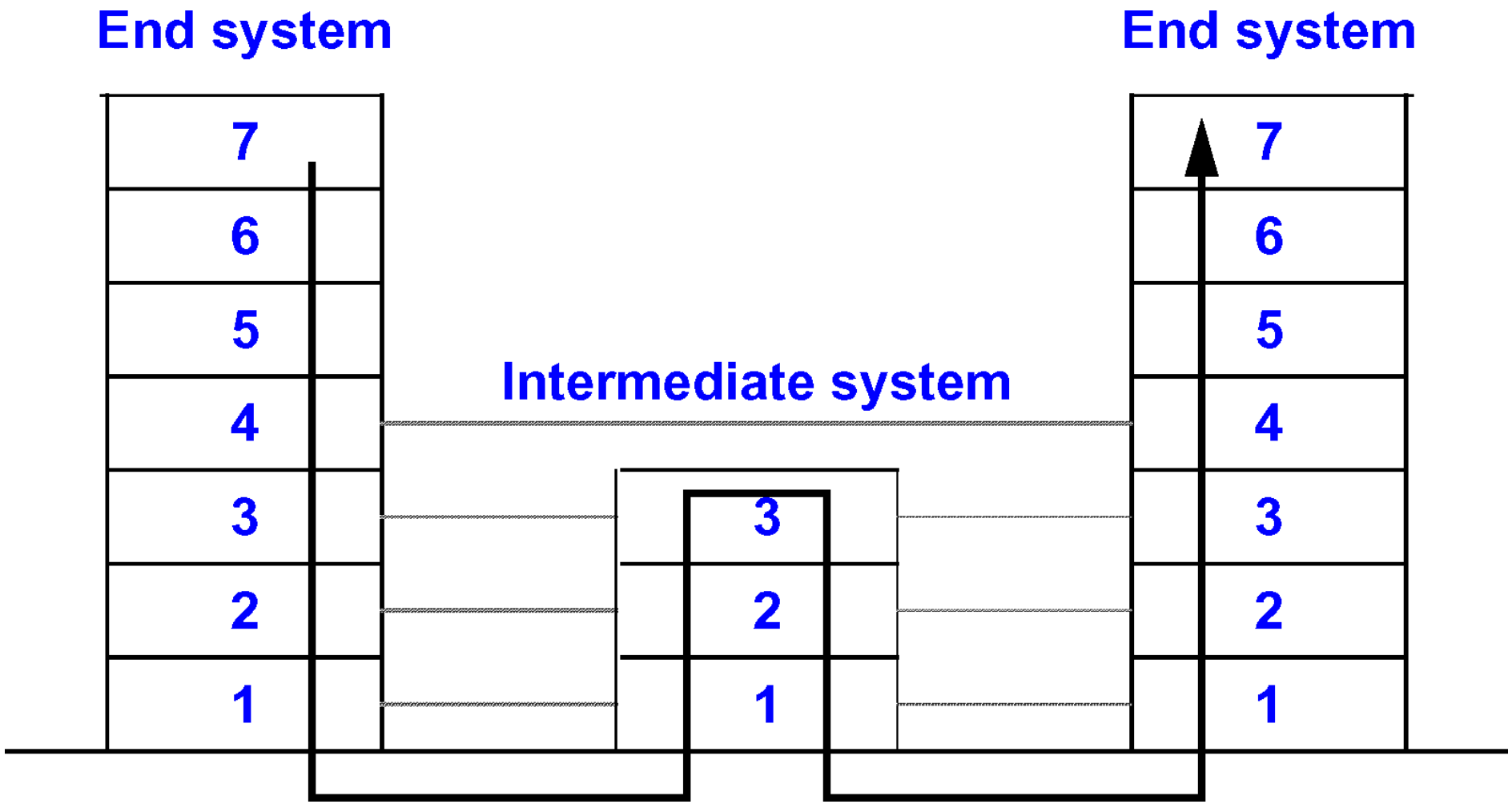
OSI Architecture

Actual data flow between two systems:



OSI Architecture

Real data flow with intermediate systems:



ISO-OSI Layers: Functions

Layer	Function

1
Physical
	Provide physical connection
	ensure that a **bit** '1' sent is also received as a bit '1' (and not as bit '0')
	•
	• mechanics: connector type, cable/medium,..
	• electronics: voltage, bit length, …
	• procedural:
	  • unidirectional or simultaneously bidirectional
	  • initiating and terminating connections

2
Data Link
	reliable data transfer between adjacent stations with **frames**
	•
	• data frames and control frames
	• error recognition and correction within the frame:
	  • corruption, loss, duplication
	• handling of fast sender, slow receiver:
	  • flow control
	• distributed access control:
	  • Medium Access Control (MAC)

ISO-OSI Layers: Functions

Layer	Function

3
Network
	transfer **packets** from endsystem to endsystem
	• internetworking:
	  • link (sub-)nets to achieve end-to-end connecitivity
	  • exchange of packets
	  • addressing
	• routing
	•
	• congestion control (too many packets on one path)
	• quality of service

ISO-OSI Layers: Functions

Layer	Function

4
Transport
	End-to-end transfer of **segments** from source application (process) to destination application (process)
	
	• address & identify transport service users (processes)
	• data transfer between applications in end-systems
	• provide reliability
	  • connection management
	  • error control, …
	•
	• transparent with respect to underlying technologies and underlying networks
	
	• flow control, error control / reliability, congestion control, …

ISO-OSI Layers: Functions

Layer	Function
5 Session	support a “session” over a longer period • synchronization (during interrupted connection) • token management (coordinate the simultaneous processing of different applications)

6
Presentation
	data presentation independent from the end system
	• negotiating the data structure,
	• conversion into a global data structure
	• examples:
	  • data types: date, integer, currency,
	  • ASCII, Unicode, …

7
Application
	application related services
	• examples:
	  • electronic mail, directory service
	  • file transfer, WWW, P2P, …

Comment:

- layers should be considered as
  - concepts (real implementation unit can be different)
  - guidelines only (real-world can be different)

8 Layers, Services and Protocols

Layer Concept

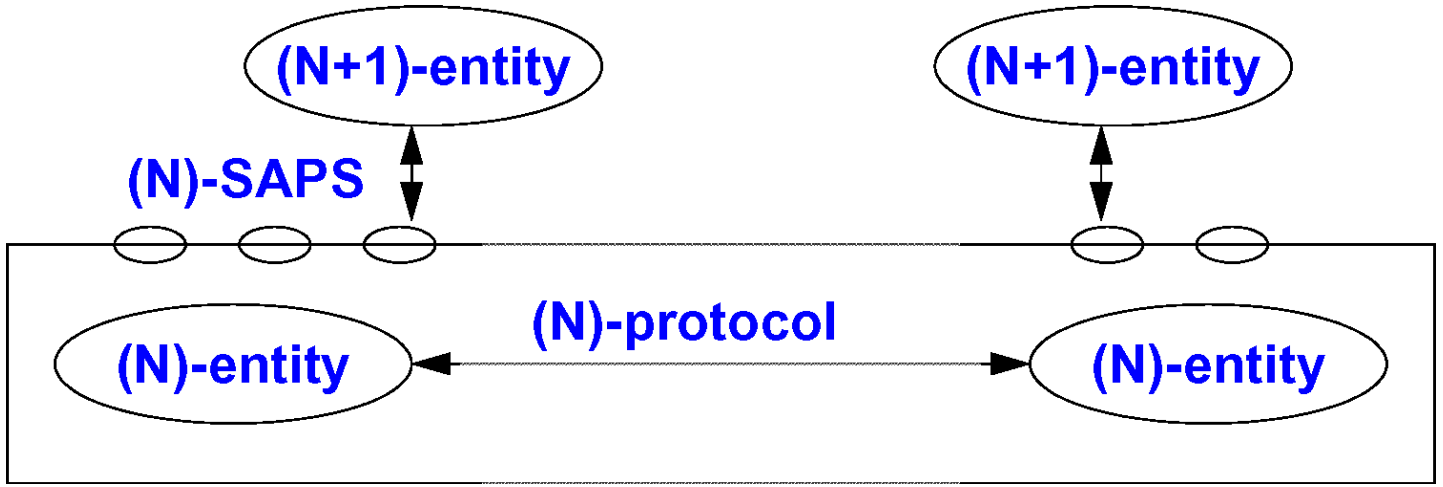
Protocol:
- Communication between entities on the same Layer

Service:
- Communication between adjacent Layers

Data Units:
- Exchanged with protocols or services

→ PDU, SDU

Layer Concept



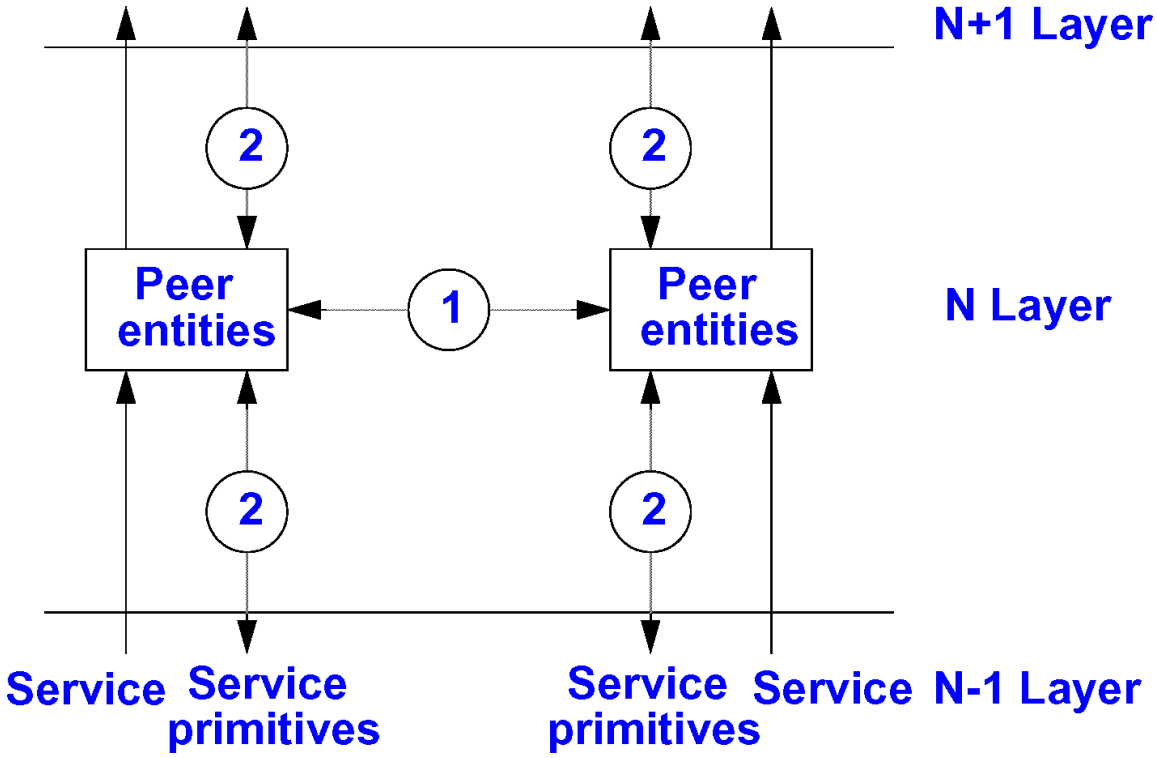
N-Layer
- abstraction level with defined tasks

N-Entity
- active elements within a layer
- process or intelligent I/O module
- peer entities: corresponding entities on different systems

N-Service Access Point, N-SAP
- service identification

N-Protocol:
- a set of rules for transferring data between N-entities

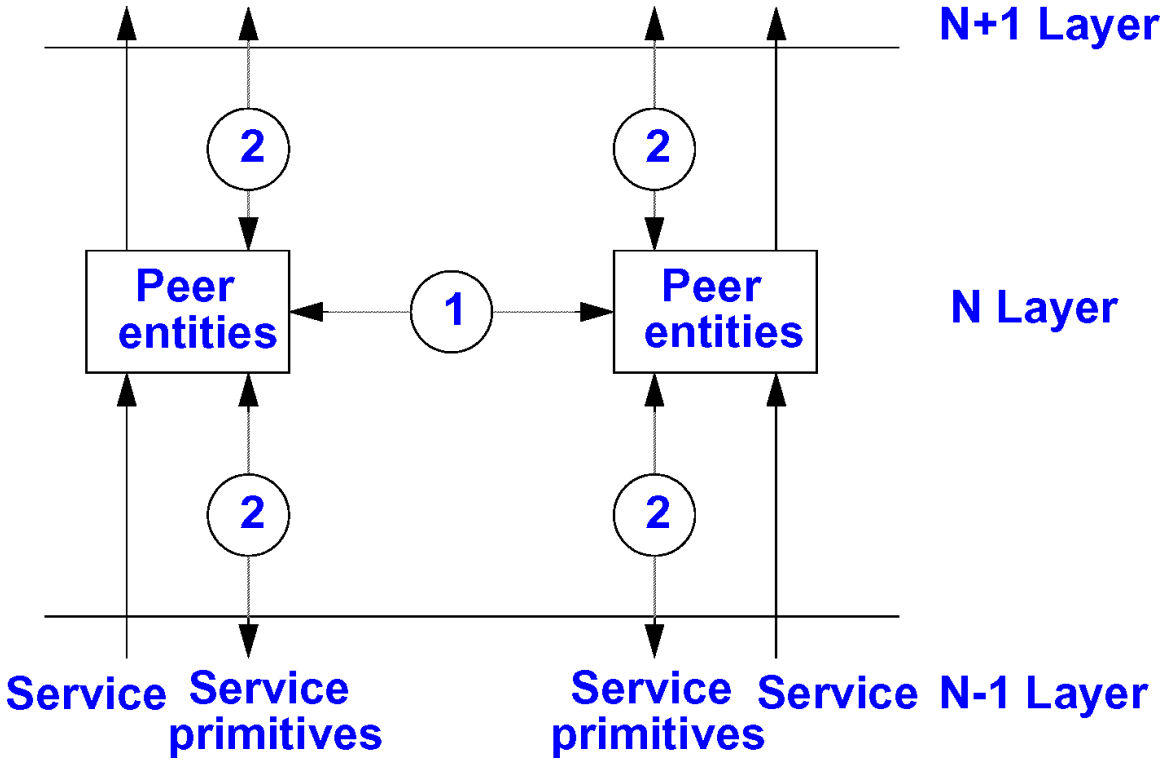
Protocol: Communication between peers on same layer



Protocol

- rules for syntax (format) and semantics (contents) of the data transfer (frames, packets, segments, messages) between the active peer entities

Service: Communication between adjacent layers



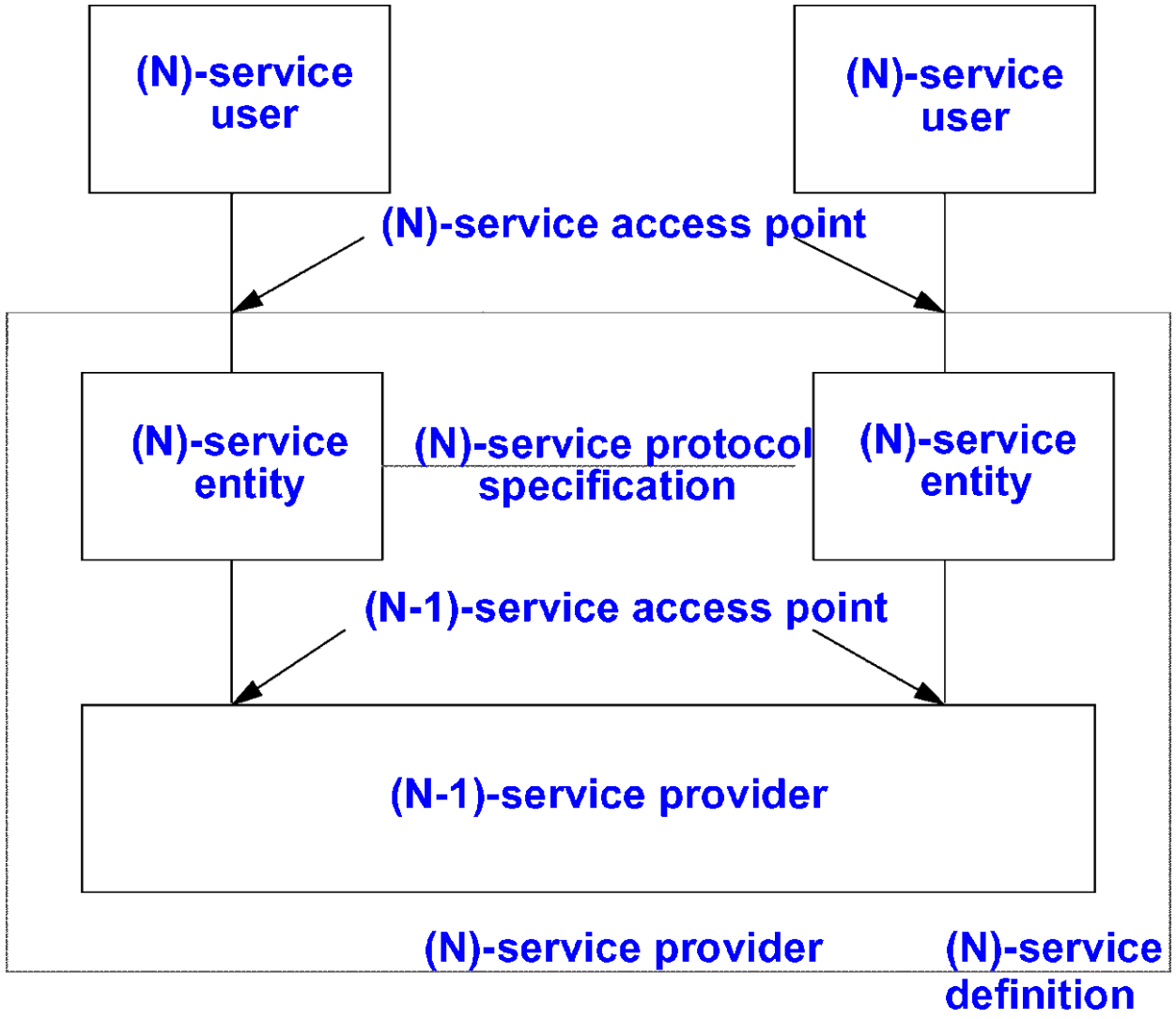
Service

- set of primitives/operations/functions which one layer offers to the next (upper) layer
- characterized by the "interface"
- does not reveal anything about the implementation

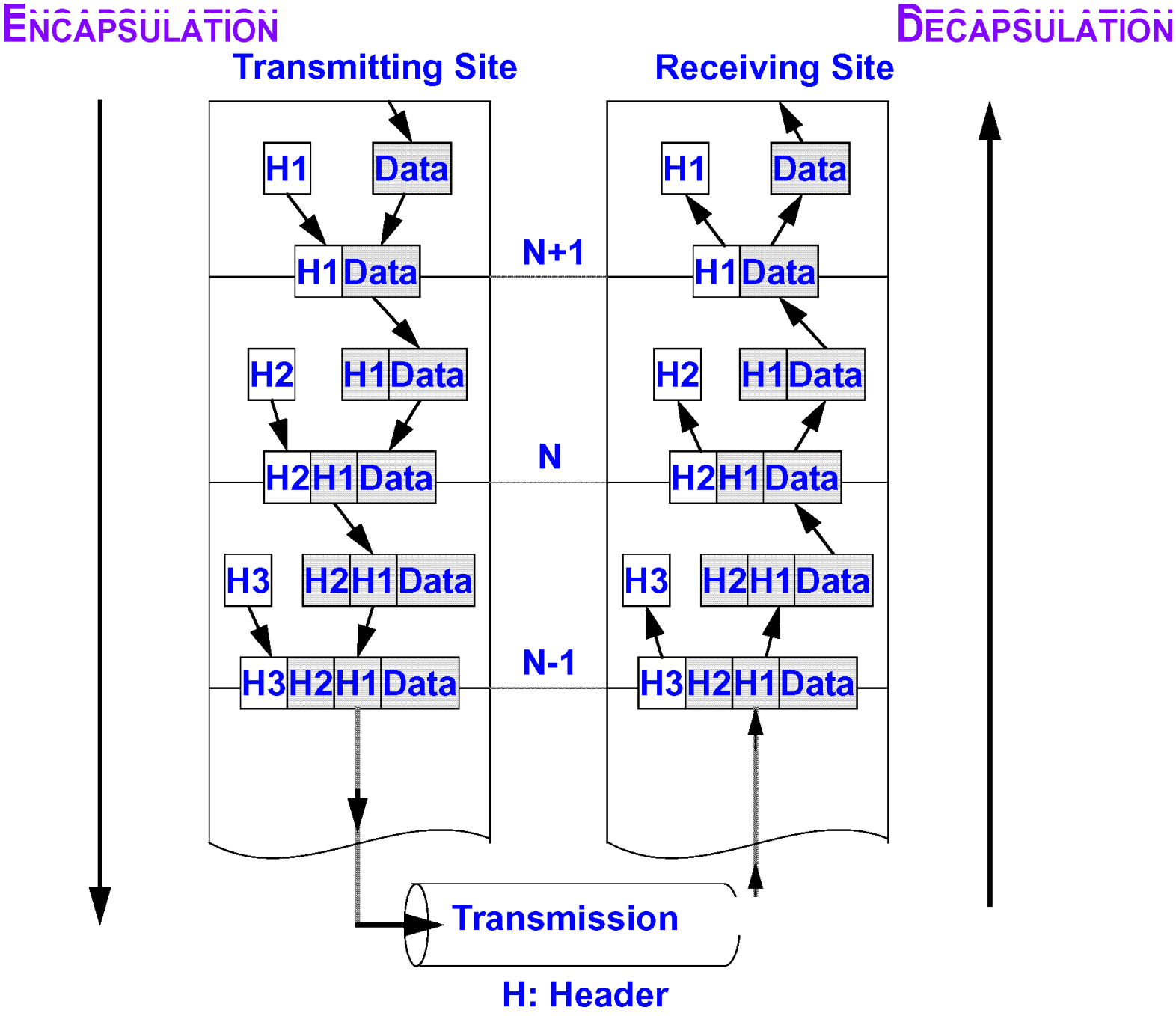
Service Provider and Service User

Service User

Service Provider

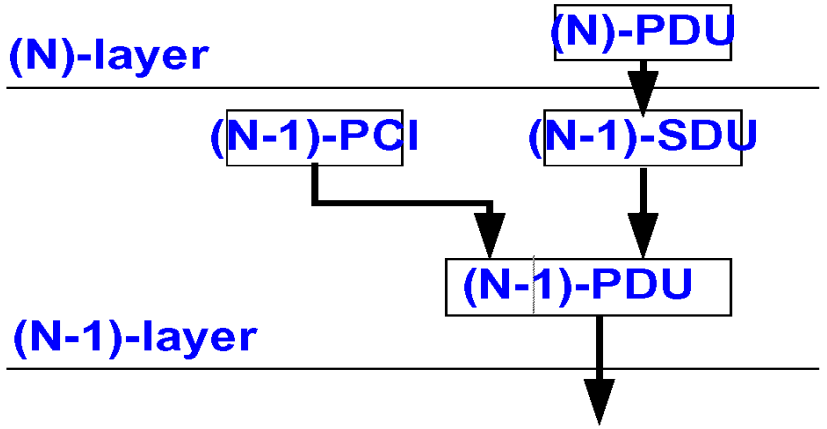


Nested Protocol Data Units (PDUs)

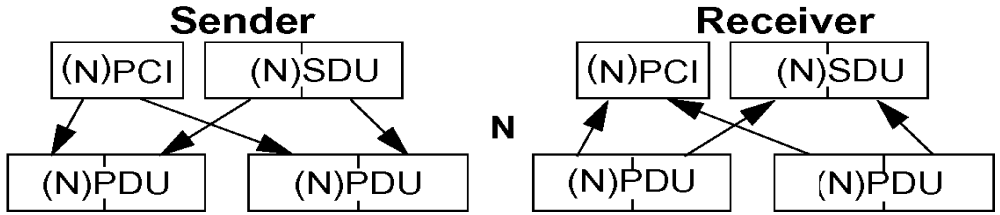


Service Data Units and Protocol Data Units

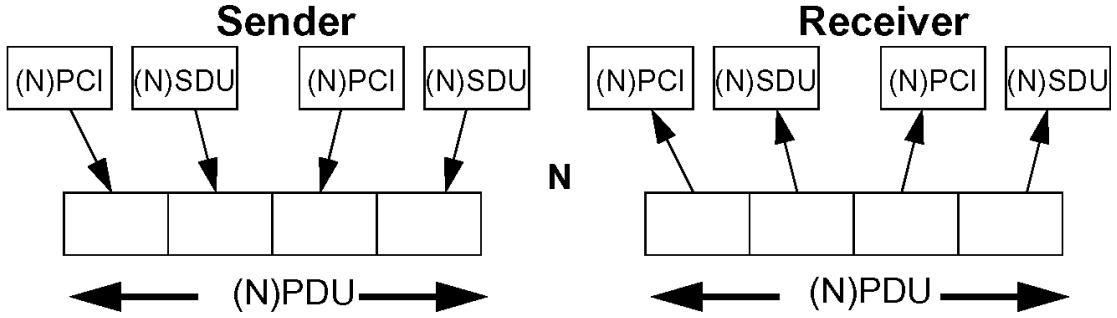
Basis:



With segmentation / reassembling



Combining (multiplexing) several smaller units



abbreviations:

- SDU Service Data Unit
- PCI Protocol Control Information
- PDU Protocol Data Unit = PCI+SDU

9 Parallelism, Connections, (Un)Confirmed Service

Parallelism in Communications

Connections

Multiplexing and Splitting (of connections)

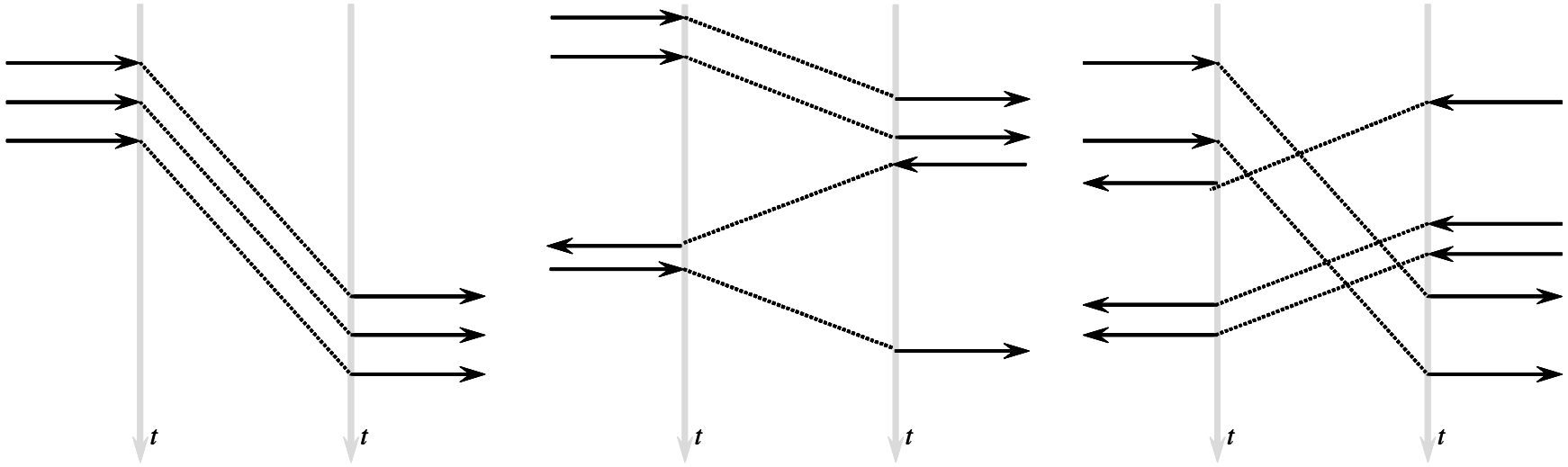
Confirmed and Unconfirmed Service

Parallelism in Communications

Simplex Communication
- data is always transferred in one direction

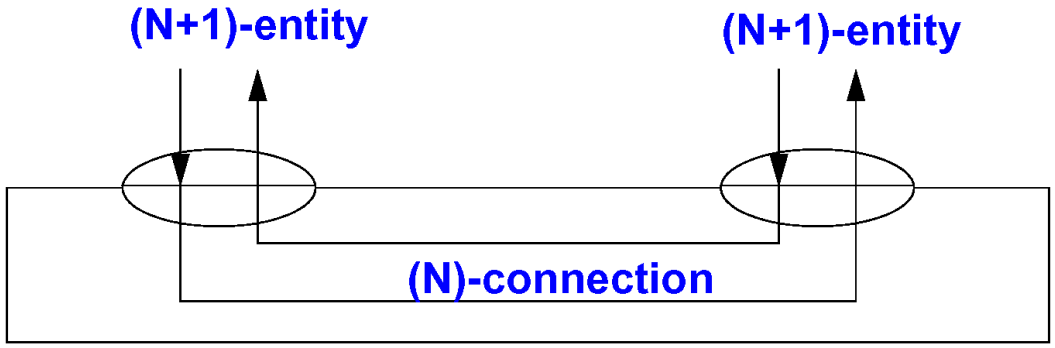
Half-Duplex-Communication (aka semi-duplex)
- data is transferred in both directions
- but never simultaneously

Full-Duplex-Communication
- data can flow simultaneously in both directions



Connection-oriented / Connection-less

Connection Oriented Service



Connection oriented:

Three phases:

1. connect
2. data transfer
3. disconnect

Classical analogy: telephone service

- applications (preferably):
  - regularly recurring data units
  - longer duration
  - quality of service guarantees (time, bandwidth)

Connectionless Service

Connectionless (Datagram Service)

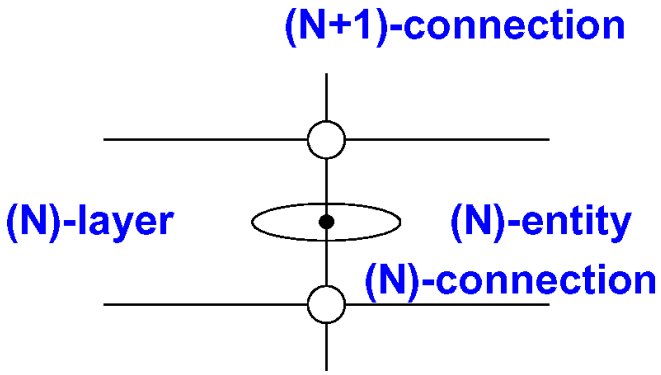
- transfer of isolated unit data

Classical analogy: letter delivery

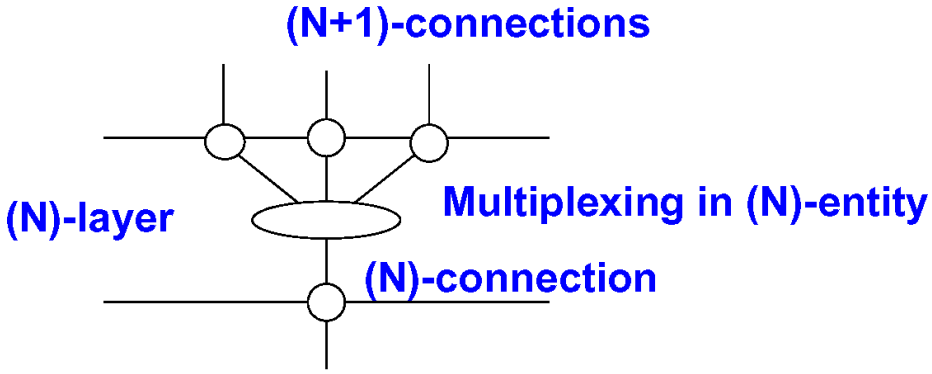
- applications (preferably):
  - one-time data transfer
  - short duration

Multiplexing and Splitting (of connections)

1-to1:

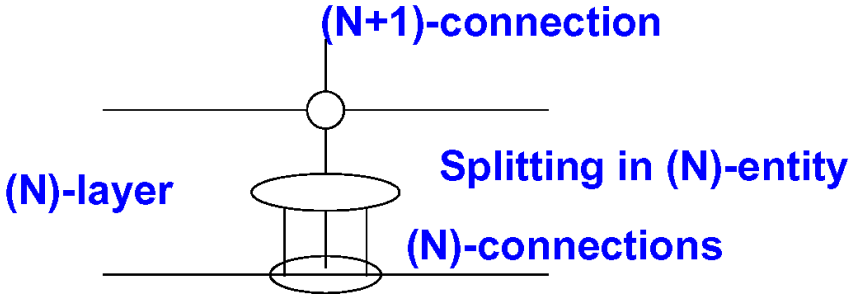


Multiplexing / Demultiplexing:



Splitting / Recombining:

- (also called “upward” multiplexing)



Confirmed and Unconfirmed Service

Service primitives

- define a service in an abstract manner
- are usually parameterized

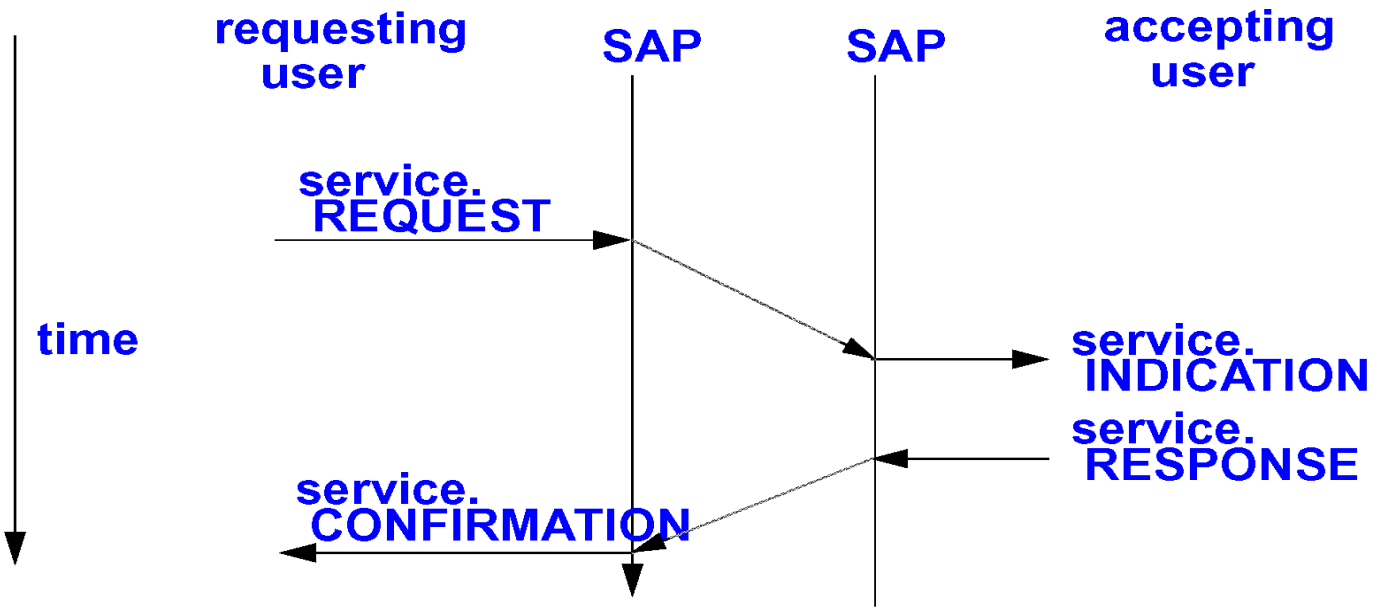
Types:

1. service. REQUEST
2. service. INDICATION
3. service. RESPONSE
4. service. CONFIRMATION

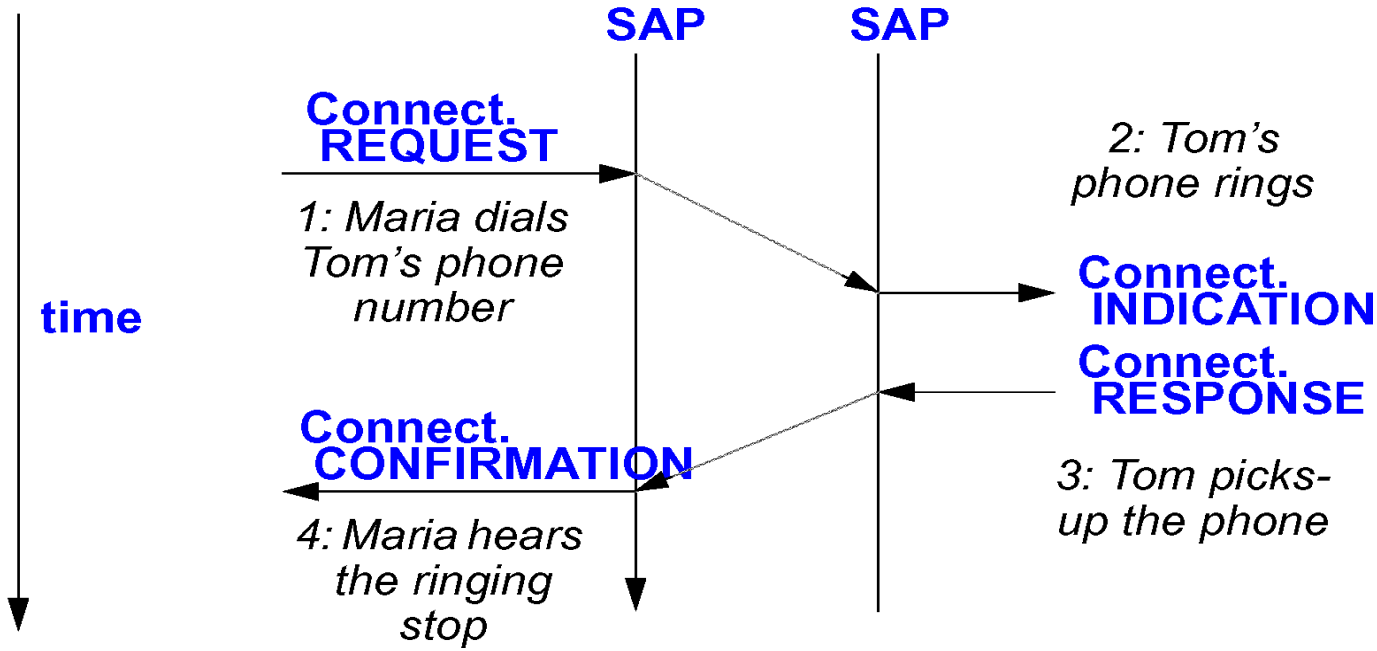
Example:

- Connect. REQUEST
- Connect. INDICATION
- Connect. RESPONSE
- Connect. CONFIRMATION

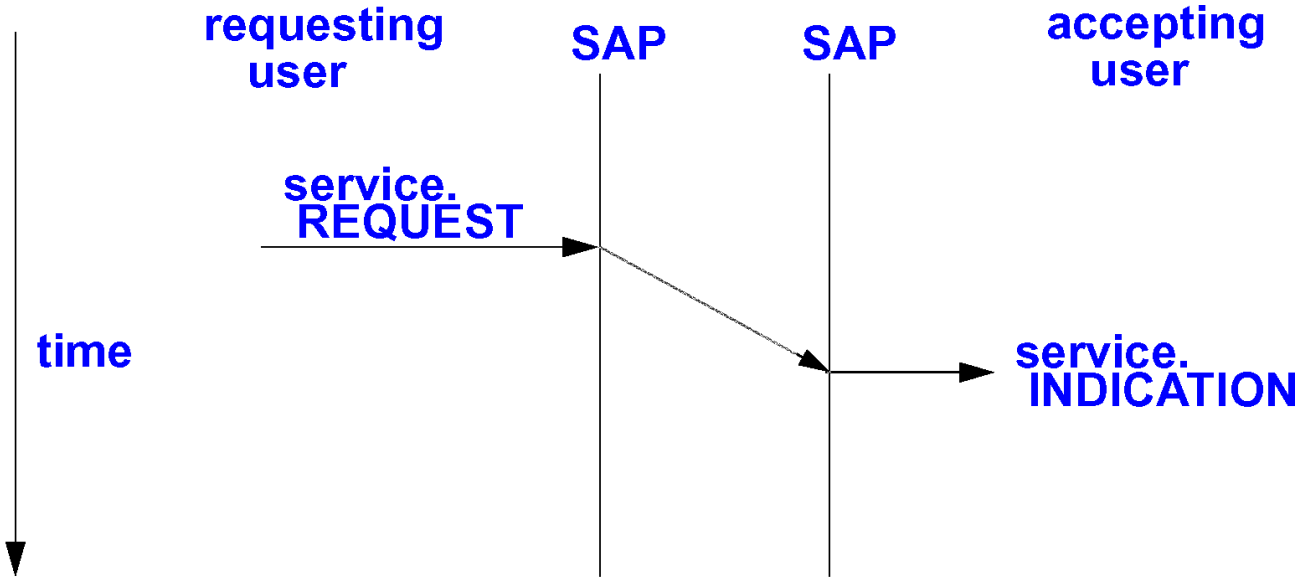
Confirmed Service



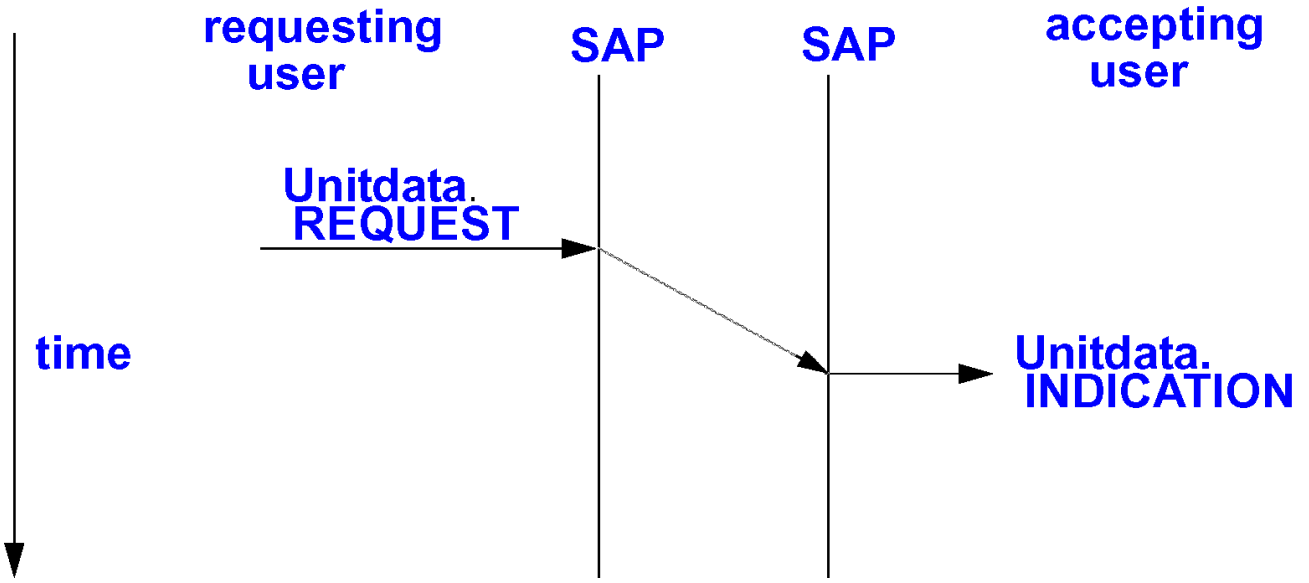
Example:



Unconfirmed Service



Example:



Service Primitives: Practical View

Above service primitives are quite abstract

More concrete service primitives
to establish a simple connection-oriented service
(such as “socket interface”)

Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

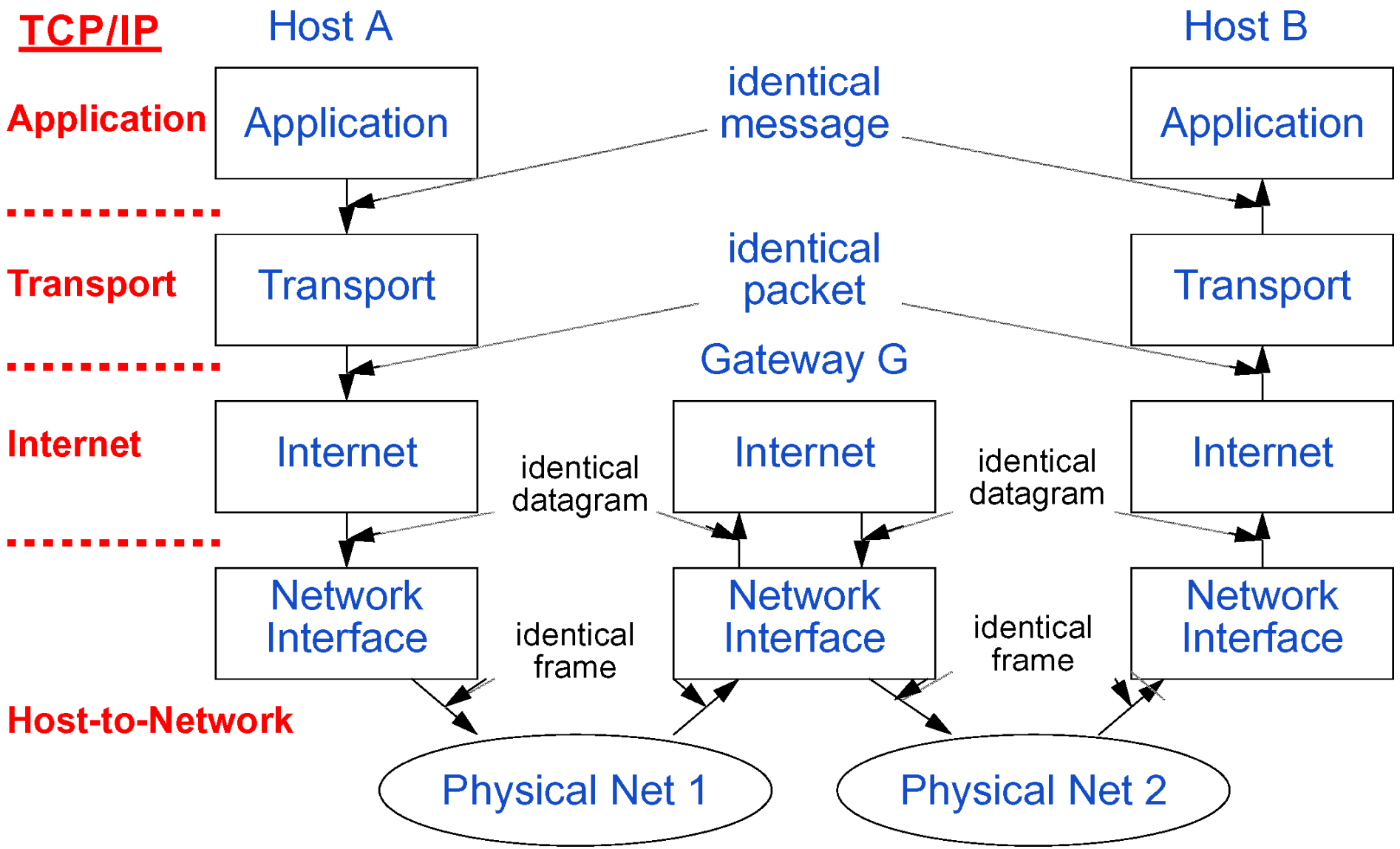
OSI (Open Systems Interconnection) Reference Model

7	Application Layer
6	Presentation Layer
5	Session Layer
4	Transport Layer
3	Network Layer
2	Data Link Layer
1	Physical Layer

TCP/IP Reference Model Internet Architecture

- ISO-OSI presentation, session and application layer merged
- ISO-OSI data link layer and physical layer merged to form Network Interface

TCP/IP Reference Model: Internet Architecture



TCP/IP Reference Model: Some Critique

Service, interface, and protocol not distinguished

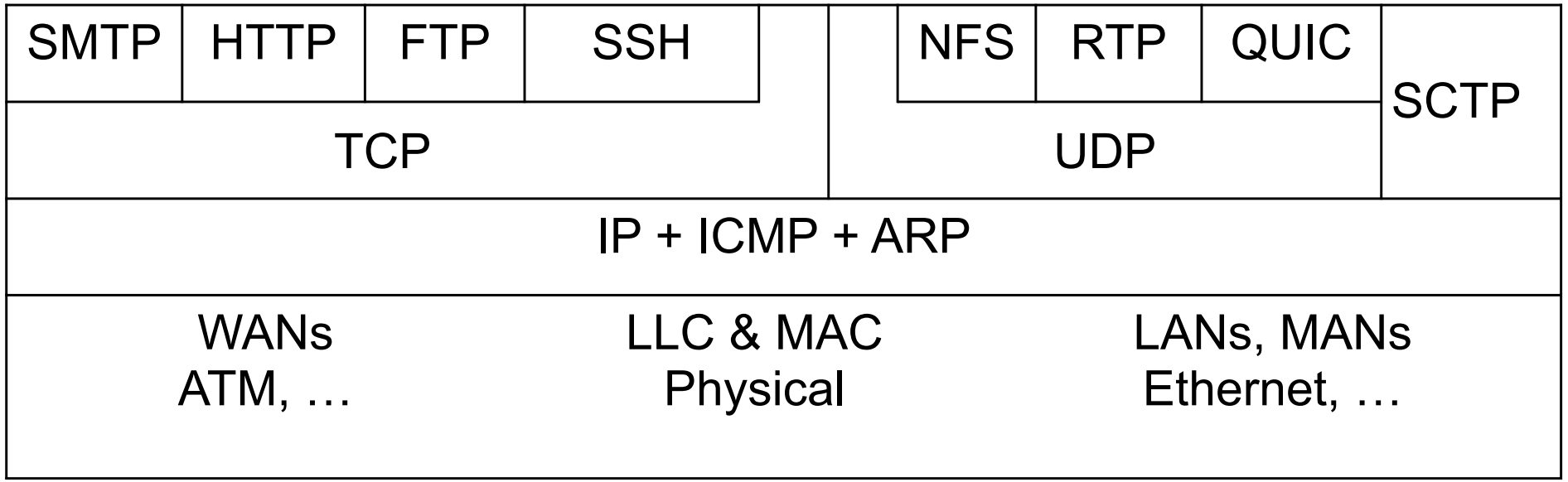
Not a general model

Minor protocols deeply entrenched, hard to replace

Data link and physical layer combined to form
Network Interface or Host-to-Net

- hardly any statements in the model about this
- no mention of physical and data link layers
- not really a ’layer’

Some Well-Known Internet Protocols

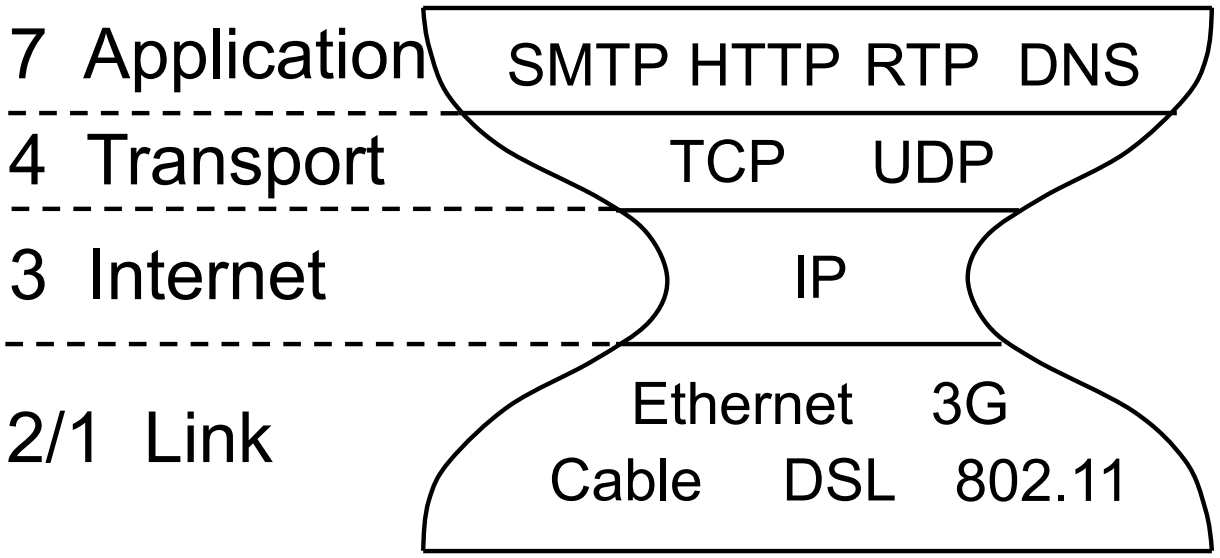


ARP	=	Address Resolution Protocol
FTP	=	File Transfer Protocol
HTTP	=	Hypertext Transfer Protocol
IP	=	Internet Protocol
ICMP	=	Internet Control Message Protocol
LLC	=	Logical Link Control
MAC	=	Media Access Control
NFS	=	Network File System
SMTP	=	Simple Mail Transfer Protocol
SSH	=	Secure Shell
TCP	=	Transmission Control Protocol
UDP	=	User Datagram Protocol
SCTP	=	Stream Control Transmission Protocol

Typical Internet View on Layers and Protocols

IP is the “narrow waist” of the Internet

- Supports many different links below and apps above



Source: Wetherall, lecturer materials 1-7 slide 6

Comparing the Reference Models

ISO-OSI: standardized too late

- implementations usually worse than those of Internet protocols
- some issues have not been sufficiently clear
  - resp. committee compromises ...
- in general, however, mainly good concepts

TCP/IP (Internet)

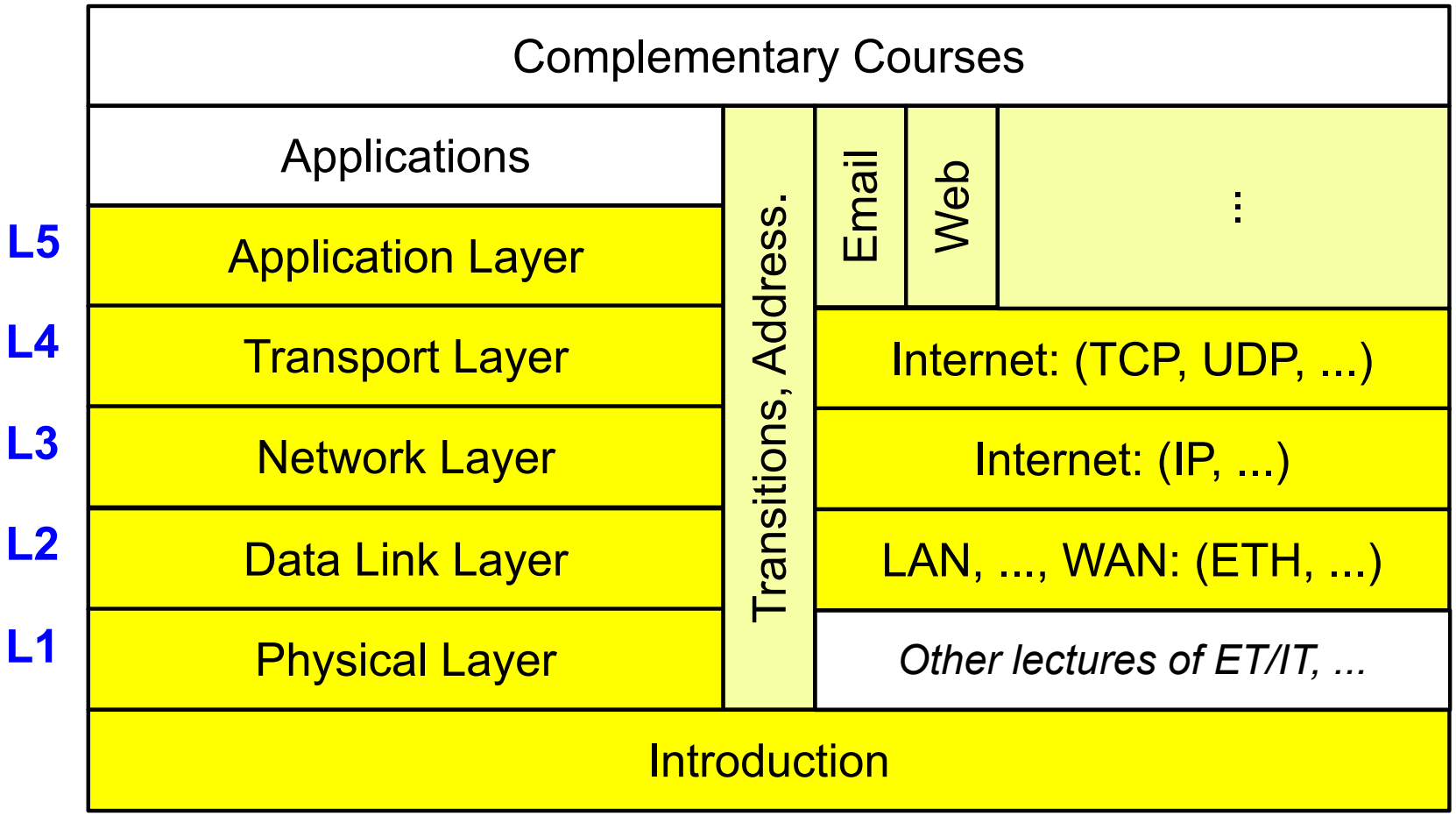
- TCP/IP already prevalent
  - and also application protocols, e.g. SMTP, now WWW / HTTP, etc.
- integrated into UNIX (BSD)

Hybrid 5-Layer Model

Model considered here:

Layer		Function
5	Application	application related services incl. ISO-OSI L5 and L6 (as far as necessary)
4	Transport	connection from source application (process) to destination application (process)
3	Network	end-system to end-system
2	Data Link	data transfer between adjacent stations
1	Physical	sent bit ‘1’ is also received as bit ‘1’

i.e. Structure used within the course



11 Standardization

Term "standardization"

- Standardization is the methodical simplification of material and immaterial objects for the benefit of the general public, executed jointly by the interested circles

- communication means compatibility, i. e. exchange is important
- in general: not legally binding

Types

- de facto
  - manufacturer or user driven
  - e.g. Ethernet, Internet, ...
- de jure
  - e.g. telephone, ...
- usually a combination of both

➔ Panels for Standardization

Panels for Standardization:

ISO: International Organization for Standardization (http://www.iso.org)

- national organizations for standardization send delegates
  - DIN: the national German institute for standardization
  - ANSI (American National Standards Institute)
  - AFNOR (France), BSI (GB), ...
- organized
  - in more than 200 Technical Committees (TC)
  - TC has subcommittees (SC)
  - SC has working groups (WG)
- steps for standardization
  1. Working Draft (WD)
  2. Draft Proposal (DP)
  3. Draft International Standard (DIS)
  4. International Standard (IS)
- some ISO figures
  - > 200 technical committees, > 500 subcommittees, > 2000 working groups, and ad hoc study groups
  - > 23745 International Standards and standards-type documents (as of 04/2021) e.g., in 2009: 1038 International Standards and standards-type docs published

Panels for Standardization

ITU: International Telecommunication Union (http://www.itu.int)

- since 1947 part of the UN (United Nations)
- among others subdivision such as
  - ITU-R: radio communication
  - ITU-T: telecommunication (important here)
- until 1993, ITU-R was know as CCITT: Comite Consultatif International de Telegraphie et Telephonique
  - international union of post and telecom
  - plenary meeting every 4 years
  - passing of "recommendations" example SDL, CHILL, ...
- example: V.24 by ITU-T (also known as EIA RS-232)

ETSI: European Telecommunications Standards Institute

ECMA: European Computer Manufacturers Association

IEEE: Institute of Electrical and Electronics Engineers

- IEEE actually worldwide the biggest professional organization
- among others resp. for standards, e.g. LANs IEEE 802 later also ISO 8802

Industry Fora:

- Bluetooth
- 3GPP
- ...

Panels for Standardization: Internet Society

Internet (Internet Society)

- in the mid-80s a multiple of networks was designated as the "Internet"
- Jan. 1992: (actual) foundation of the Internet Society
- objective: to distribute the Internet (protocols & services)

Areas of the Internet Society:

- IAB: Internet Architecture Board
  - founded in 1983 to involve researchers in the ARPANET
  - today it is the most supreme Internet board
- IAB oversees/nominates
  - IETF (Internet Engineering Taskforce)
    - divided into areas and then into working groups (e. g. ipv6)
    - actual board
  - IRTF (Internet Research Taskforce)

- RFCs (Requests for Comments)
  - http://www.ietf.org/rfc.html
  - e.g.,
    - RFC 791: „Internet Protocol“, September 1981
    - RFC 6177: “IPv6 Address Assignment to End Sites”, March 2011
  - work in progress: Internet Drafts

Panels for Standardization: Internet Society

But: from S. Bradner: The Internet Standards Process -- Revision 3, RFC 2026, October 1996

```
**********************************************************
*                                                        *
*   It is important to remember that not all RFCs        *
*   are standards track documents, and that not all      *
*   standards track documents reach the level of         *
*   Internet Standard. In the same way, not all RFCs     *
*   which describe current practices have been given     *
*   the review and approval to become BCPs. See          *
*   RFC-1796 [6] for further information.                *
*                                                        *
**********************************************************
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Internet Standards Track

- Standards Track Maturity Levels
  - Proposed Standard
  - Draft Standard
  - Internet Standard
- Non-Standards Track Maturity Levels
  - Experimental
  - Informational
  - Historic

Panels for Standardization: Internet Society

Tasks of the INTERNET

- connect different networks over gateways
- define protocols that will work on all subnets
- define a standardized addressing pattern for a very large network
- define a global routing architecture