Operating Systems & Computer Networks
10. Networked Computer & the Internet

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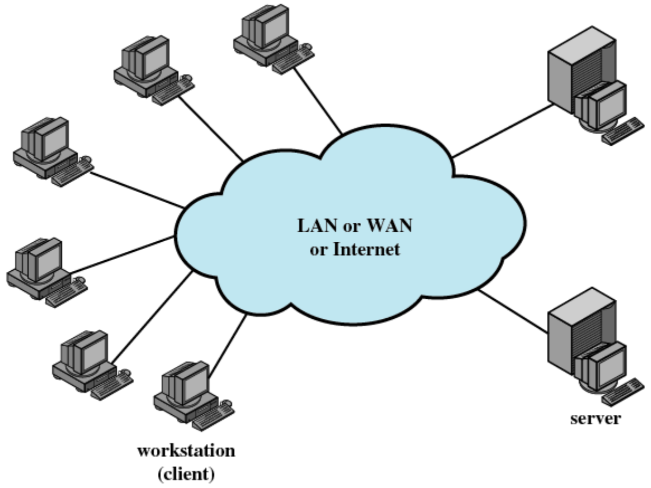

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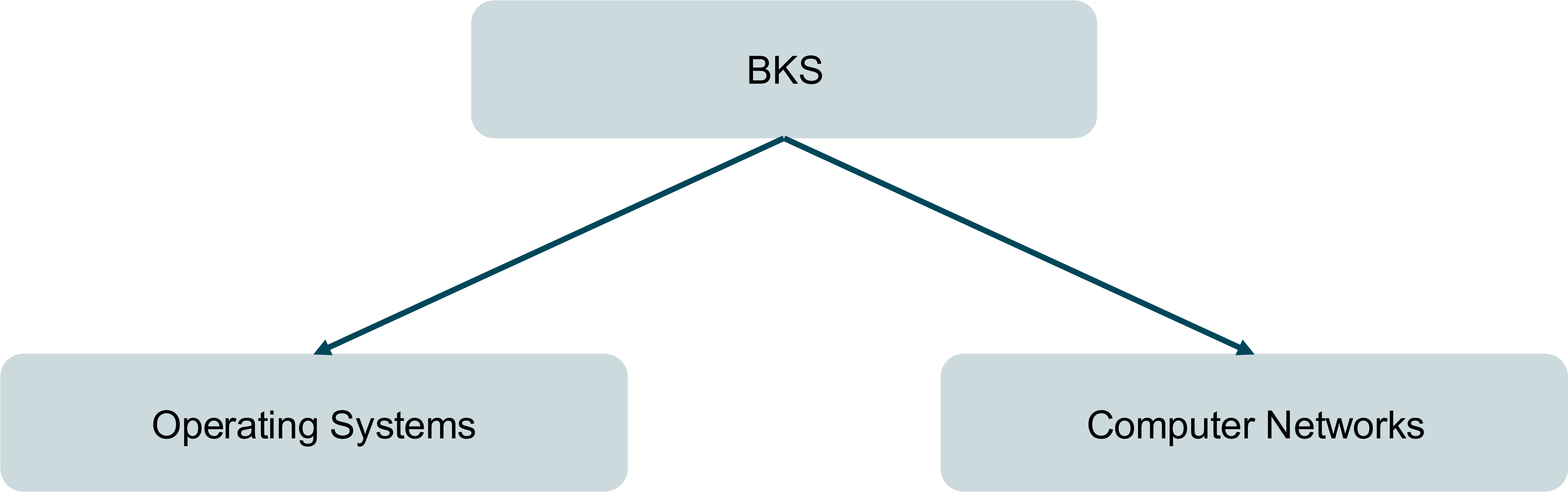


Roadmap

8. **Networked Computer & Internet**
9. Network Access Layer I – Physical Layer
10. Network Access Layer II – Data Link Layer
11. Internet Layer – Network Layer
12. Transport Layer
13. Applications

Lernziele

- Sie nennen:
  - die Schichten des ISO/OSI-Modells und des TCP/IP-Protokollstacks

Networked Computers

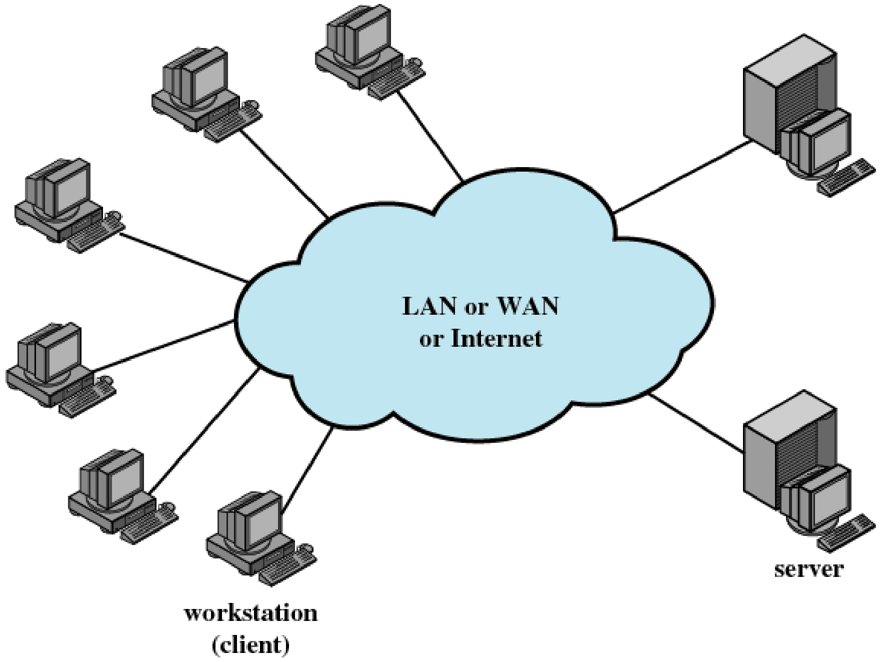
Motivation I

Questions:

How can a user/process communicate over the network?

How can (possibly distant) computers exchange data?

How does a computer know which other computer it should be talking to?



Motivation II

www.mi.fu-berlin.de

160.45.117.199

Socket

- Enable communication between a client and server
- Concatenation of a Port and an IP address form a socket, 160.45.117.199:80 (http://www.mi.fu-berlin.de)

OS Support for Networking I

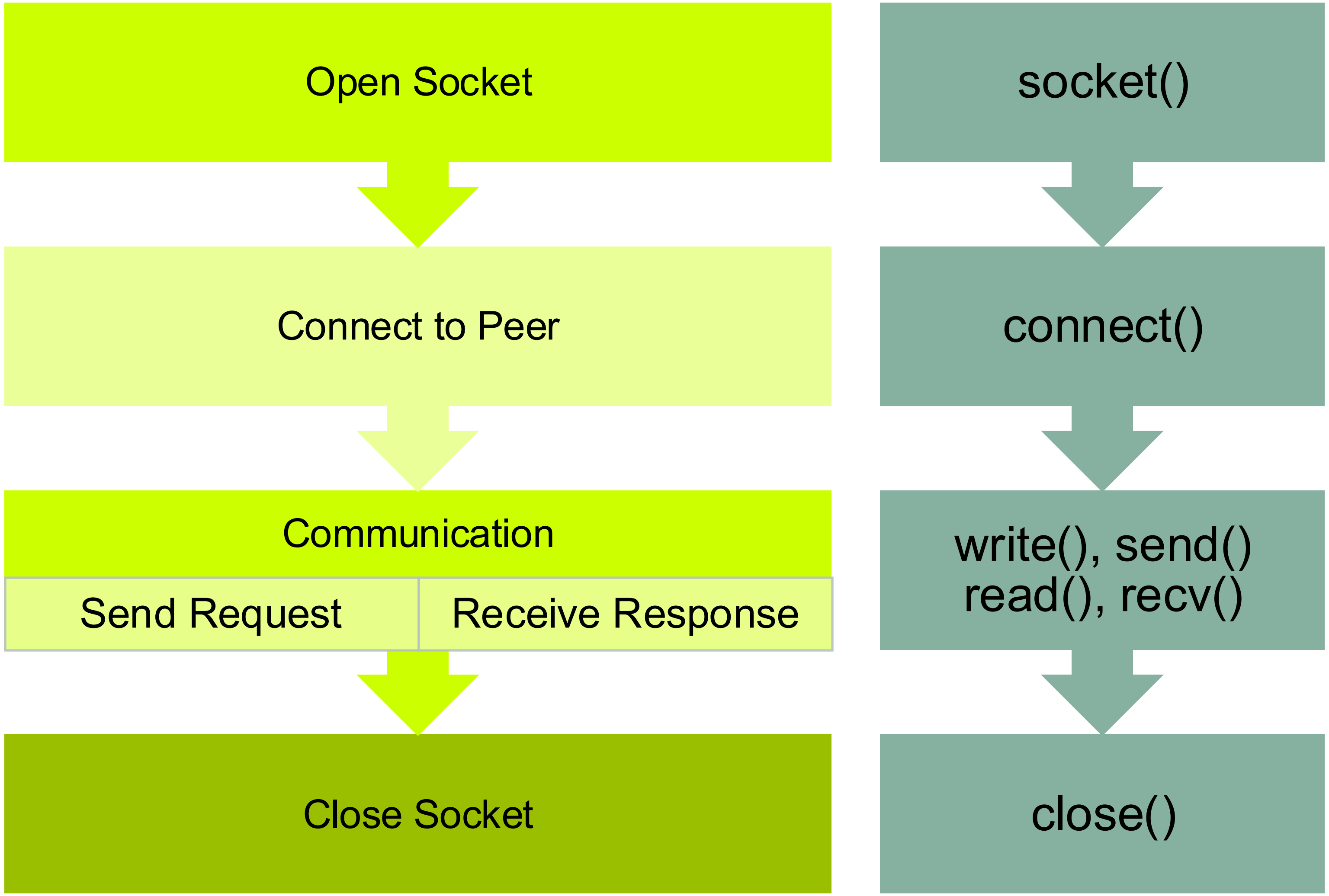
Types of Sockets (classical Internet)

Stream sockets
- Use Transmission Control Protocol (TCP)
- Reliable data transfer

Datagram sockets
- Use User Datagram Protocol (UDP)
- Delivery is not guaranteed

➢ Processes may open sockets to transparently communicate with processes on remote computers

OS Support for Networking II



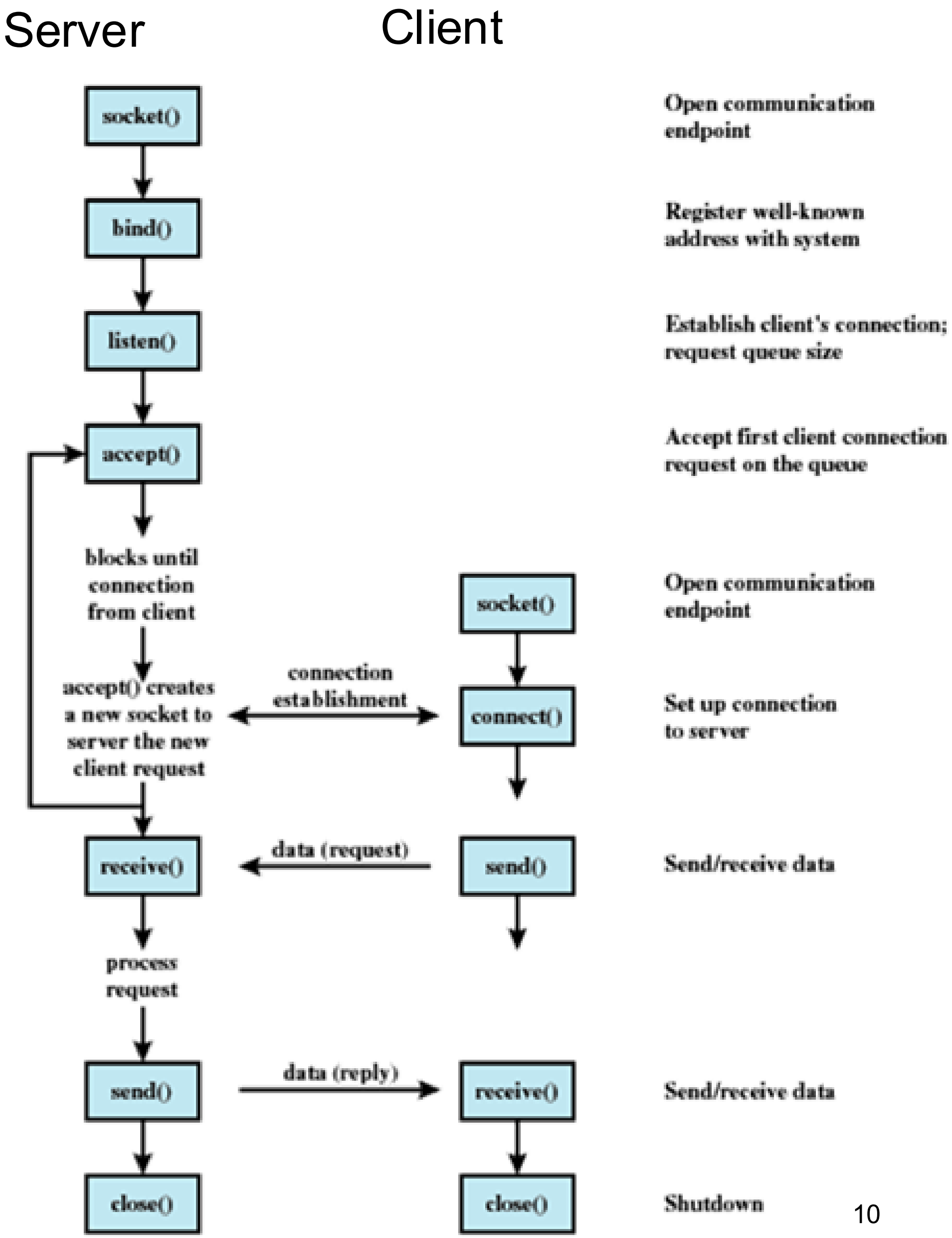
Socket Creation and Operation

System call

```
int socket(int domain, int type, int protocol)
```

Parameters

- **`domain`** Protocol family
  - ➢ e.g. **`PF_INET`** for TCP/IP
- **`type`**
  - ➢ Stream or datagram
- **`protocol`** (optional)
  - ➢ e.g. TCP or UDP
    (for TCP/IP networking)



Datagram Communication

Simplest possible service: unreliable datagrams

Sender

```
1. int s = socket(…);
2. sendto(s,
      buffer,
      datasize,
      0,
      to_addr,
      addr_length);
```

- `to_addr` and `addr_length` specify destination

Receiver

```
1. int s = socket(…);
2. bind(s, local_addr, …);
3. recv(s,
      buffer,
      max_buff_length,
      0);
```

- Will wait until data is available on socket `s` and put the data into `buffer`

Byte Streams over Connection-Oriented Socket

For reliable byte streams, sockets have to be connected first

Receiver has to accept connection

Client

1. `int s = socket(…);`
2. `connect(s, destination_addr, addr_length);`
3. `send(s,buffer, datasize, 0);`
4. Arbitrary `recv()/send()`
5. `close (s);`

- Connected sockets use a `send` without address information

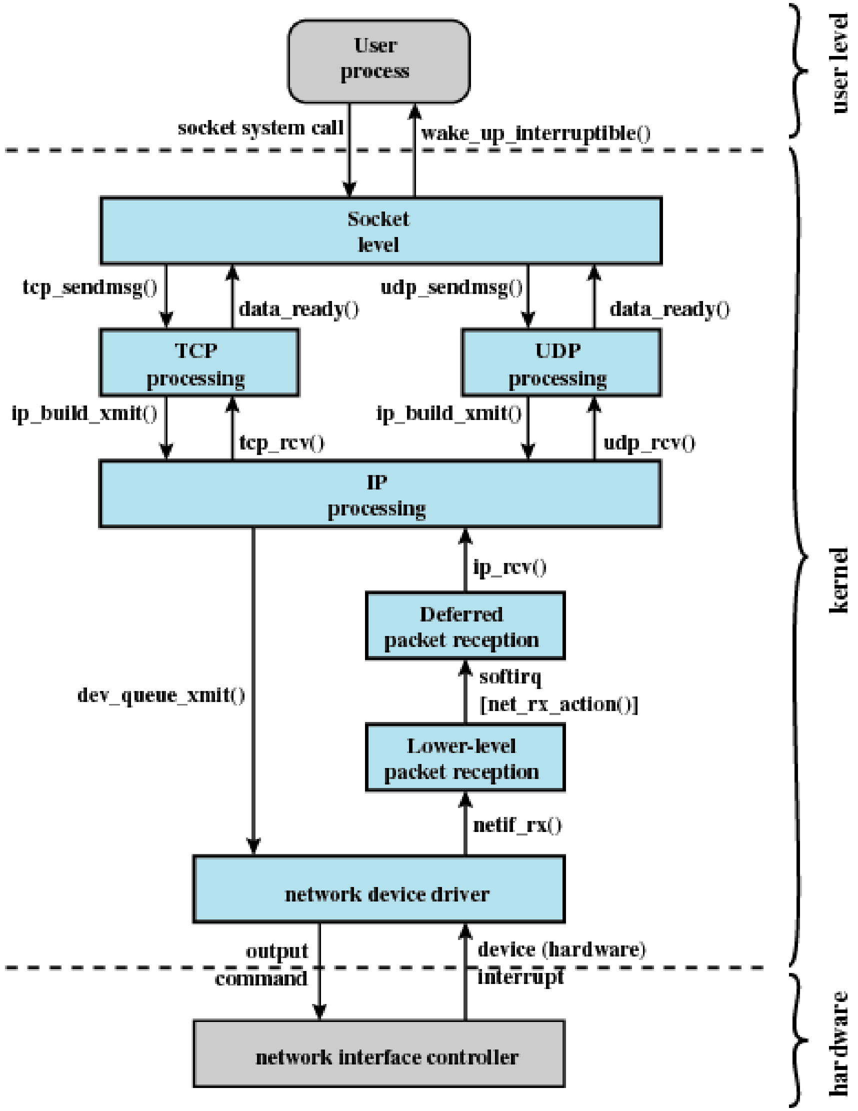
Server

1. `int s = socket(…);`
2. `bind(s, local_addr, …);`
3. `listen(s, …);`
4. `int newsock = accept(s, *remote_addr, …);`
5. `recv(newsock, buffer, max_buff_length, 0);`
6. Arbitrary `recv()/send()`
7. `close (newsock);`

   ...

8. `close(s);`

Kernel-level Socket Support



API to user space

TCP / UDP implementation

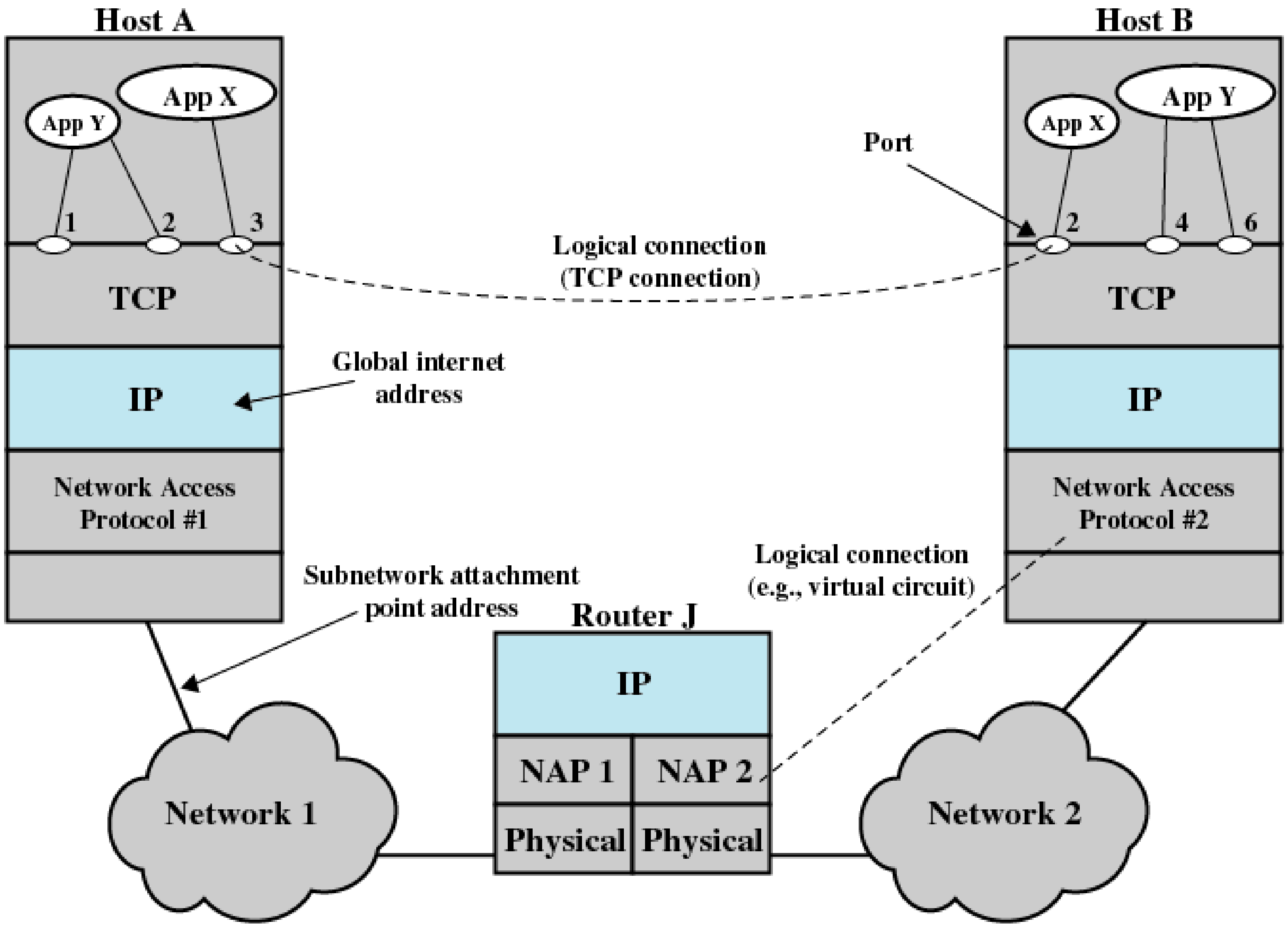
Internet Protocol (IP) implementation

Device driver (includes method to access communication medium)

Layered communication architecture

The Internet

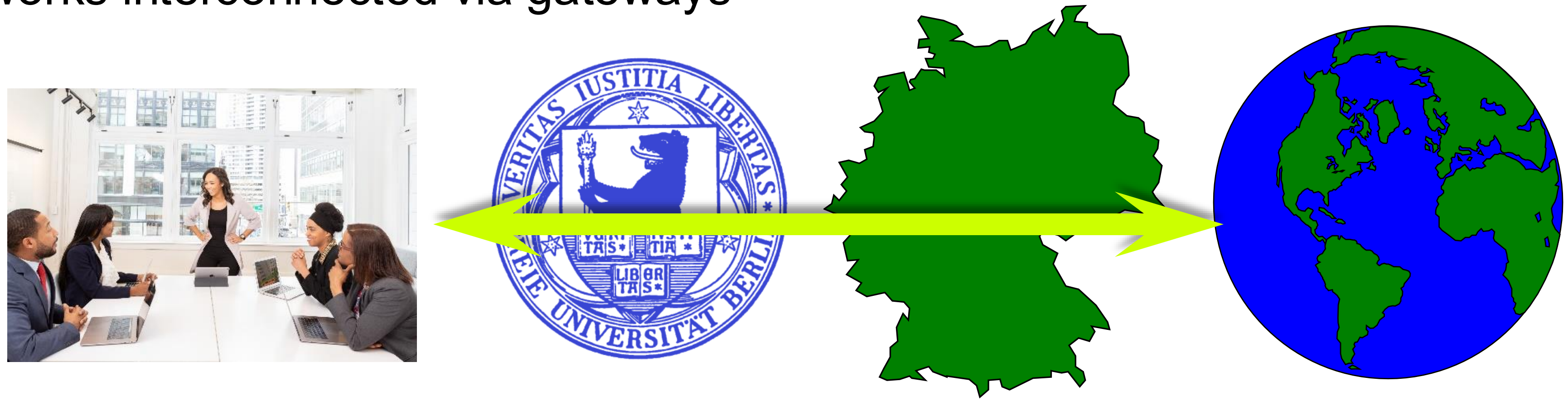
Internet / TCP/IP Network Stack



The Internet

The Internet consists of

- many computers
  - using same network protocol family TCP/IP
    - IP on top of lower-level protocol (Ethernet, WLAN, Bluetooth, ...)
  - that are (directly or indirectly) connected to each other
  - that offer or use certain services
- many users that have direct access to the services
- many networks interconnected via gateways



Computer Science Dept. FU Berlin Germany World

Structure of the Internet (Concept)

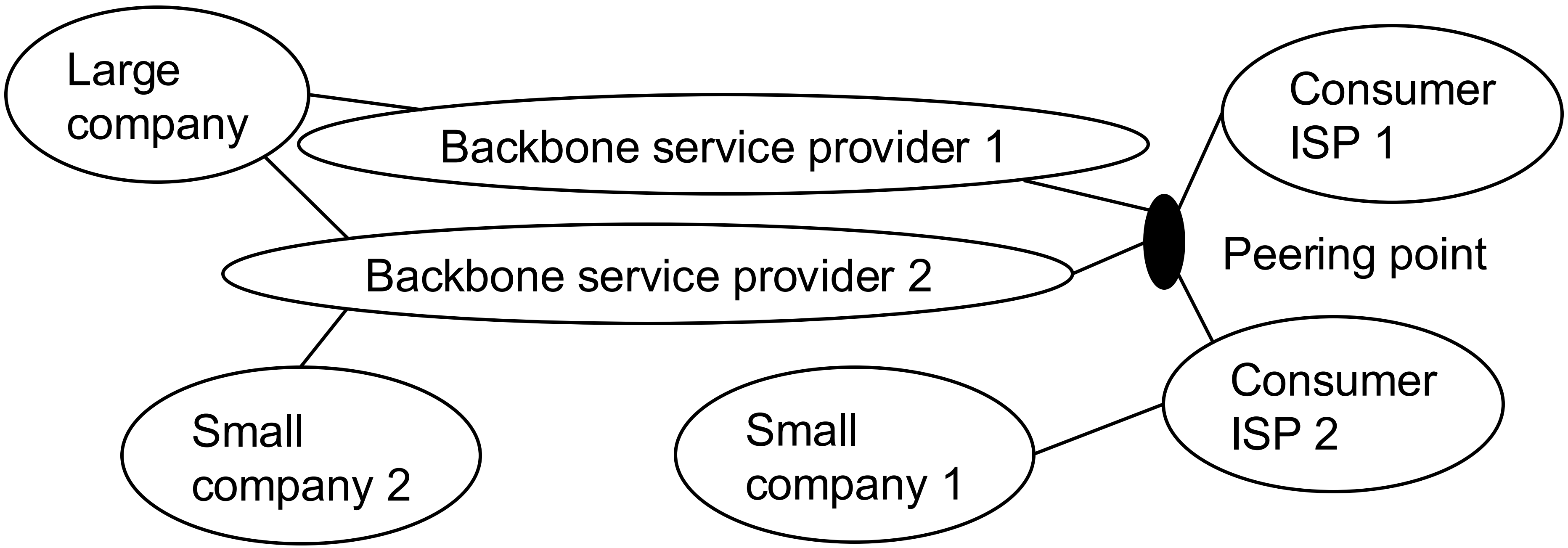
Backbone service providers

Consumer Internet Service Provider (ISP)

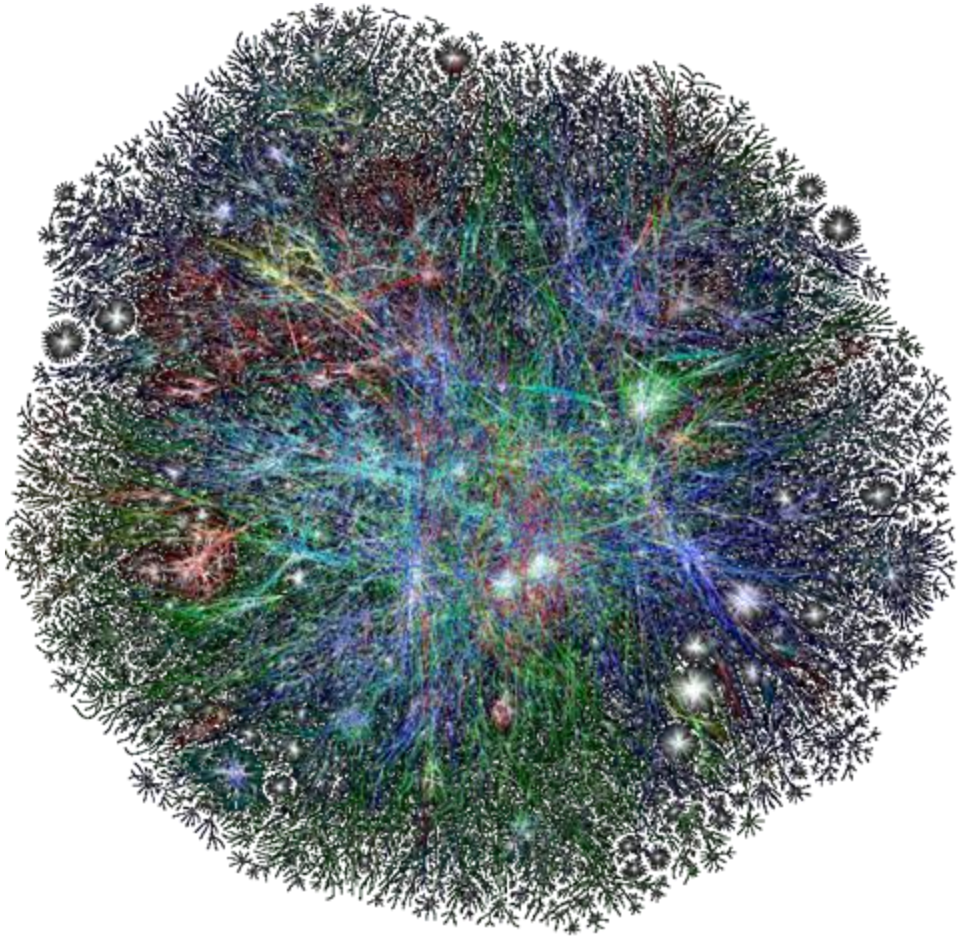
Peering Points – shortcuts between operators

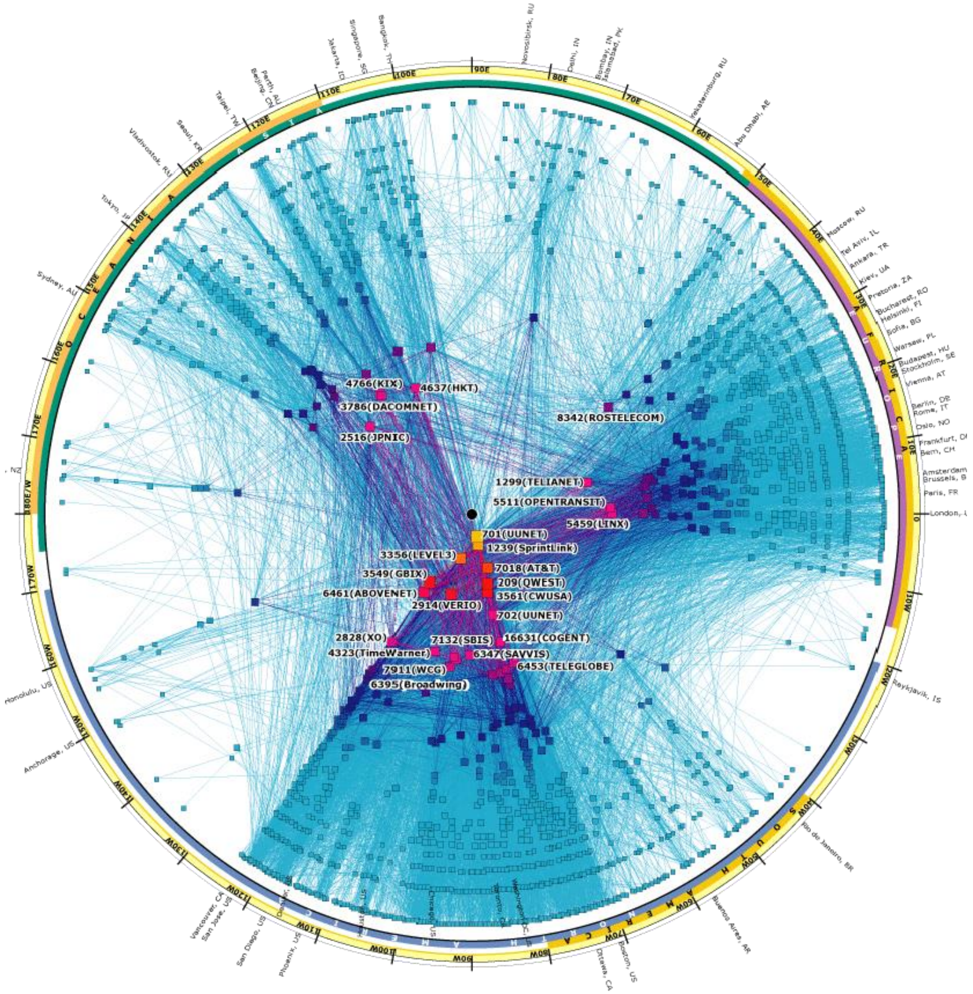
Consumers

- Direct backbone connectivity (companies) or ISP (private)



Structure of the Internet (“Reality”)





Source: www.caida.org

Exemplary Services in the Internet

World Wide Web (WWW)

- World-wide interlinked resources
- Based on “Hypertext Transfer Protocol” (HTTP)

Electronic mail (email)

- Exchange of digital multimedia messages
- Based on “Simple Mail Transfer Protocol” (SMTP)

File transfer

- Exchange of files
- Based on “File Transfer Protocol” (FTP)

Network management

- Monitoring and control of networked systems
- Based on “Simple Network Management Protocol” (SNMP)

P2P, VoIP, IPTV, CDN, ...

Many company-specific services: Skype, Gaming, ...

Classical Internet Design Principles

Minimalism and autonomy

- Independent operation of the network, no internal changes necessary if connected to other networks

“Best-Effort” services

- Network tries as best as possible to transmit data end-to-end
- Reliable communication is feasible through retransmission
  - Today several extensions towards quality-of-service (QoS) support exist

Stateless intermediate systems

- No intermediate system (routers) should keep state related to any end-to-end communication
  - Big difference to classical telephone networks (circuit vs. packet switched)
  - Alternatives necessary for quality-of-service support

Decentralized control

- No global, centralized control of all interconnected networks

Do we still have this situation today with >60% traffic handled by Google, Amazon, Facebook, Apple …?

Some (Historical) IP Design Principles

RFC 1958, based on papers from mid-80s

Make sure it works – before writing the standard

Keep it simple

Make clear choices

Exploit modularity

Expect heterogeneity

Avoid *static* options and parameters

Look for a good design; it need not be perfect

- 80-20 rule: 80% of effects comes from 20% of causes

Be strict when sending and tolerant when receiving

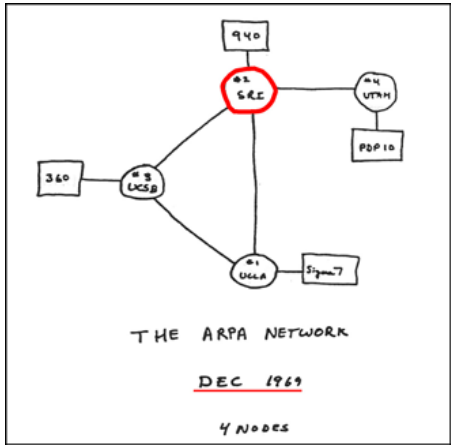
Think about scalability (with regard to nodes and traffic)

Consider performance and cost

➢ Looking back, some choices are not optimal anymore.

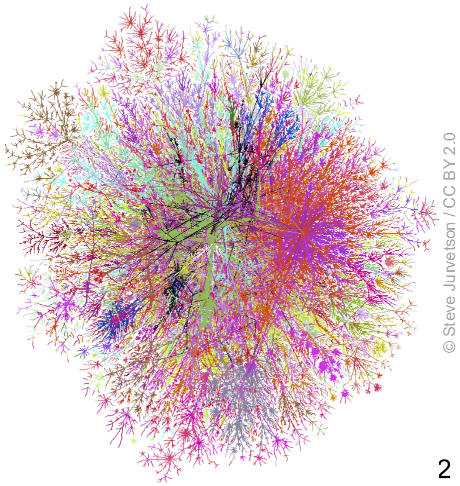
Development of the Internet

1962	DoD (Department of Defense): “Defense depends on communication.”
1967	ARPA (Advanced Research Project Agency) of the DoD: Project reliable packet network at SRI
1969	First “Internet” (4 hosts)
1971	Start of ARPAnet, the first Internet backbone
1974	New protocol suite: TCP/IP (Transmission Control Protocol/Internet Protocol)
1980	Integration of TCP/IP protocols into UNIX (BSD)
1988	IP connection to the Internet from Germany via EUnet - IRB Dortmund and XLink Karlsruhe
1991	EBONE: European backbone
1995	Internet becomes visible due to WWW
1996	University Corporation for Advanced Internet Development - Internet2
1999	Second Internet2-Backbone: Abilene
~2000	Rise and fall of dotcoms
2006	VoIP, Web 2.0 hype (and history repeats…)
2009	Clouds, more clouds
2010+	Everything is mobile (> 4.5bn subscribers), apps rule…
20xy	Internet of Things with > 30bn devices, IPv6 finally everywhere



Scan of ARPANET logic map, circa 1969, © SRI International

1969
…
2020

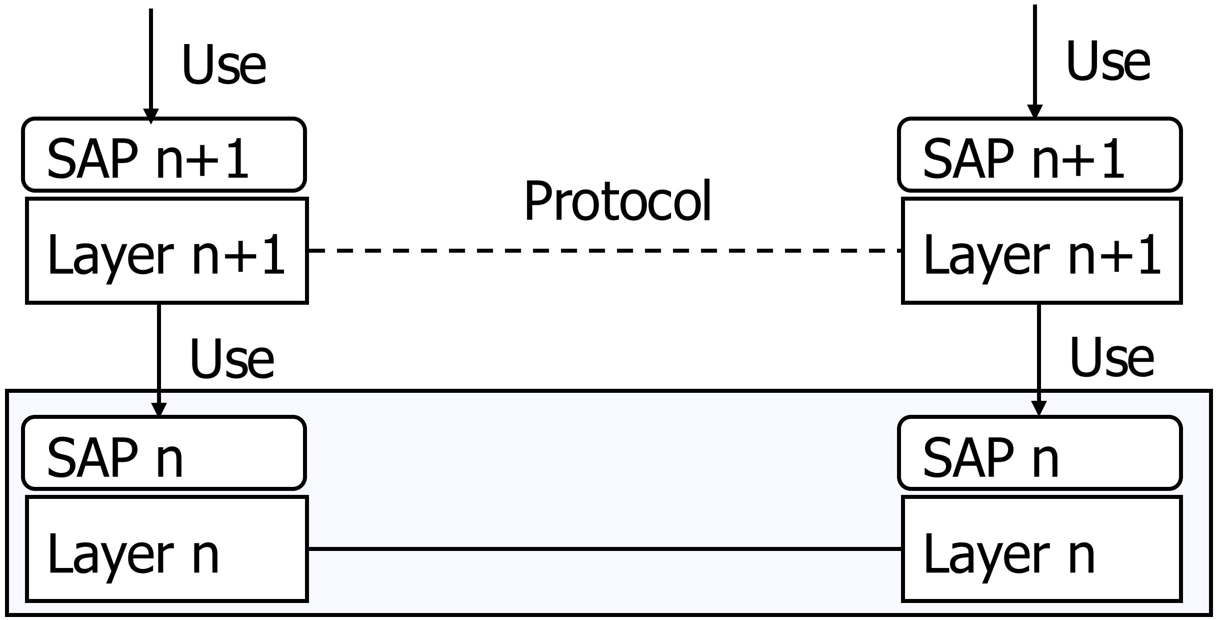


Protocols

Protocols

Protocols are a set of rules

- Describe how two (or more) remote parts of a layer cooperate to *implement the service* of the given layer
  - Behavior, packet formats
- These remote parts are called *peer protocol entities* or simply *peers*
- Use the service of underlying layer to exchange data with peer

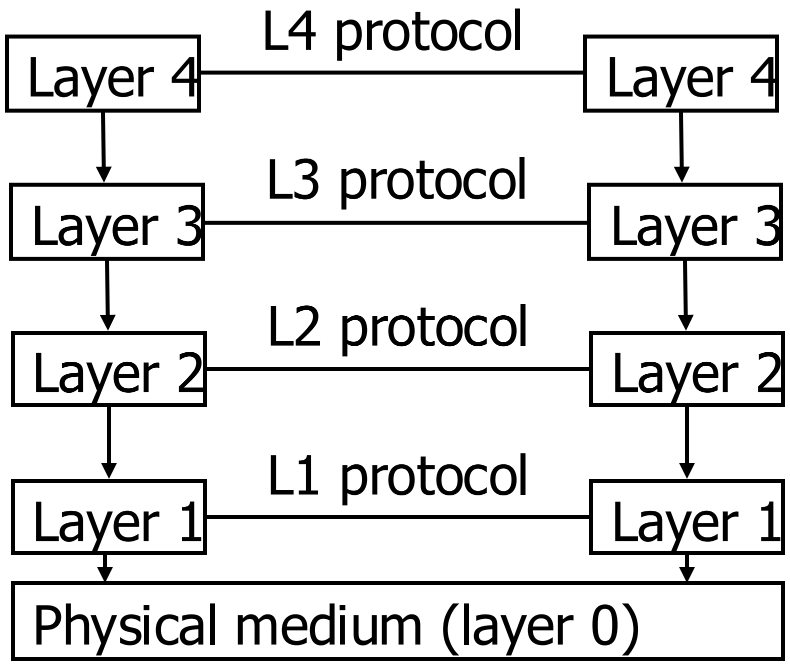


Protocol Stacks

Typically, several layers and thus several protocols in real system

Layers/protocols are arranged as *(protocol) stack*

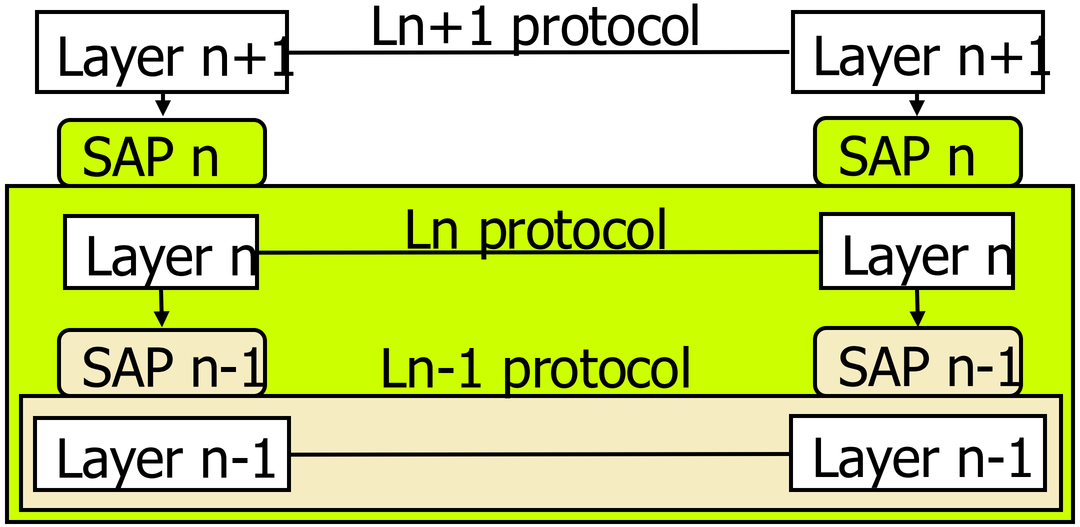
- One atop the other, *only* using services from directly beneath (so-called *strict layering*)



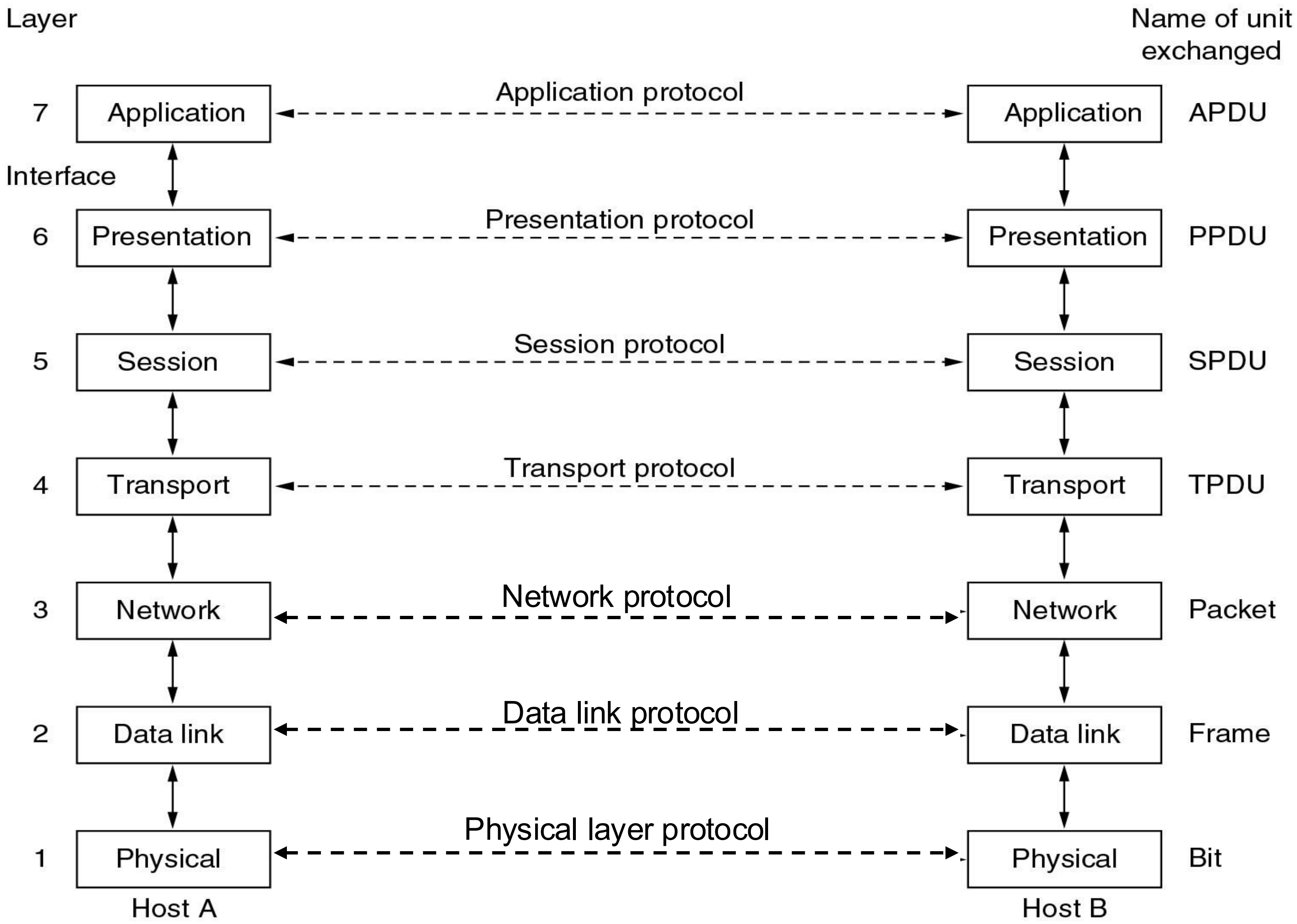
Layers Do Not Care About Distributed Lower Layers

A given layer n+1 does not care about the fact that its lower layer is actually distributed …

- Layer n+1 imagines layer n as something that “just works”, has service access points where they are necessary
- In reality, layer n of course is distributed in turn, relying on yet lower layers
- At the end, the physical medium (layer 0) is transporting signals (as physical representation of data)



ISO/OSI 7-layer Reference Model



PDU: Protocol Data Unit

Seven Layers (in brief)

1. **Physical layer**: Transmit raw bits over a physical medium

2. **Data Link layer**: Provide a (more or less) error-free transmission service for data frames over a shared medium

3. **Network layer**: Solve the forwarding and routing problem for a network

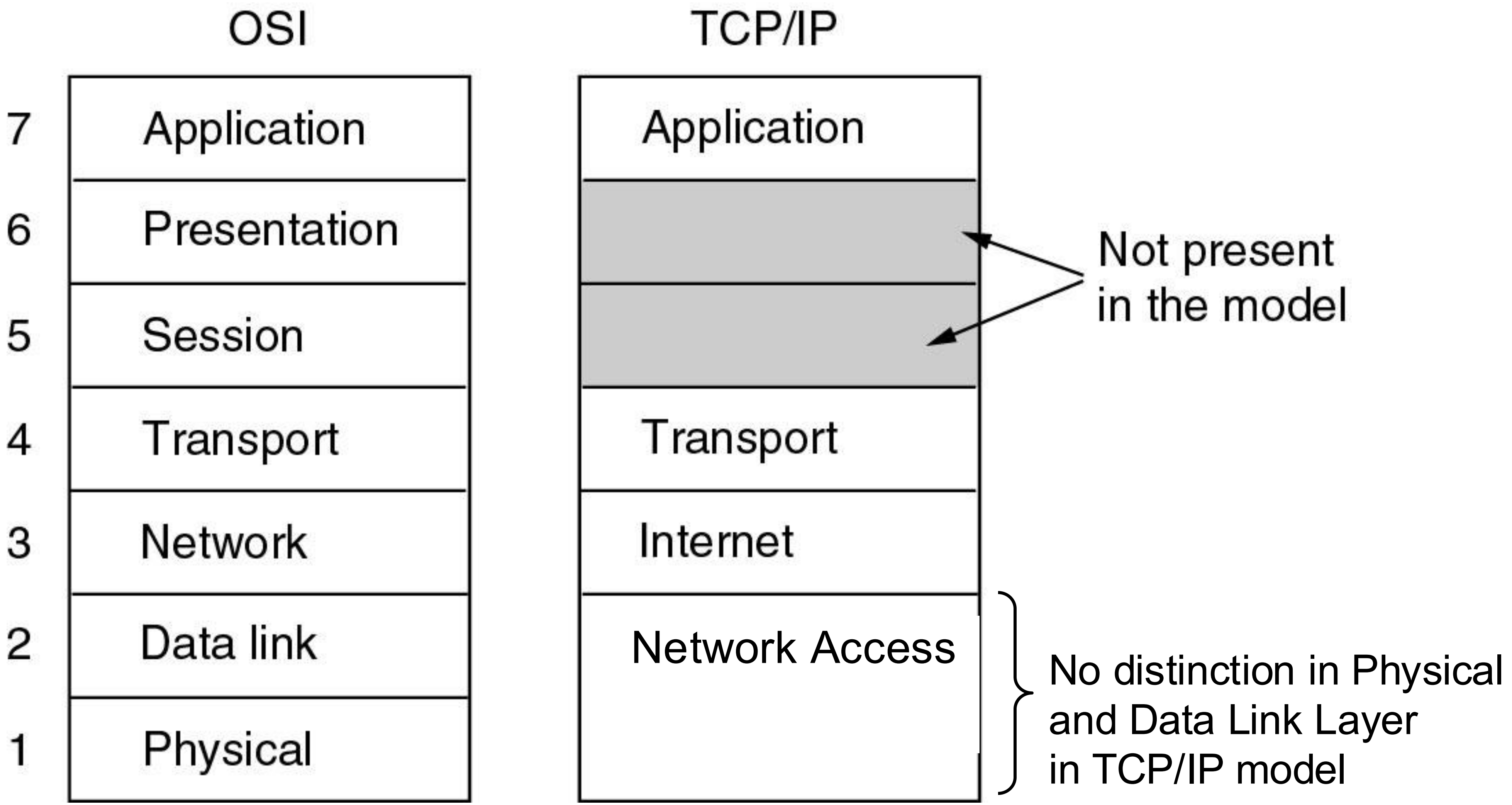
4. **Transport layer**: Provide (possibly reliable, in order) end-to-end communication, overload protection, fragmentation

5. **Session layer**: Group communication into *sessions* which can be synchronized, checkpointed, …

6. **Presentation layer**: Ensure that syntax and semantic of data is uniform between all types of terminals

7. **Application layer**: Actual application, e.g., protocols to transport web pages

TCP/IP Protocol Stack



ISO/OSI versus TCP/IP

ISO/OSI: Very useful model, almost non-existing protocols

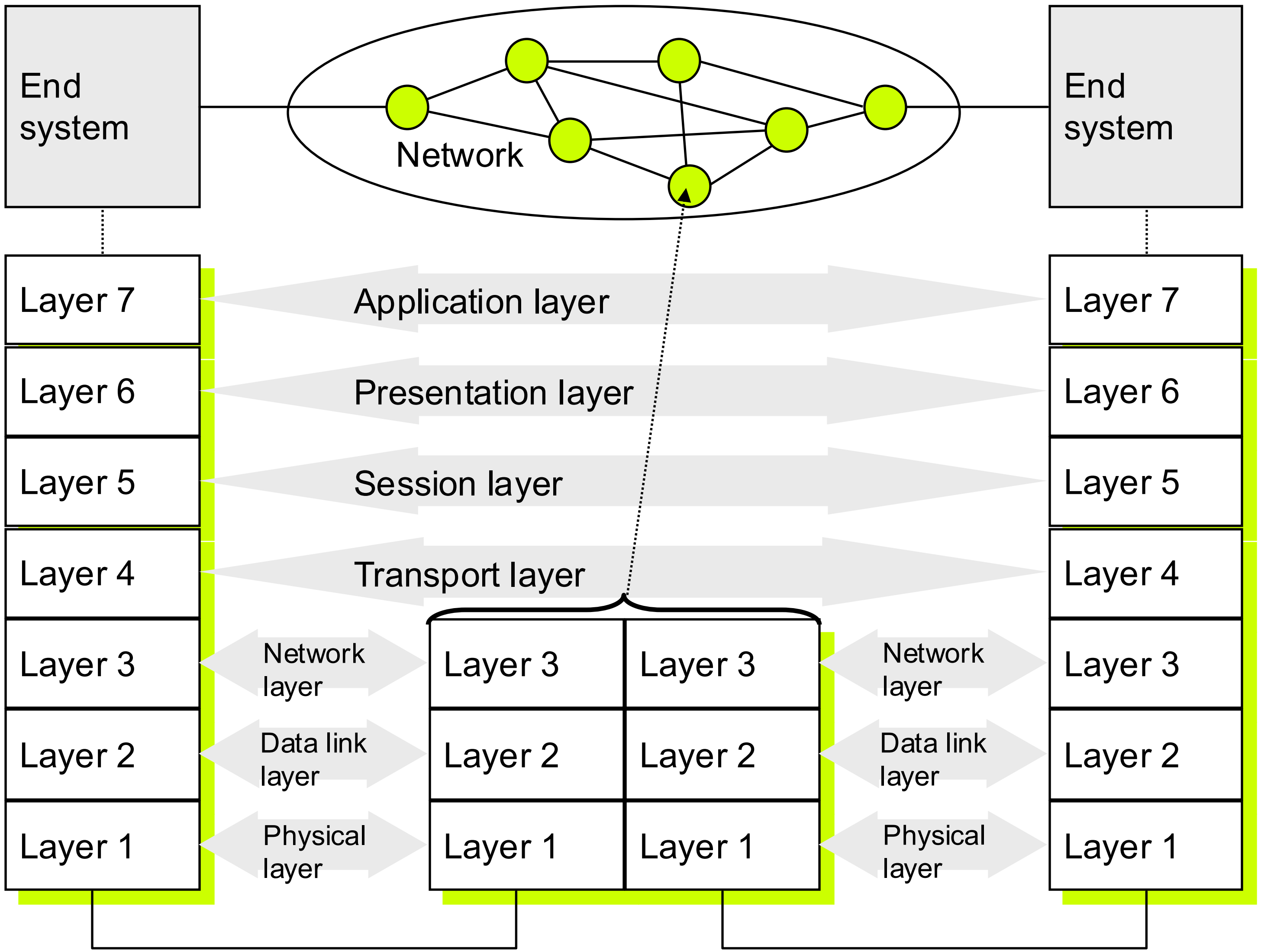
TCP/IP: Non-existing model, very useful protocols

➢Use simplified ISO/OSI model, but treat TCP/IP protocol stack in context of this model

- With suitable add-ons especially for the lower layers

5	Application layer
4	Transport layer
3	Network layer
2	Data link layer
1	Physical layer

7 Layers with Intermediate System

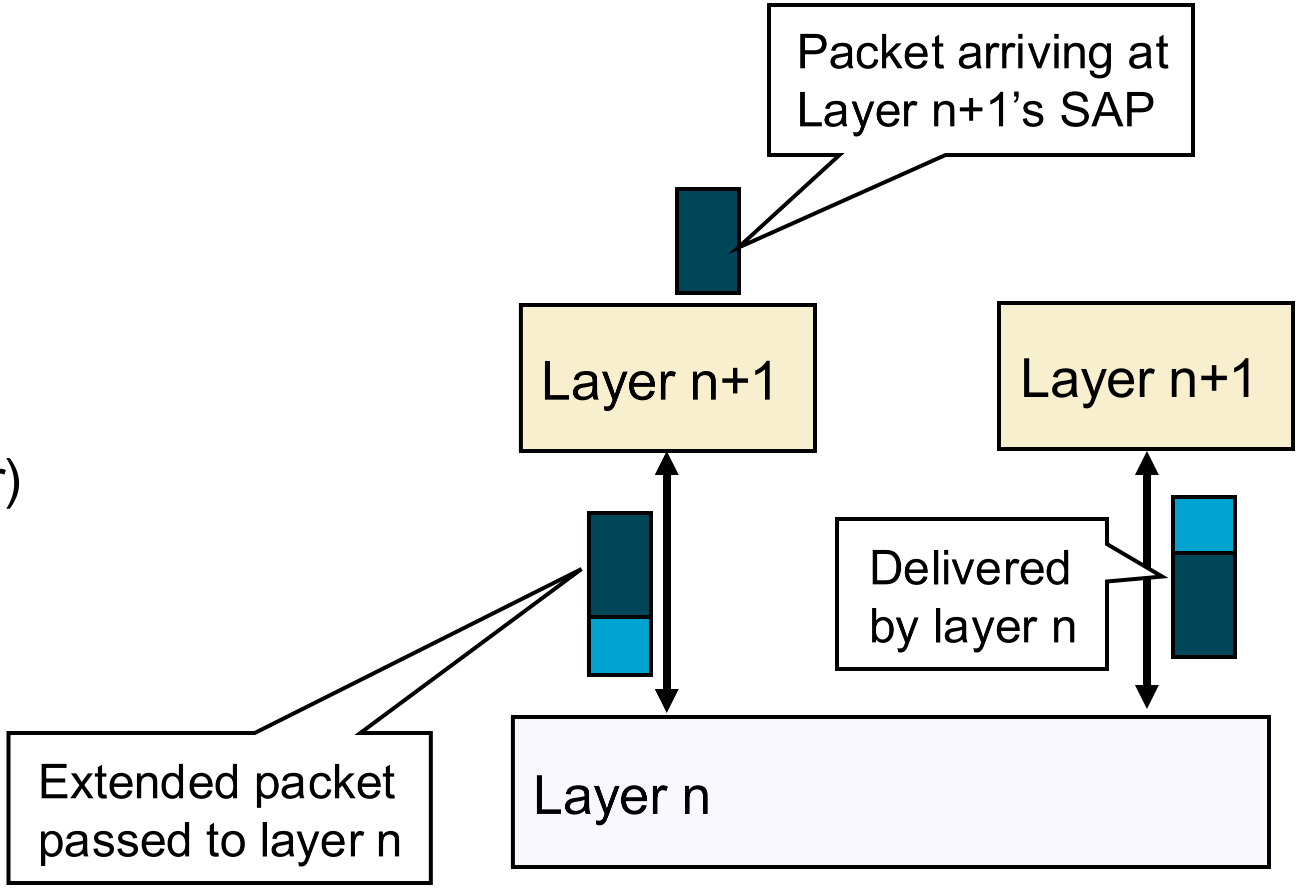


Protocols and Messages

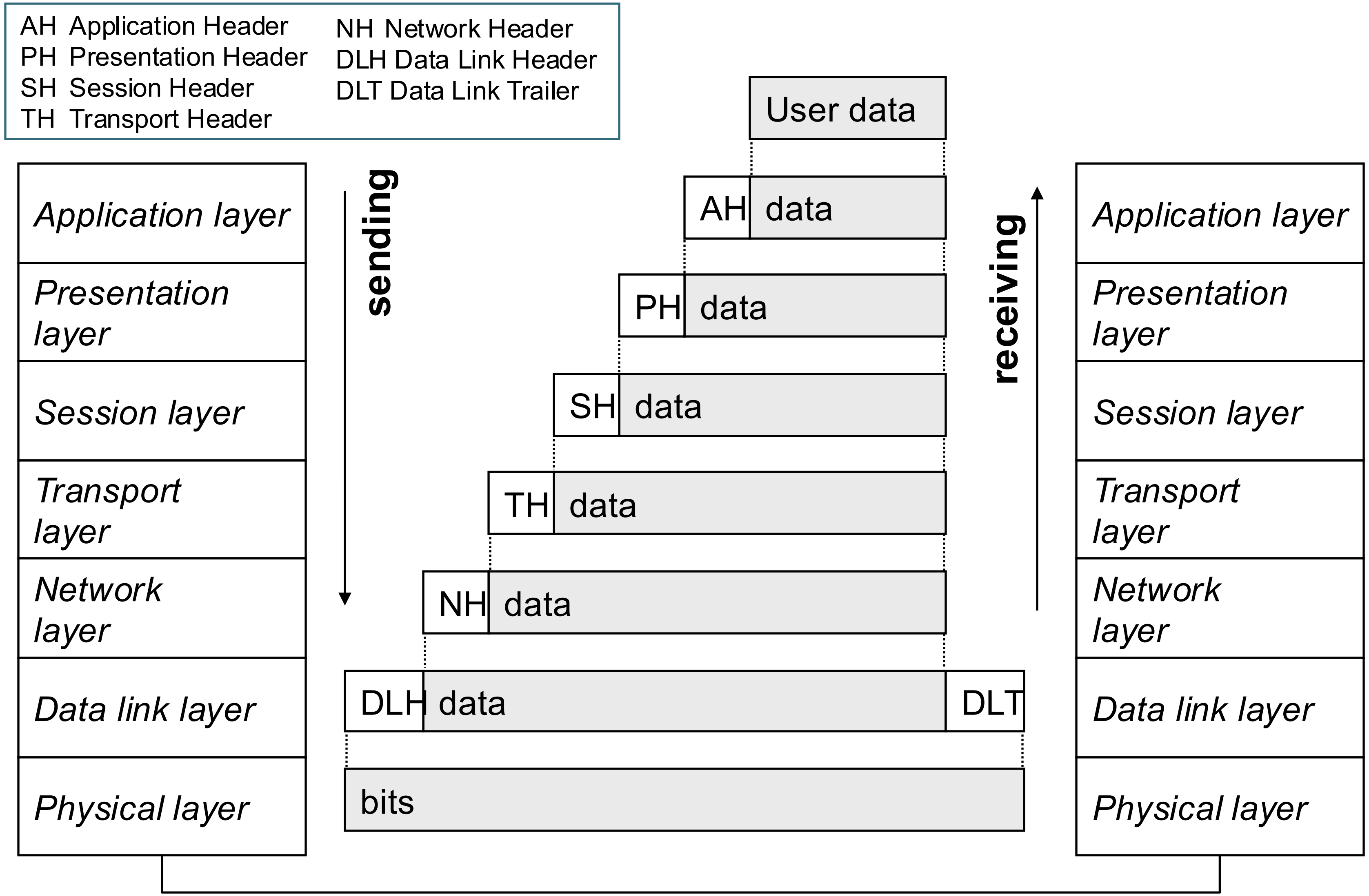
When using lower-layer services to communicate with remote peer, administrative data is usually included in those messages

Typical example:

- Protocol receivers data from higher layer
- Adds own administrative data (header/trailer)
- Passes the extended message down to the lower layer
- Receiver will receive original message plus administrative data



Encapsulation of Data



Roadmap

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