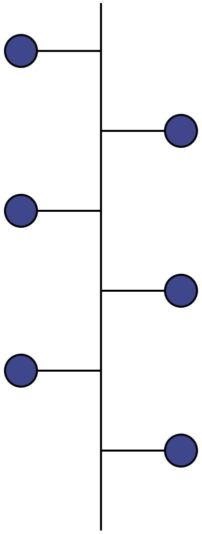
Introduction to Communication Networks and Distributed Systems



Unit 2: Reference Models and Inter Process Communications

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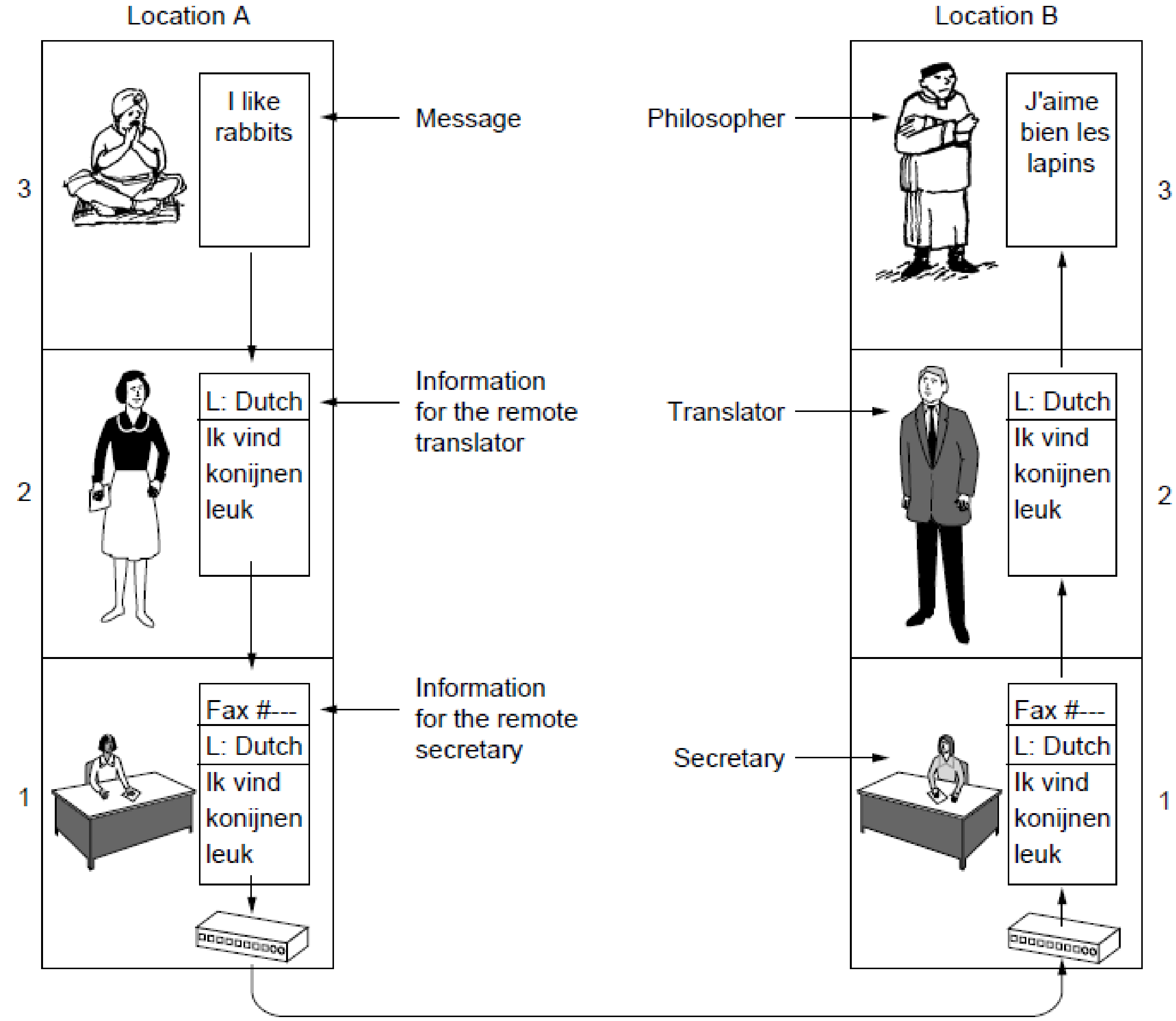
TKN Telecommunication Networks Group

Networking…The reality is even more complex…

Philosophers

Assistants

Office clarks



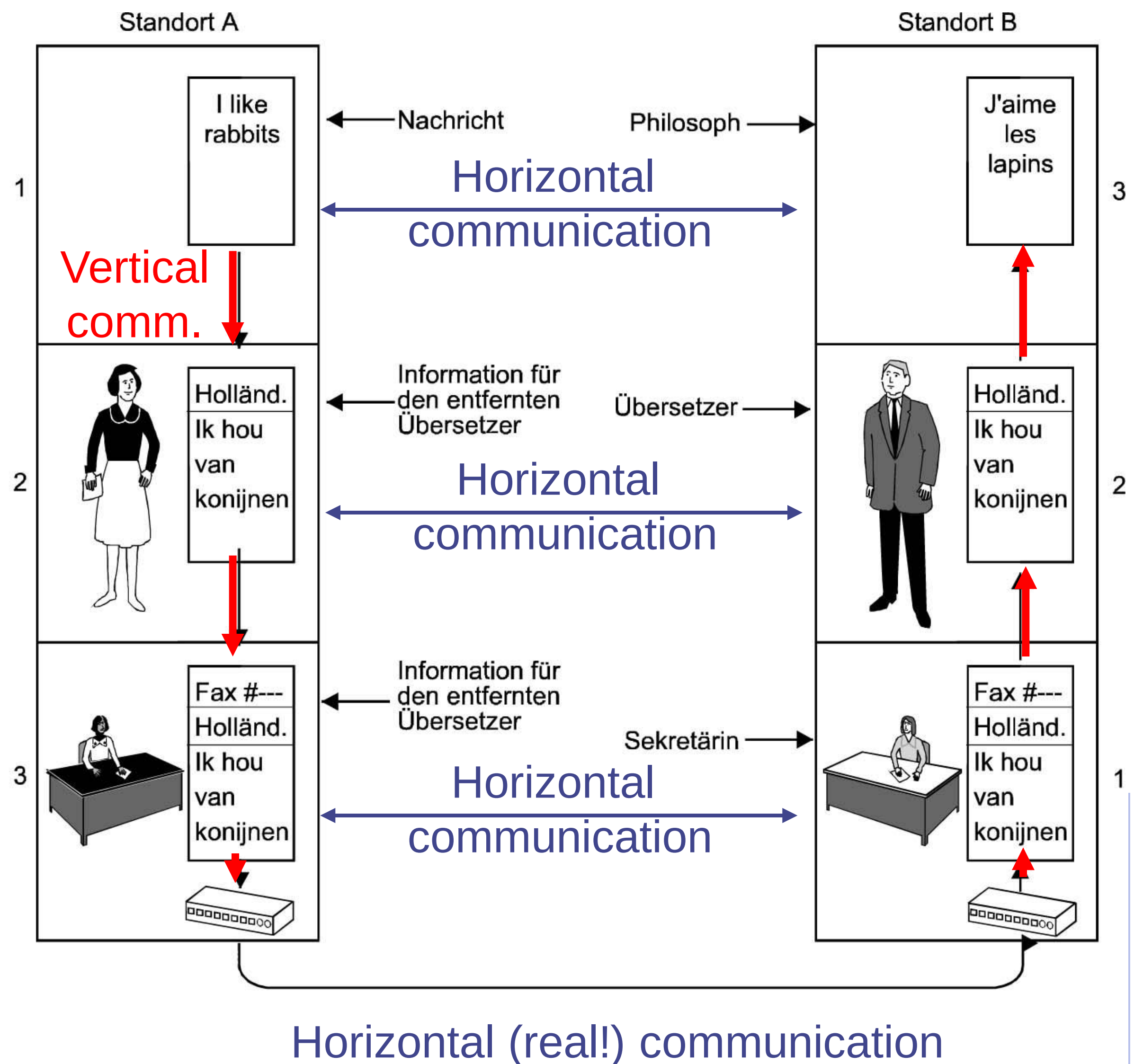
Computer Networks, Fifth Edition by Andrew Tanenbaum and David Wetherall, © Pearson Education-Prentice Hall, 2011

The reference model

- To keep complexity of communication systems tractable:
  - division in subsystems with clearly assigned responsibilities – layering
- Each layer offers a particular service
  - more abstract and more powerful the higher up in the layering hierarchy
- To provide a service, a layer has to be distributed over remote devices
- Remote parts of a layer use a protocol to cooperate
  - Make use of service of the underlying layer to exchange data
  - Protocol is a horizontal relationship, service a vertical relationship
- Layers/protocols are arranged as a (protocol) stack
  - One atop the other, only using services from directly beneath
  - ⇒Strict layering

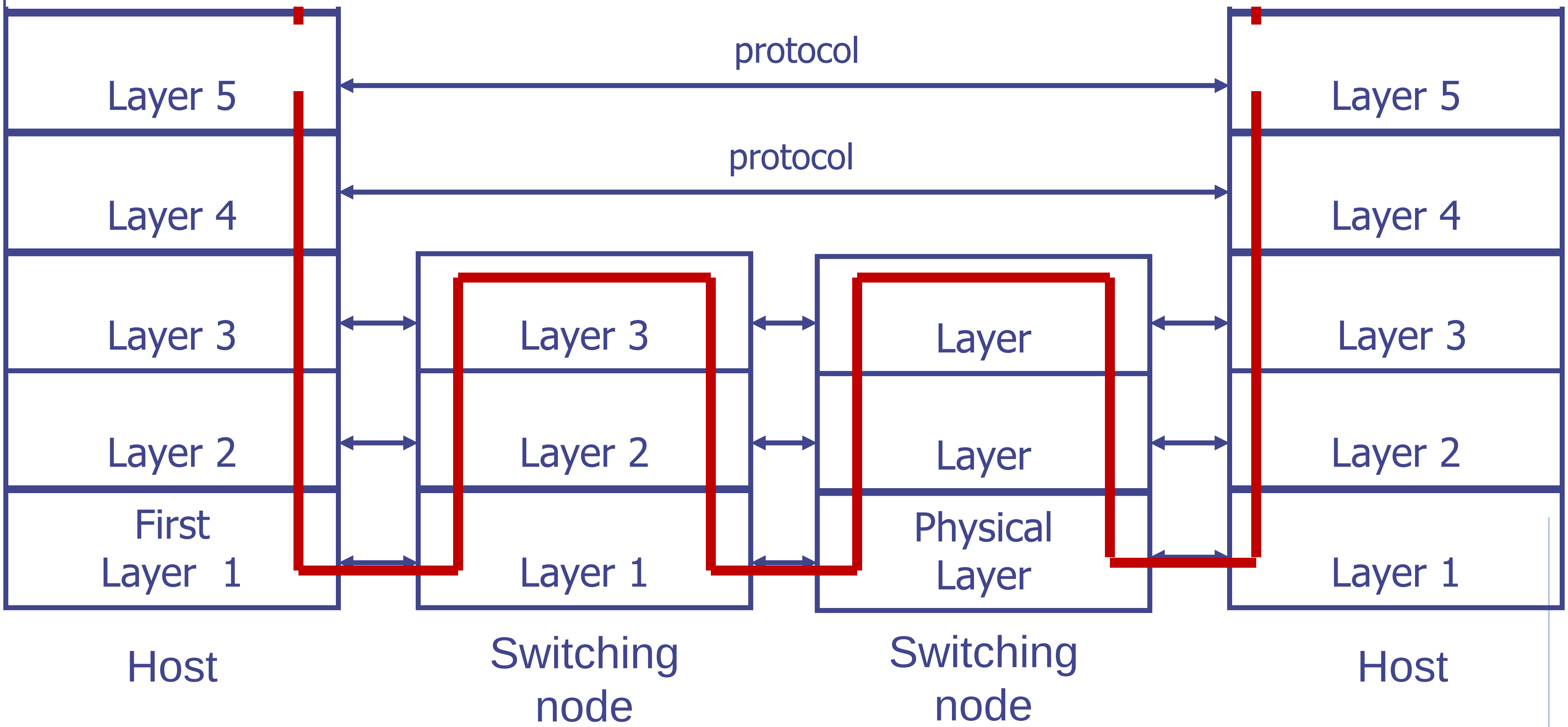
Analogy: Nested layers as nested translations

- Vertical vs. horizontal communication
  - Vertical: always real
  - Horizontal: may be real or virtual



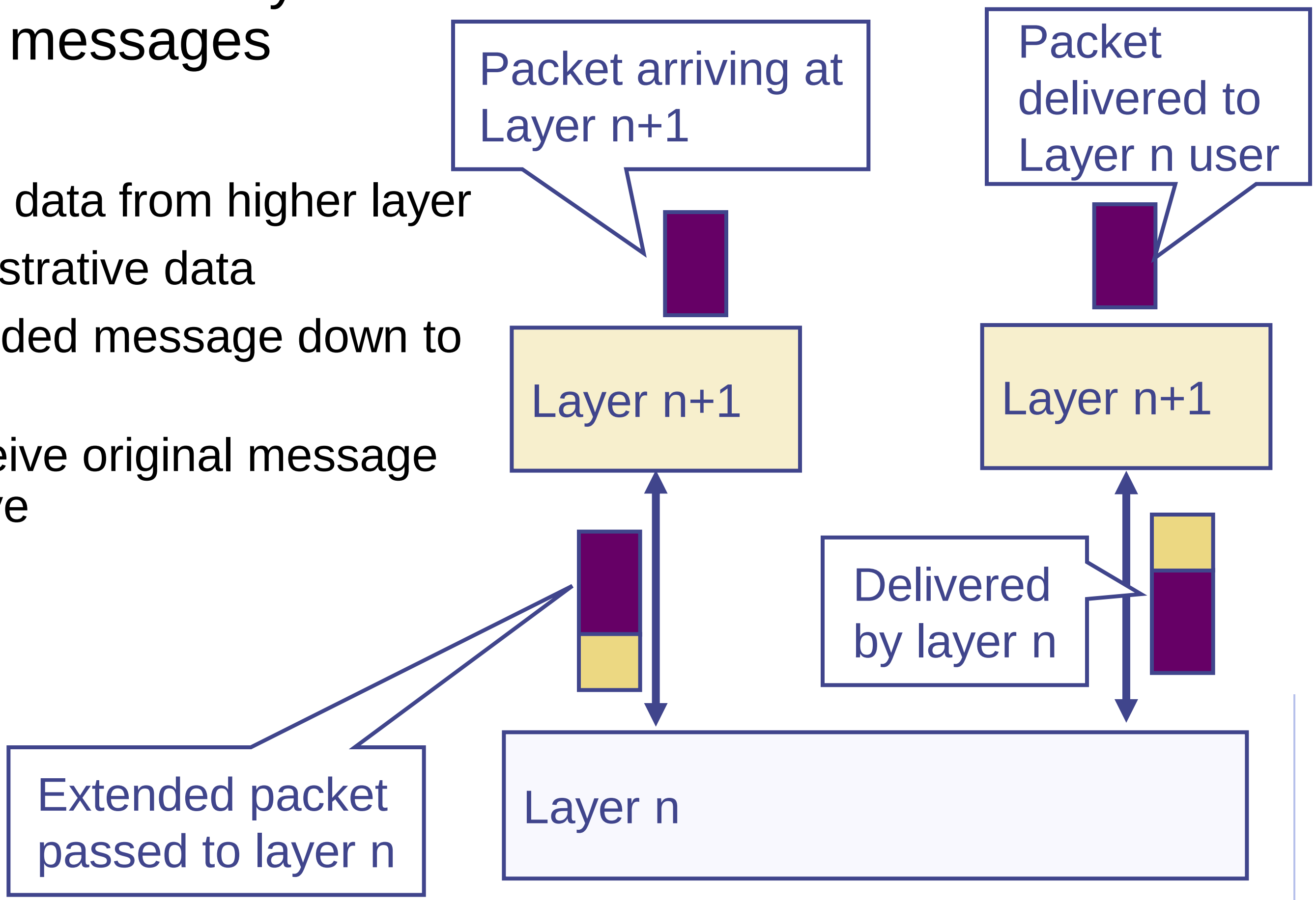
Multi-layer Architecture

- Number of Layers, and
  { services, naming and addressing conventions } / Layer
- Functions to be executed in each layer
- Protocols: (host-to-host, node-to-node, host-to-node)



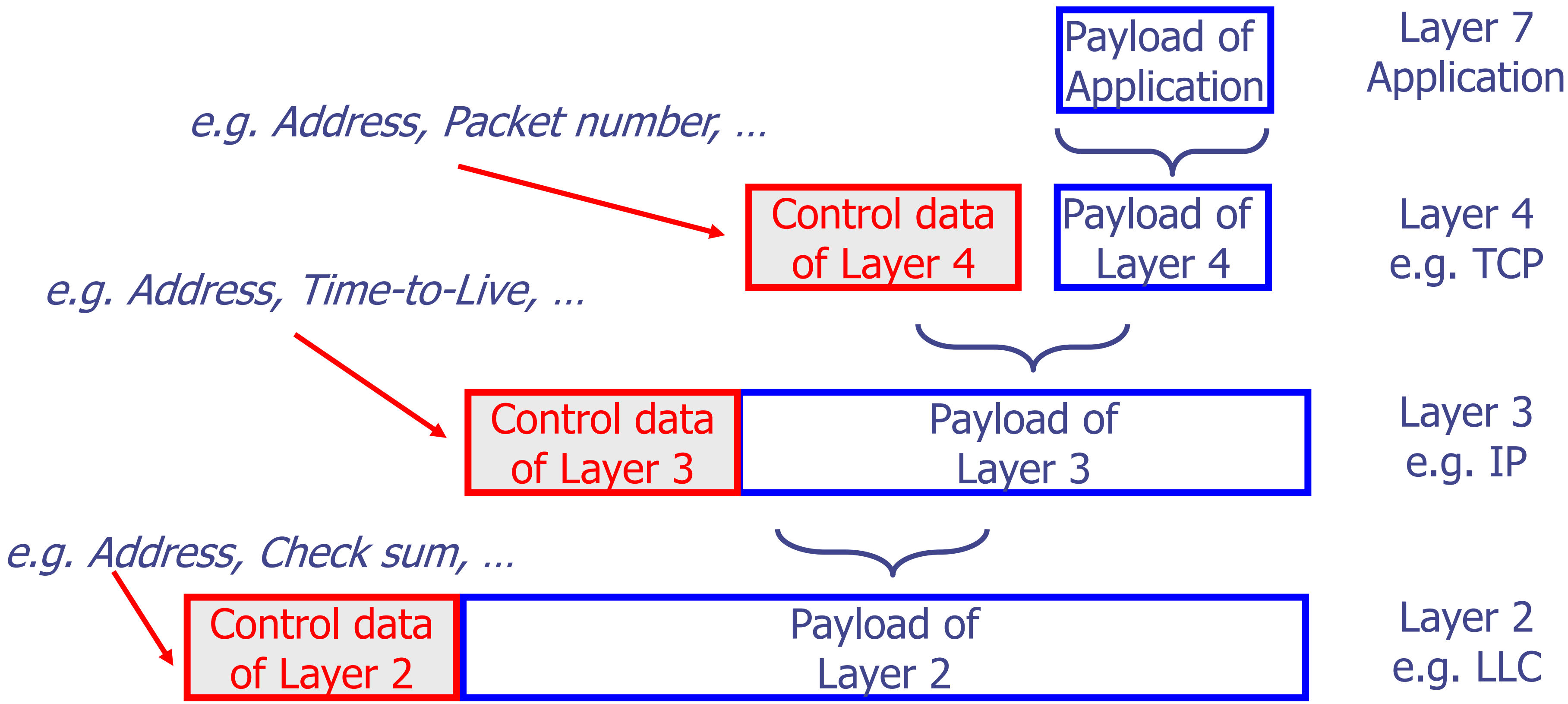
Protocols and messages

- When using lower-layer services to communicate with the remote peer, administrative data is usually included in those messages
- Typical example
  - Protocol receives data from higher layer
  - Adds own administrative data
  - Passes the extended message down to the lower layer
  - Receiver will receive original message plus administrative data
- Encapsulating
  - Header or trailer



Embedding messages

- Messages from upper layers are used as payload for messages in lower layers



How to structure functions/layers?

- Many functions have to be realized
- Not each function Is necessery in each Layer..
- How to actually assign them into layers to obtain a real, working communication system?
  - This is the role of a specific reference model
- Two main reference models exist
  - ISO/OSI reference model (International Standards Organization Open Systems Interconnection)
  - TCP/IP reference model (by IETF – Internet Engineering Taskforce)

Standardization

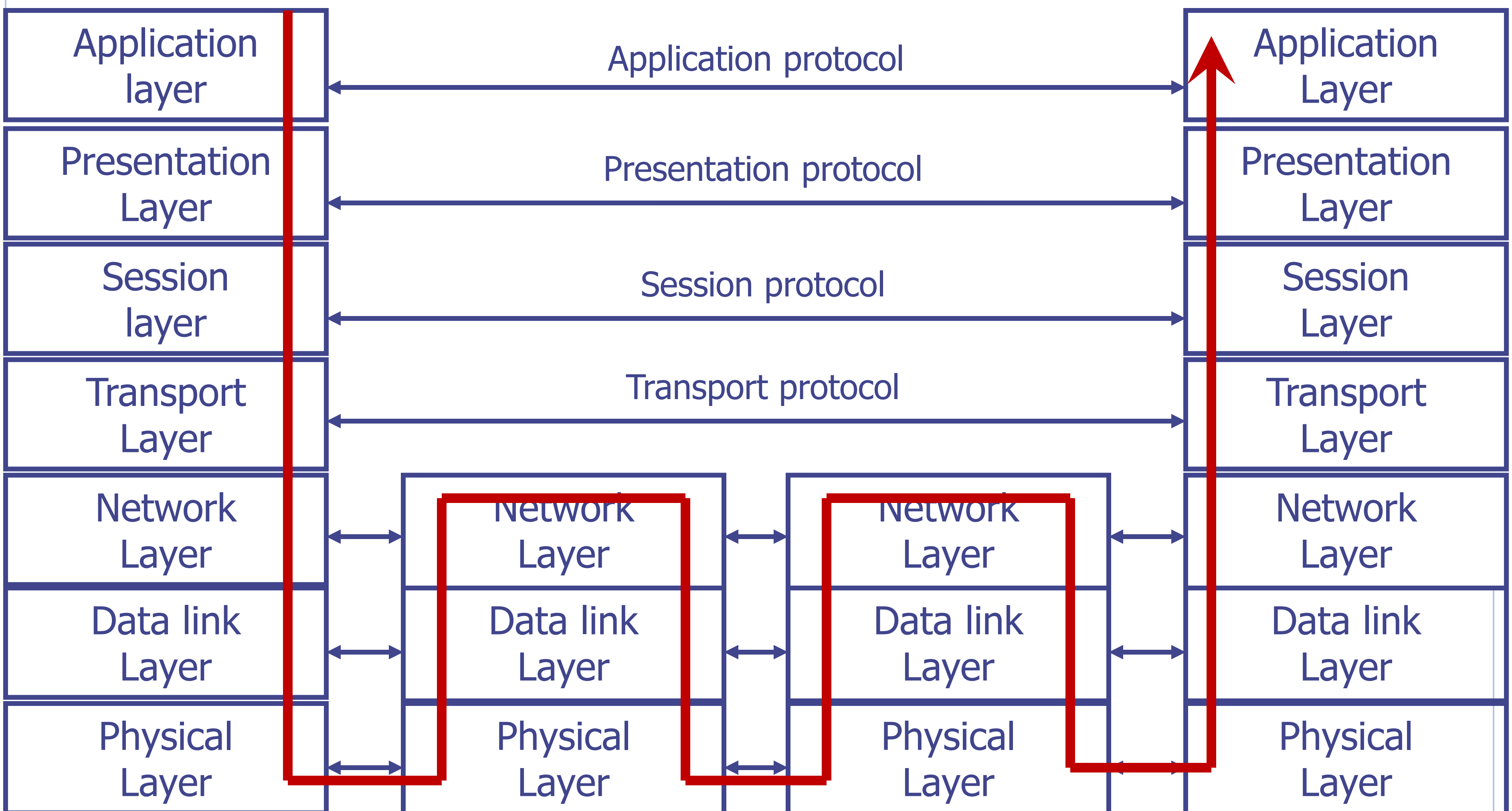
- To build large networks, standardization is necessary
- Traditional organization
  - **ISO**- Int. Standardization Organization , **ITU** - (Int. Telecomm. Union)
  - world-wide, group national bodies, relatively slow “time to market”
- Internet
  - Mostly centered around the **Internet Engineering Task Force (IETF)** with associated bodies (Internet Architectural Board, Internet Research Task Force, Internet Engineering Steering Group)
  - Consensus oriented, focus on working implementations
  - Hope is quick time to market, but has slowed down considerably in recent years
- **IEEE Committee 802** – driving the Link Layer!
- **Manufacturer bodies** – defining de-facto standards and profiles for the IEEE/INTERNET/ …

ISO/OSI reference model

- Basic design principles
  - One layer per abstraction of the “set of duties”
  - Choose layer boundaries such that information flow across the boundary is minimized (minimize inter-layer interaction)
  - Enough layers to keep separate things separate, few enough to keep architecture manageable

- Result: 7-layer model
  - Not strictly speaking an architecture, because
  - Precise interfaces are not specified (nor protocol details !)
  - Only general duties of each layer are defined

ISO/OSI model

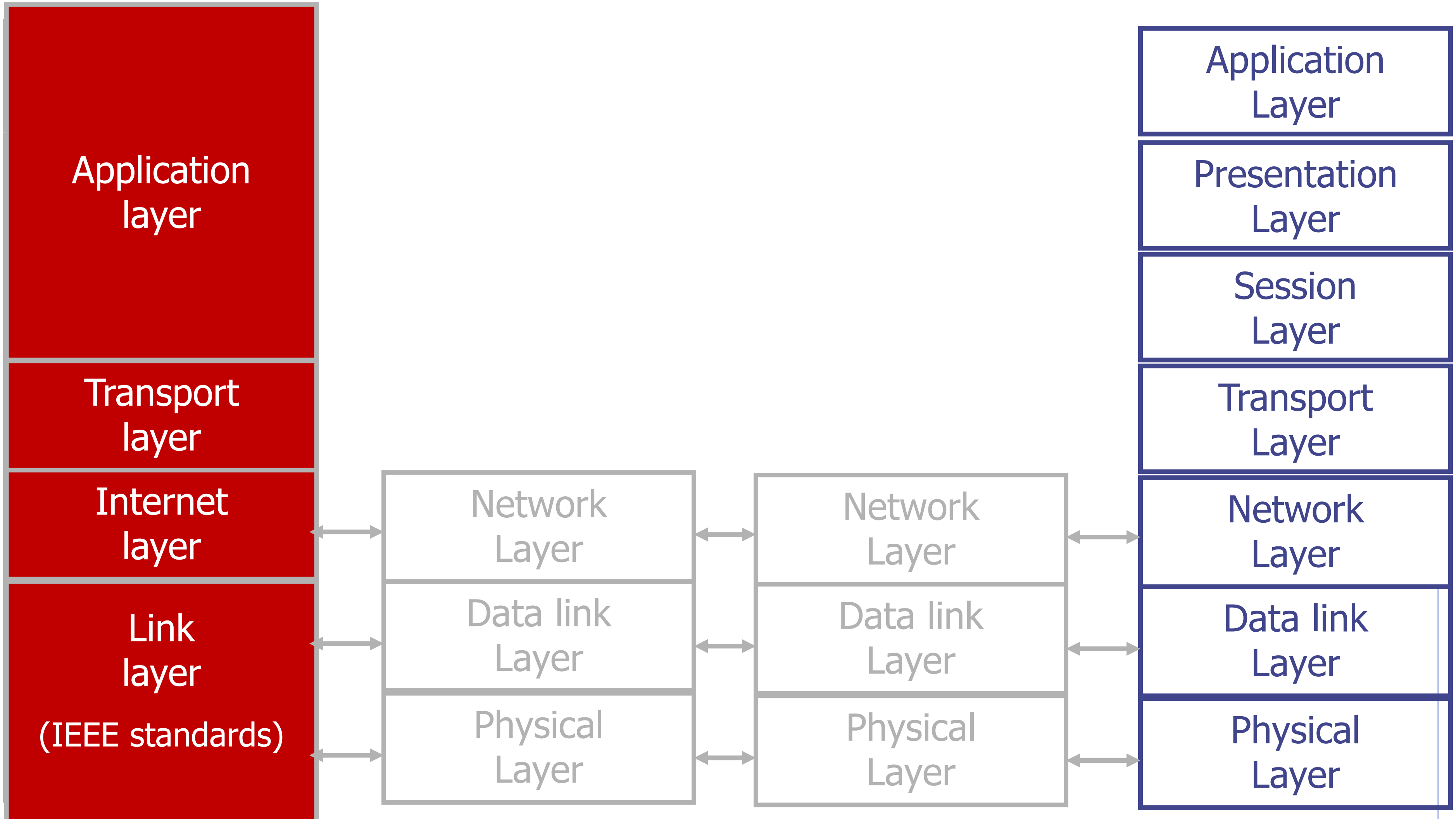


7 layers in brief

- Physical layer: Transmit raw bits over a physical medium
- Data Link layer: Provide a (more or less) error-free transmission service for data frames - also over a shared medium!
- Network layer: Solve the forwarding and routing problem for a network- bring data to a **desired host**
- **Transport layer**: Provide (possibly reliable, in order) end-to-end communication, overload protection, fragmentation to **processes**

  "Bringing data from process A to B with sufficient quality"
- Session layer: Group communication into sessions which can be synchronized, checkpointed, …
- Presentation layer: Ensure that syntax and semantic of data is uniform between all types of terminals
- Application layer: Actual application, e.g., protocols to transport Web pages

Internet Model model (in red) vs. ISO/ OSI



Some example protocols

- A communication architectures needs standard protocols in addition to a layering structure
- And: some generic rules & principles which are not really a protocol but needed nonetheless
  - Example principle: end-to-end
  - Example rule: Naming & addressing scheme
- Popular protocols of the 5-layer reference model
  - Data link layer: Ethernet & CSMA/CD
  - Network layer: Internet Protocol (IP)
  - Transport layer: Transmission Control Protocol (TCP)

Internet reference model

- Historically based on ARPANET, evolving to the Internet
  - Started out as little university networks, which had to be interconnected
- Some generic rules & principles
  - Internet connects **networks**
    - Minimum functionality assumed (just unreliable packet delivery!)
    - Internet layer (IP): packet switching, addressing, routing & forwarding

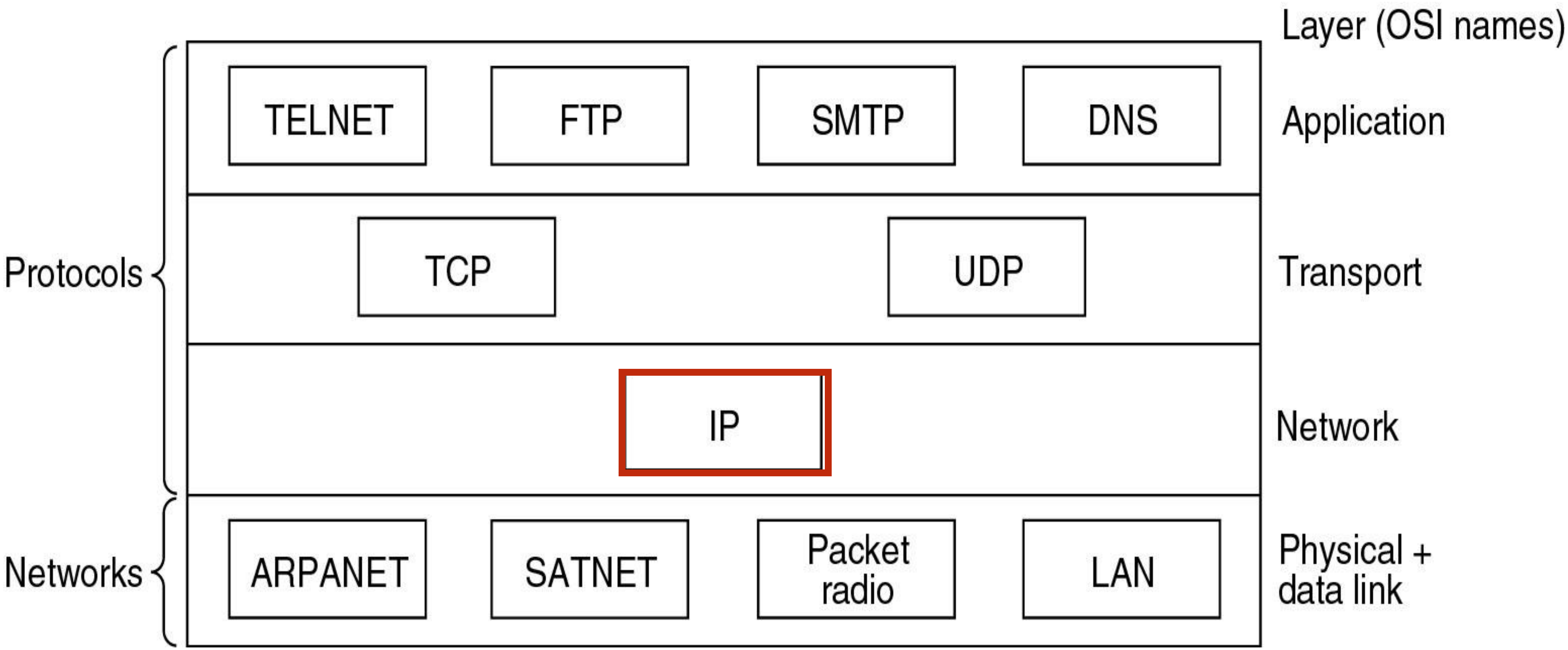
    ➔ ***Internet over everything***
  - End-to-end
    - Any functionality should be pushed to the instance needing it!
  - Fate sharing
- In effect only two layers really defined… Internet and Transport Layer - Lower and higher layers not really defined

  ➔ *Anything over internet*
- New Applications do NOT need any changes in the NETWORK!
  - Compare with the telephone network!!!

The Internet Suite of Protocols

- Over time, suite of protocols evolved around core TCP/IP protocols

  ➔ *Internet Protocol Suite is also refereed to as TCP/IP Protocol Suite*



So-called "**hourglass model**": Thin waist of the protocol stack at IP, above the technological layers

Naming & addressing in the Internet Stack

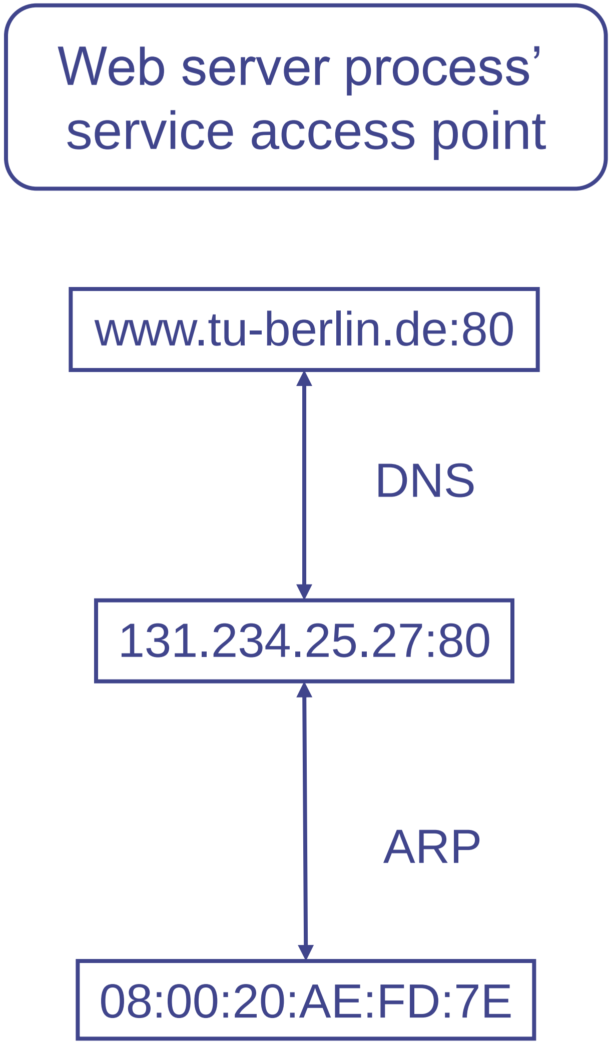
- Names: Data to identify an entity exist on different levels
  - Alphanumerical names for machines: www.tu-berlin.de

- Address: Data how/where to find an entity
  - Address of a network device in an IP network: An IP address
    - IPv4: 32 bits, structured into 4x8 bits
    - Example: 131.234.20.99 (dotted decimal notation)
  - Address of a network: Some of the initial bits of an IP address

- Address of a networked device in the LOCAL AREA (IEEE 802 standardized) network…
  - 48 bits, hexadecimal notation, example: 08:00:20:ae:fd:7e

Mapping

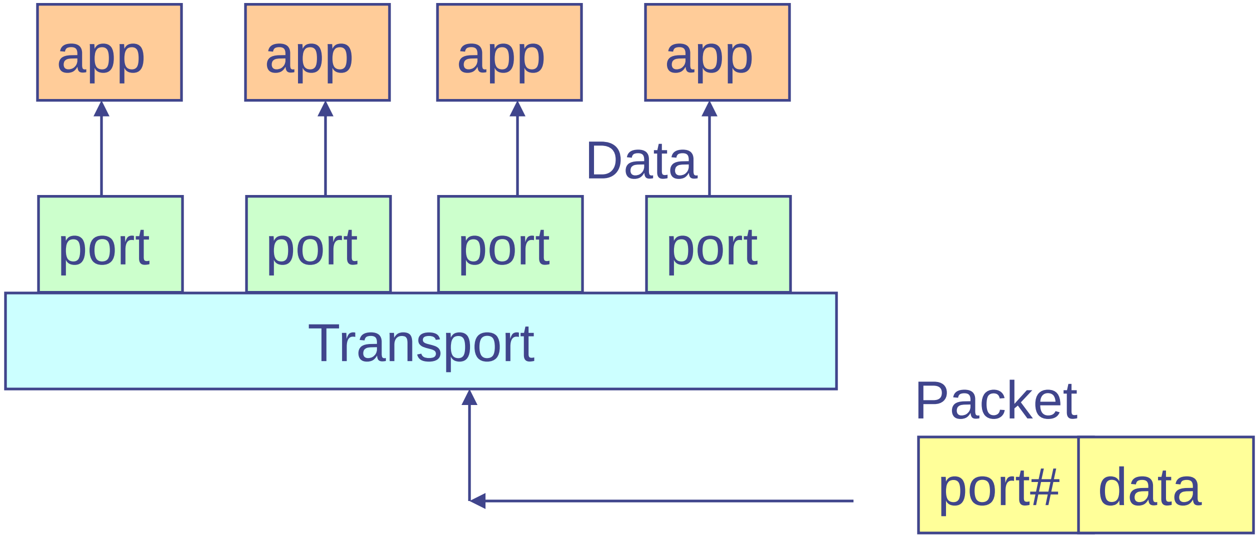
- Needed: Mapping from name to address
  - ➔ Realized by separate protocols
  - – From alphanumerical name to IP address: Domain Name System (DNS)
  - – Often also useful: Mapping from IP address to MAC name/address: Address Resolution Protocol (ARP)



Understanding Ports

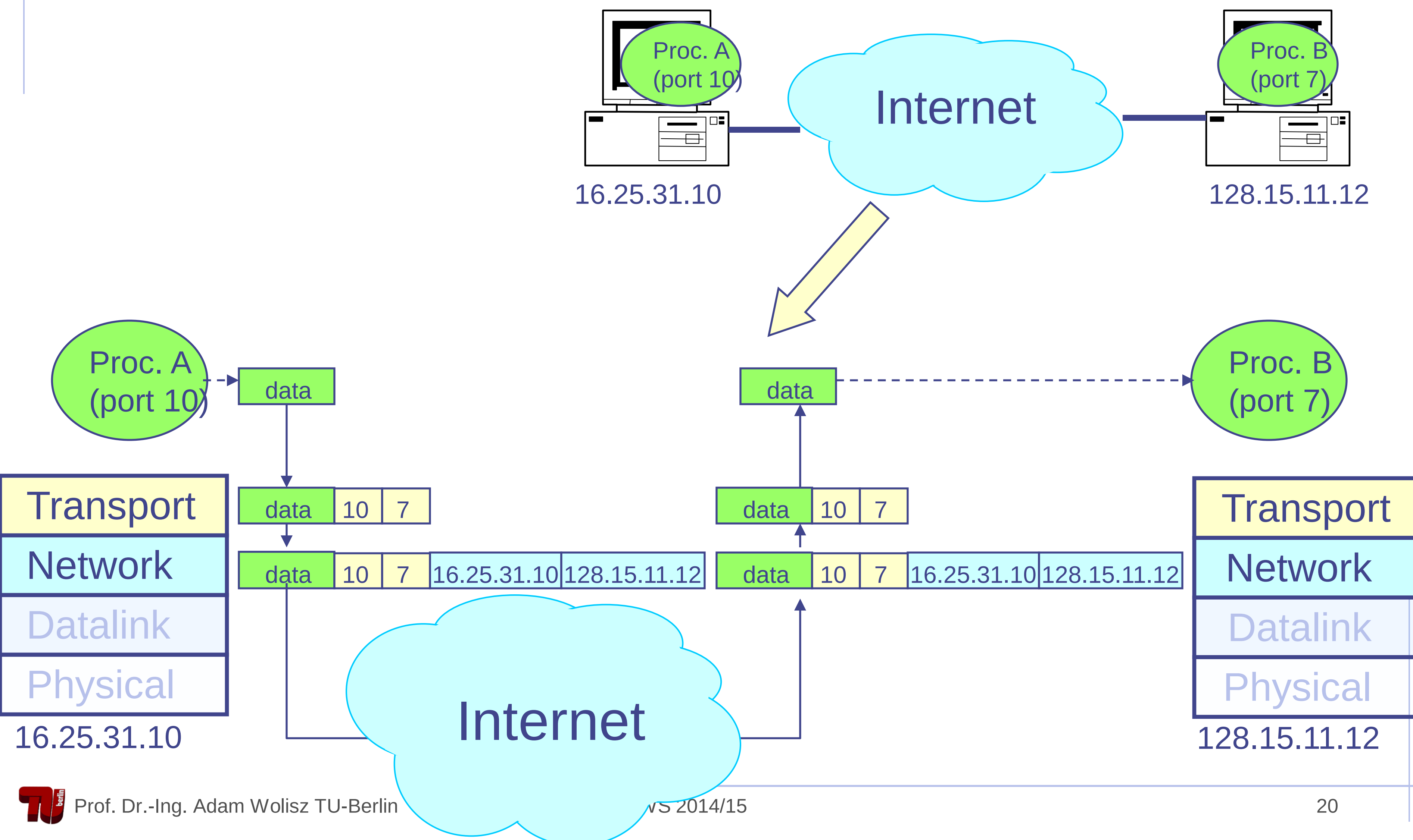
[Buya]

- Port is represented by a positive (16-bit) integer value
- Some ports have been reserved to support common/well known services: http 80/tcp; ftp 21/tcp; telnet 23/tcp; smtp 25/tcp;
- User level process/services generally use port number value >= 1024



End-to-End Layering View

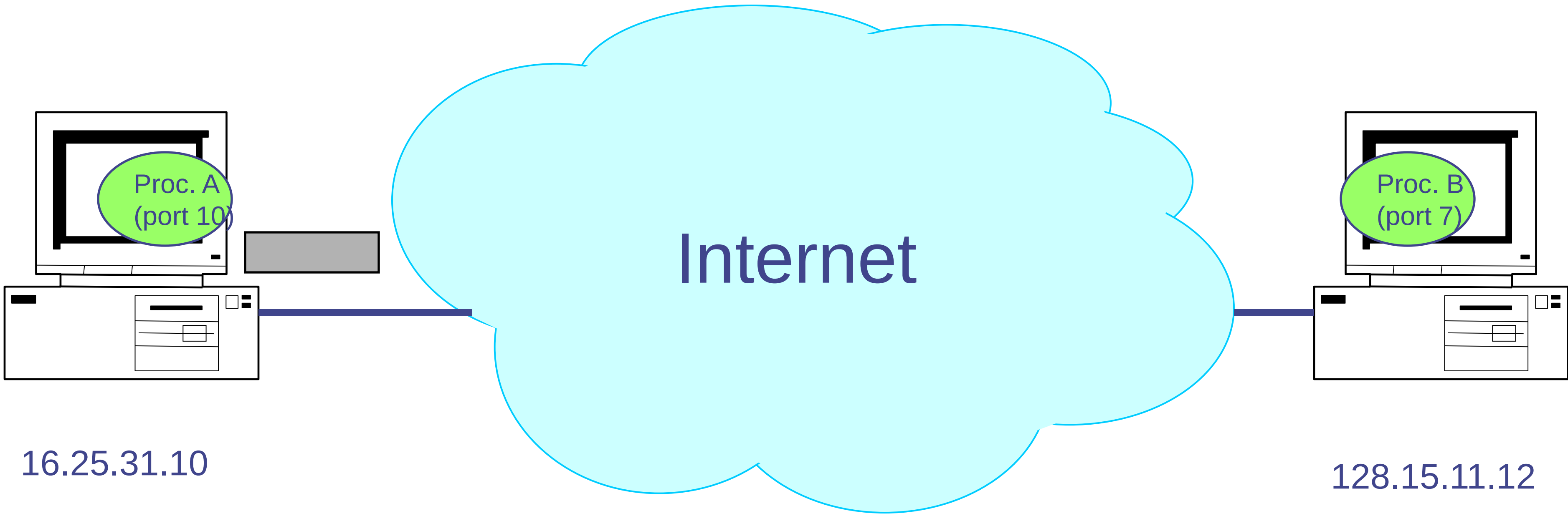
Stoica



Internet End-to-End View

[Stoica]

- Process A sends a packet to process B

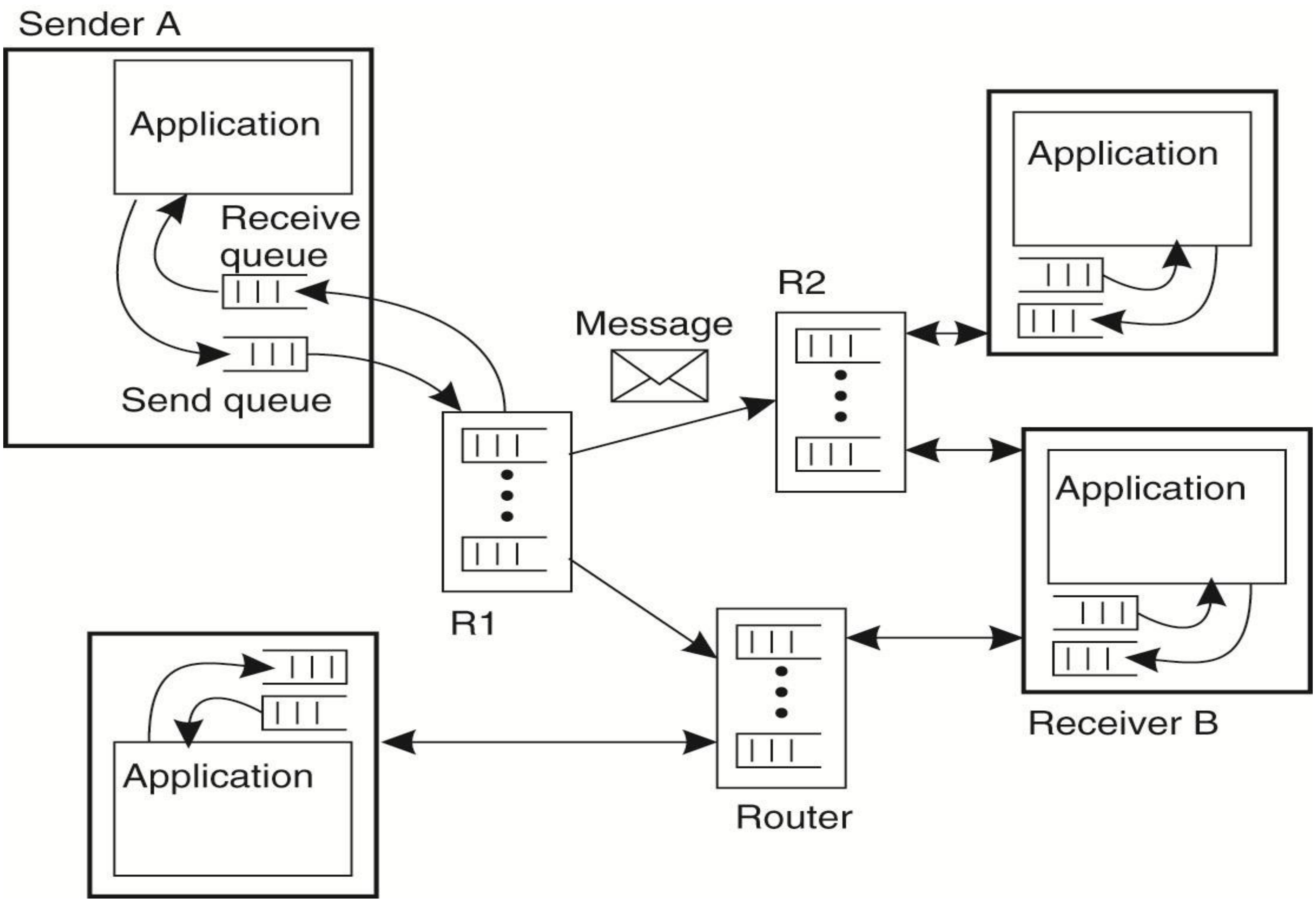


IP Address:

A four-part “number” used by *Network Layer* to route a packet from one computer to another

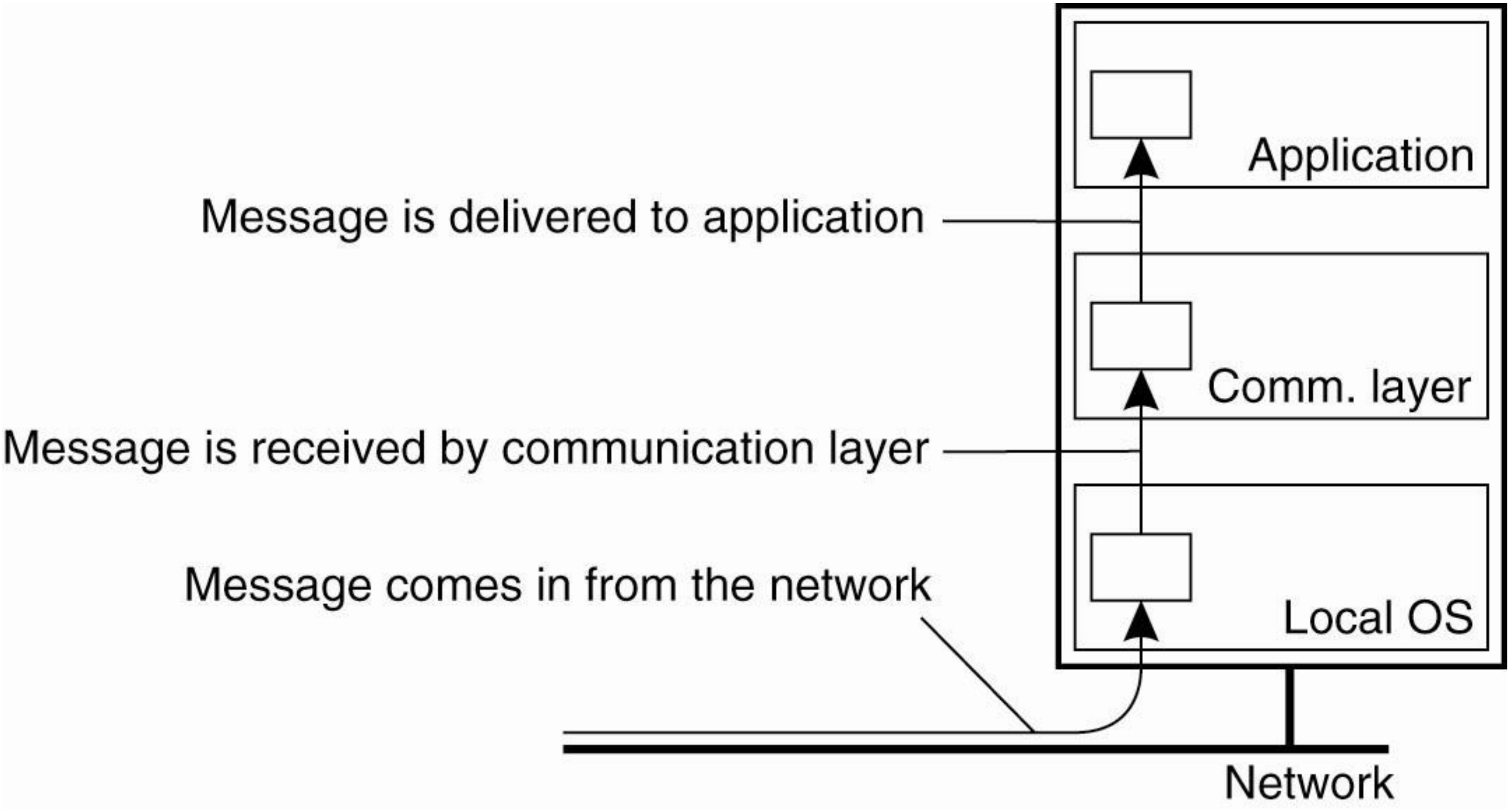
General Architecture of a Message System

[Tanenbaum]



Message Receipt vs. Message Delivery [Tanenbaum]

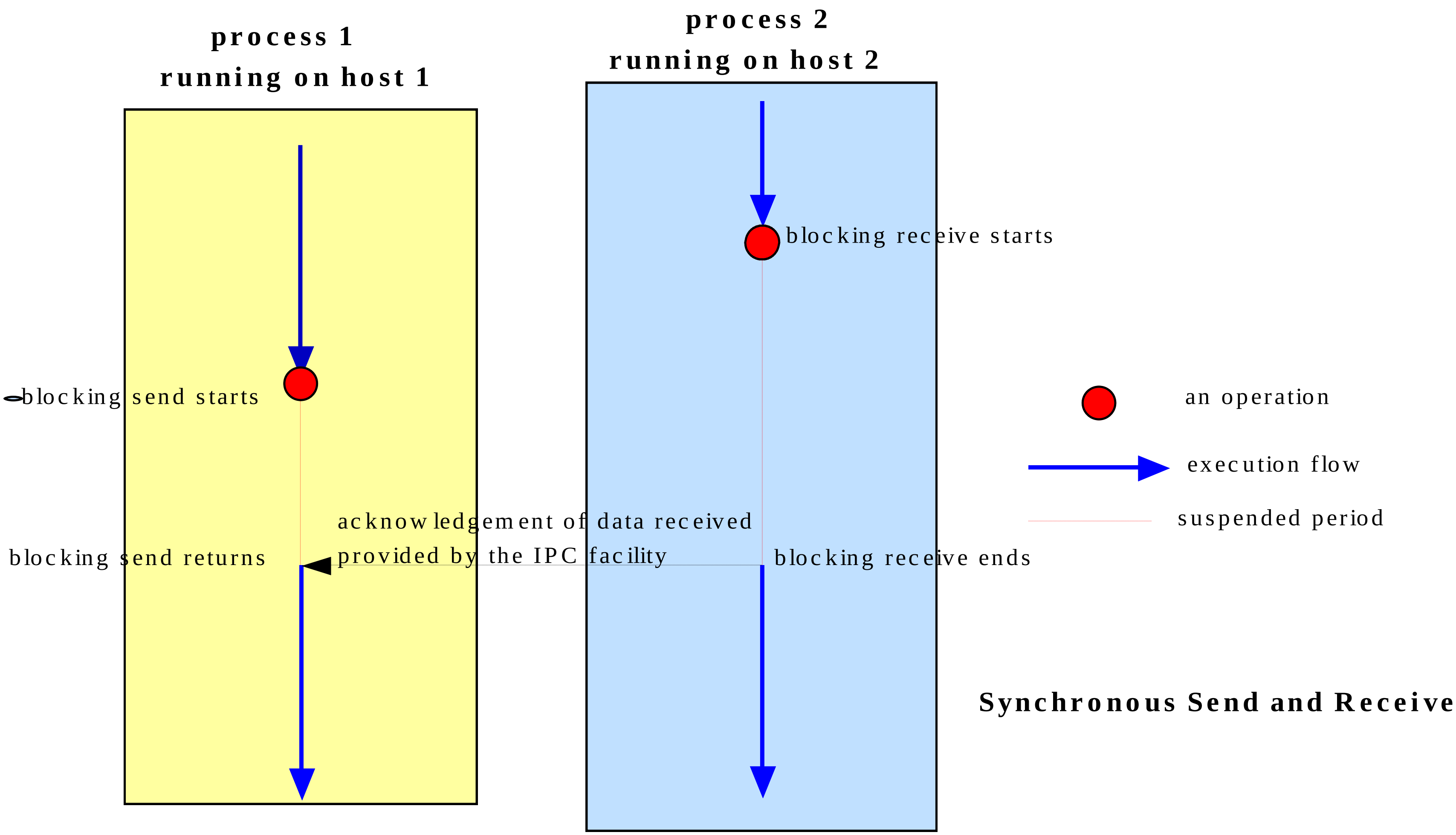
- Figure 8-12. The logical organization of a distributed system to distinguish between message receipt and message delivery.



Synchronous Interaction

- Blocking send
  - Blocks until message is transmitted
  - Blocks until message acknowledged
- Blocking receive
  - Waits for message to be received
- Known upper/lower bounds on execution speeds, message transmission delays and clock drift rates

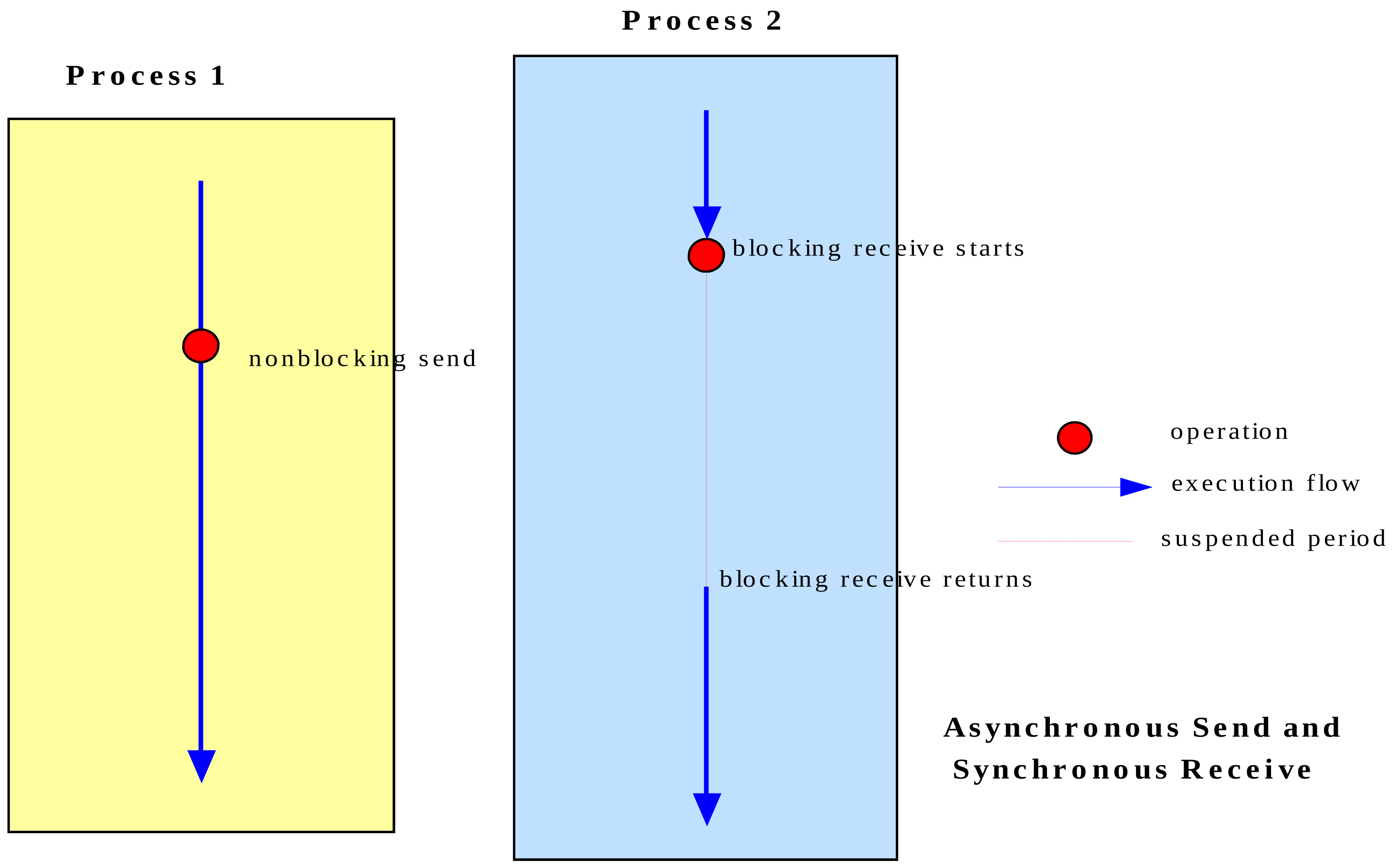
Synchronous send and receive



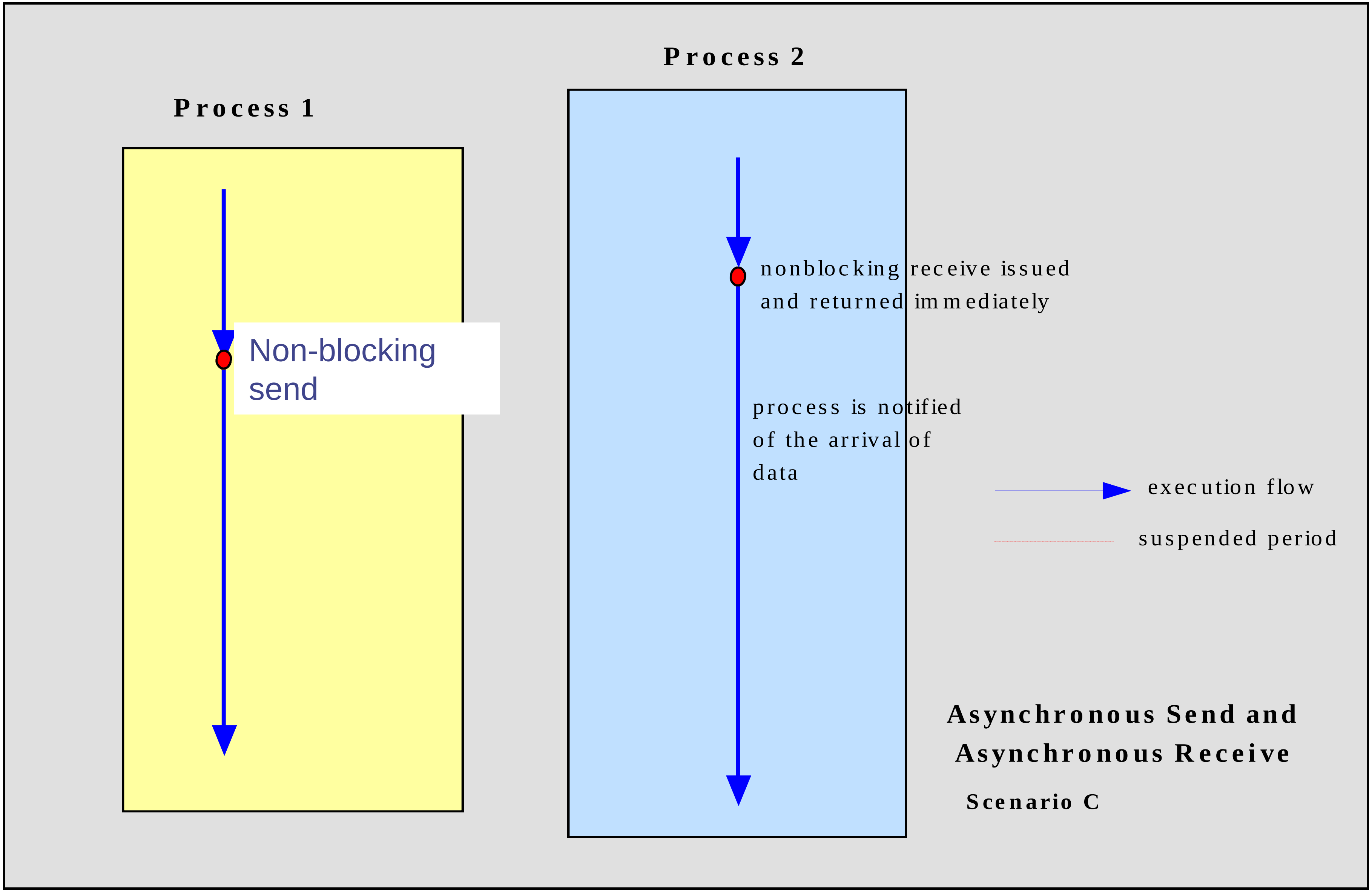
Asynchronous Interaction

- Non-blocking send: sending process continues as soon message is queued.
- Blocking or non-blocking receive:
  - Blocking:
    - Timeout.
    - Threads.
  - Non-blocking: proceeds while waiting for message.
    - Message is queued upon arrival.
    - Process needs to poll or be interrupted.
- Arbitrary processes execution speeds, message transmission delays and clock drift rates
- Some problems impossible to solve (e.g. agreement)

Asynchronous send and synchronous receive

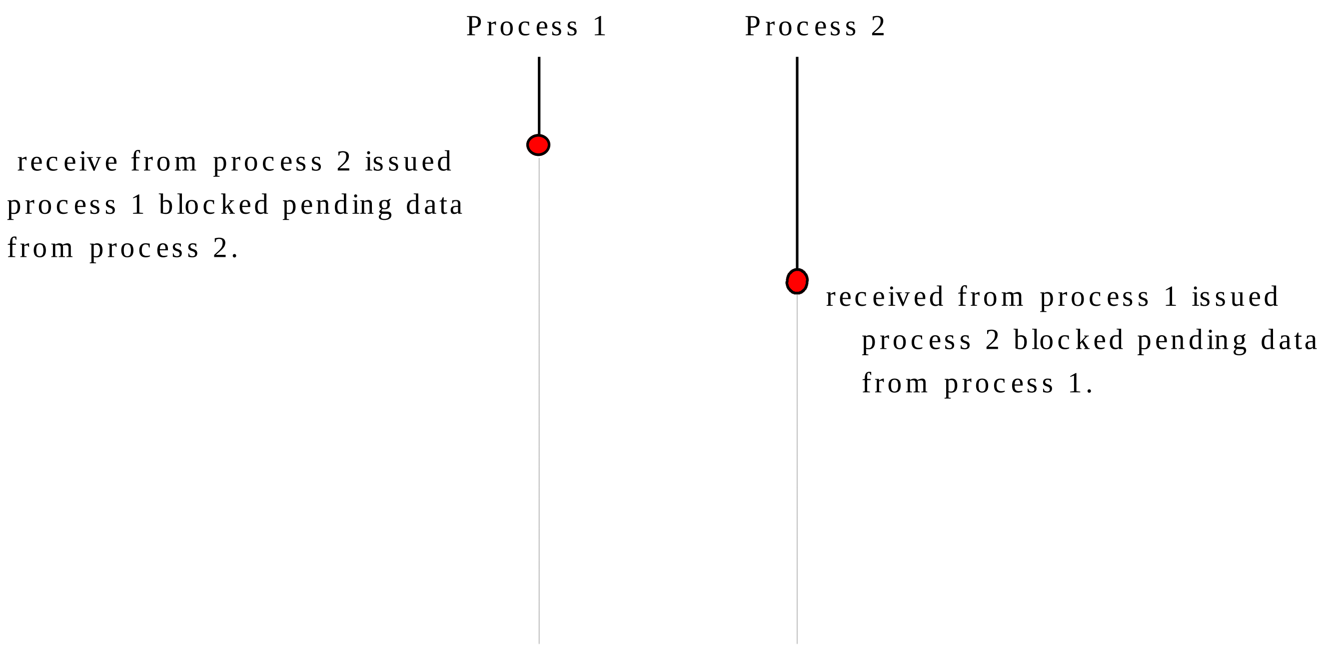


Asynchronous send and Asynchronous receive



Blocking, deadlock, and timeouts

- Blocking operations issued in the wrong sequence can cause *deadlocks*.
- Deadlocks should be avoided. Alternatively, *timeout* can be used to detect deadlocks.



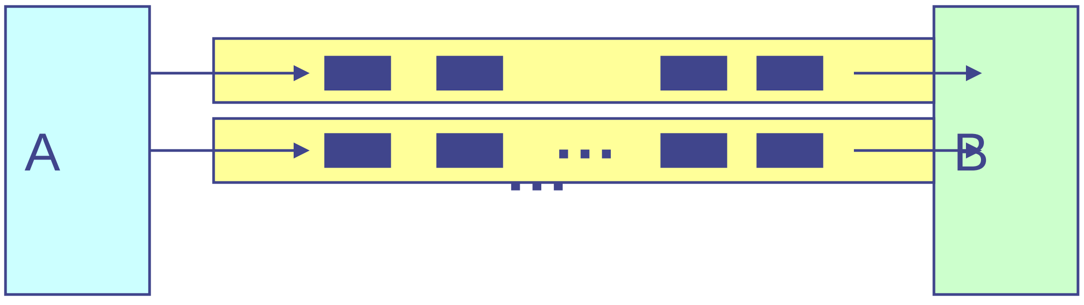
Intuitive message-passing primitives [Tanenbaum]

Primitive	Meaning
MPI_bsend	Append outgoing message to a local send buffer
MPI_send	Send a message and wait until copied to local or remote buffer
MPI_ssend	Send a message and wait until receipt starts
MPI_sendrecv	Send a message and wait for reply
MPI_isend	Pass reference to outgoing message, and continue
MPI_issend	Pass reference to outgoing message, and wait until receipt starts
MPI_recv	Receive a message; block if there is none
MPI_irecv	Check if there is an incoming message, but do not block

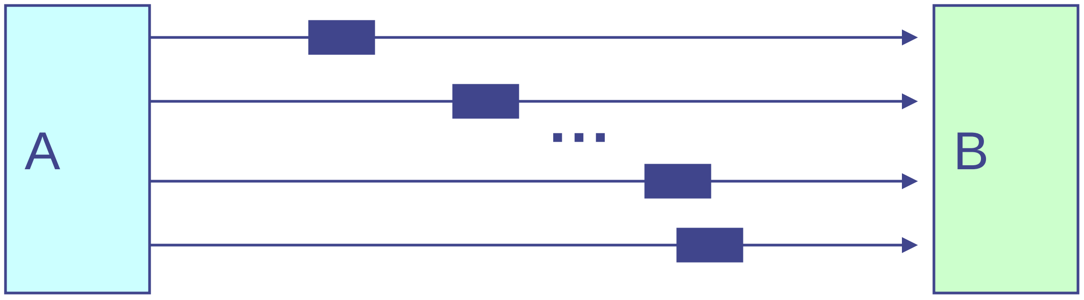
Connection-oriented vs. connection-less service

- Recall telephony vs. postal service
  - Service can require a preliminary setup phase
    ➔***connection-oriented service***
    - Three phases: connect, data exchange, release connection
    - During connect: attention of the partner assured, resources reserved….
  - Alternative: Invocation of a service primitive at any time, with all necessary information included in the invocation
    ➔***connection-less service***
    - ***Note:*** *Both are possible on top of either circuit or packet switching!*
- Connection-oriented services - primitives to handle connection
  - CONNECT – setup a connection to the communication partner
  - LISTEN – wait for incoming connection requests
  - INCOMING_CONN – indicate an incoming connection request
  - ACCEPT – accept a connection
  - DISCONNECT – terminate a connection

Two communication models [Buya]



- Connection-Oriented Communication



- Connectionless Communication

Typical examples of services

- ***Datagram service*** *(Connection –less)*
  - Unit of data are messages (limited length)
  - Correct, but not necessarily complete or in order –
  - Usually insecure/not dependable, not confirmed

    Application must provide its own reliability“

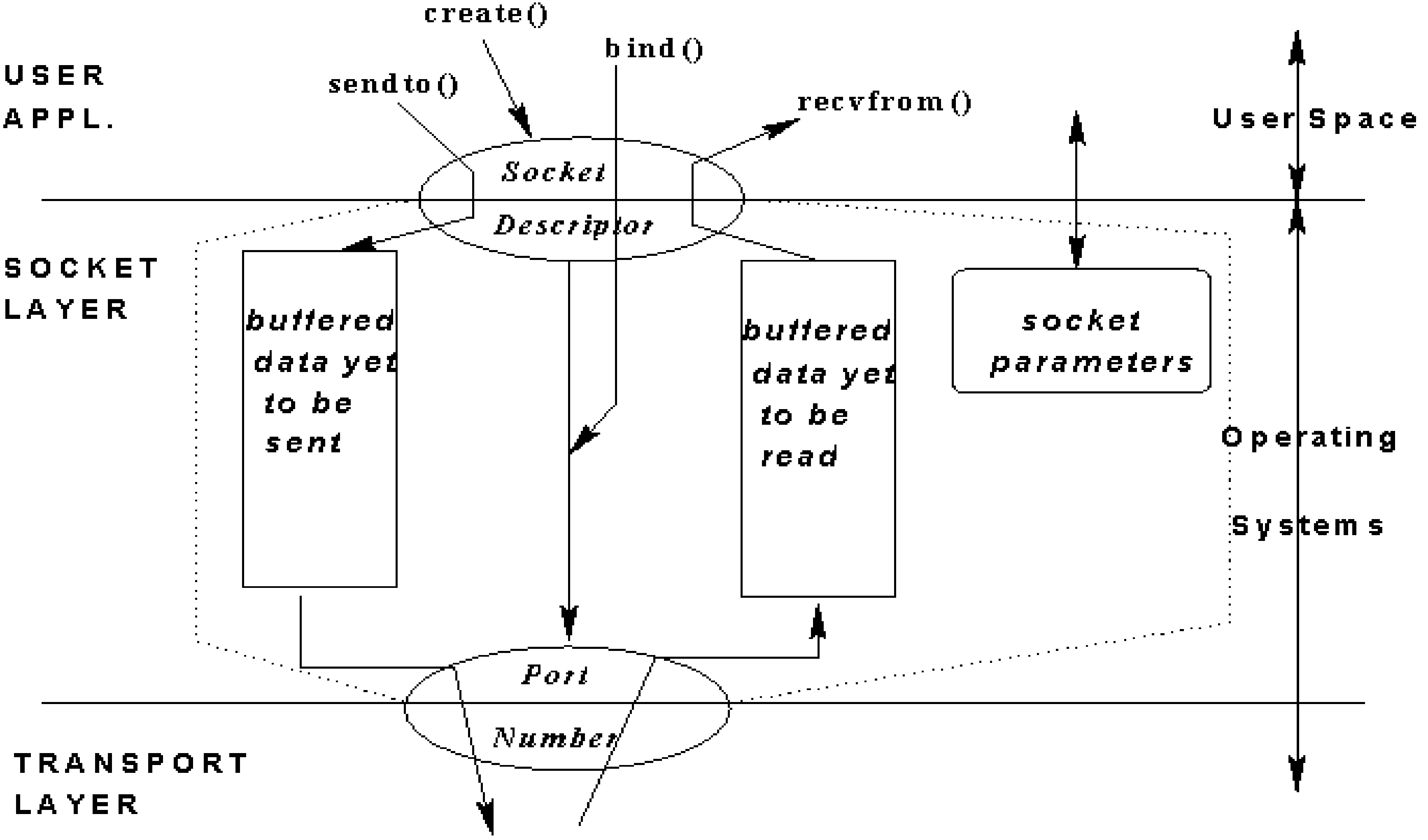
- ***Reliable byte stream*** *(connection oriented)*
  - Byte stream
  - Correct, complete, in order, confirmed - Processes have a guarantee that messages will be delivered (sender can check that!)
    - Possible to build reliability atop unreliable service .
  - Sometimes, but not always secure/dependable

Sockets: the Transport Layer API

- Sockets provide an API (Application Programming Interface) for programming networks at the transport layer.
- A socket is an endpoint of a two-way communication link between two processes located on the same machine - or located on different machines connected by a network.
- Network communication using Sockets is similar to file I/O
  - Socket handle is treated like file handle.
  - The streams used in file I/O operation are also applicable to socket-based I/O
- Socket-based communication principles are programming language independent!
- The success of this API is based on its abstraction of all possible used network protocols/underlying network topology.
  - A socket is bound to a port number so that the transport protocol can identify the application that data destined to be sent.

Socket Layer

[wonkwang]



Caution: Sockets support multiple domains!!!

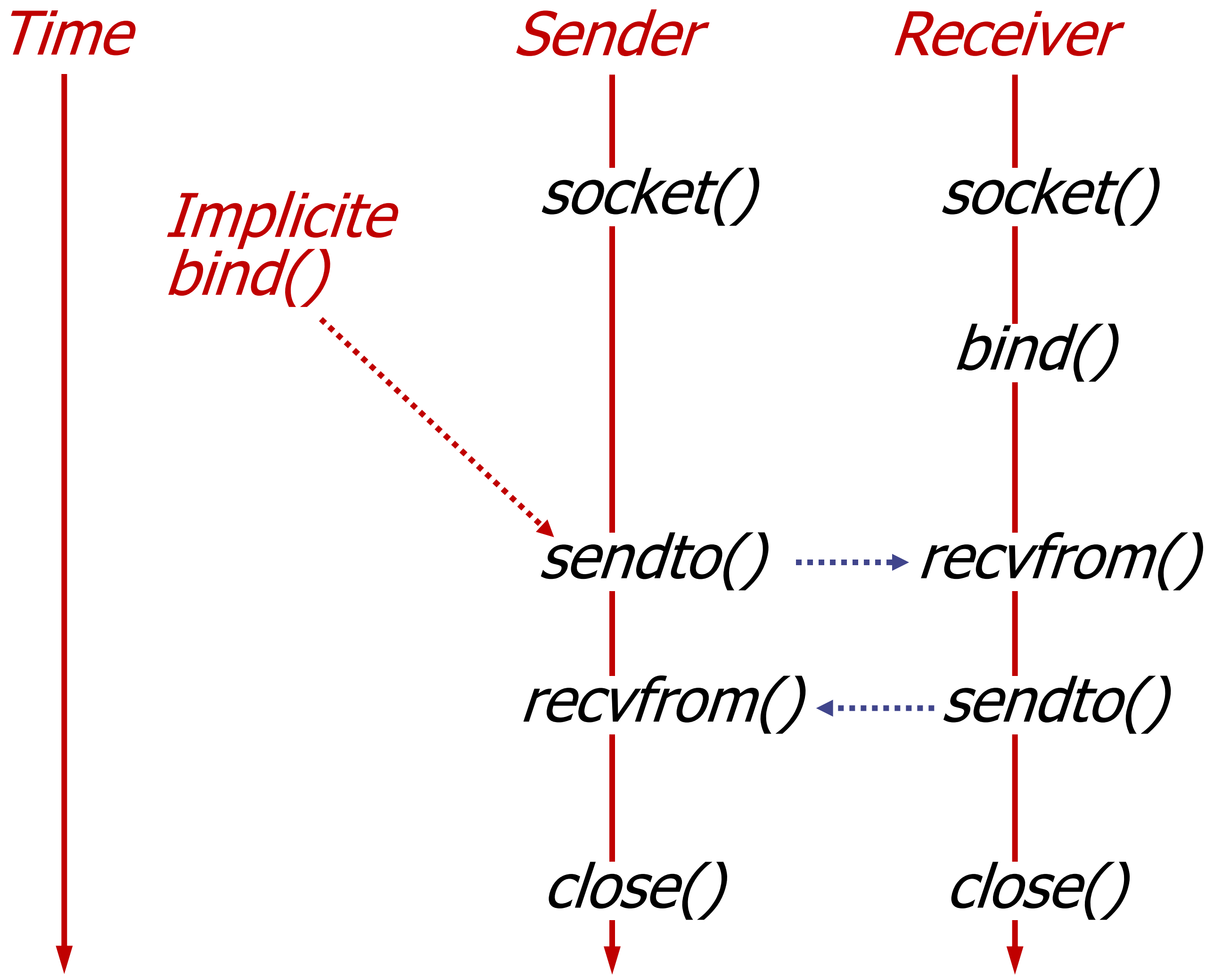
- Domain defined while socket is created!
  - int socket(int *domain*, int *type*, int *protocol*)
- *domain* is AF_UNIX, AF_INET, AF_OSI, etc.
  - AF_INET is for communication on the internet to IP addresses.
- *type* is either SOCK_STREAM (connection oriented, reliable), SOCK_DGRAM or SOCK_RAW
  - Originally more types have been envisioned
- *protocol* specifies the protocol used. It is usually 0 to say we want to use the default protocol for the chosen domain and type (note IP 4 vs. IP 6)
- While nowadays INET Domain/protocols prevail, the approach is more General.

Berkeley Sockets

Primitive	Meaning
Socket	Create a new communication end point
Bind	Attach a local address to a socket
Listen	Announce willingness to accept connections
Accept	Block caller until a connection request arrives
Connect	Actively attempt to establish a connection
Send	Send some data over the connection
Receive	Receive some data over the connection
Close	Release the connection

A VERY GOOD source of information about sockets is the Beej‘s Guide
http://beej.us/guide/bgnet/ (legally free download!)

Datagram sockets



Datagram communication over sockets

- Simplest possible service: unreliable datagrams

Sender

- `int s = socket (…);`
- **sendto** (s,
```
      buffer,
      datasize,
      0,
      to_addr,
      addr_length);
```
- `to_addr` and `addr_length` specify the destination

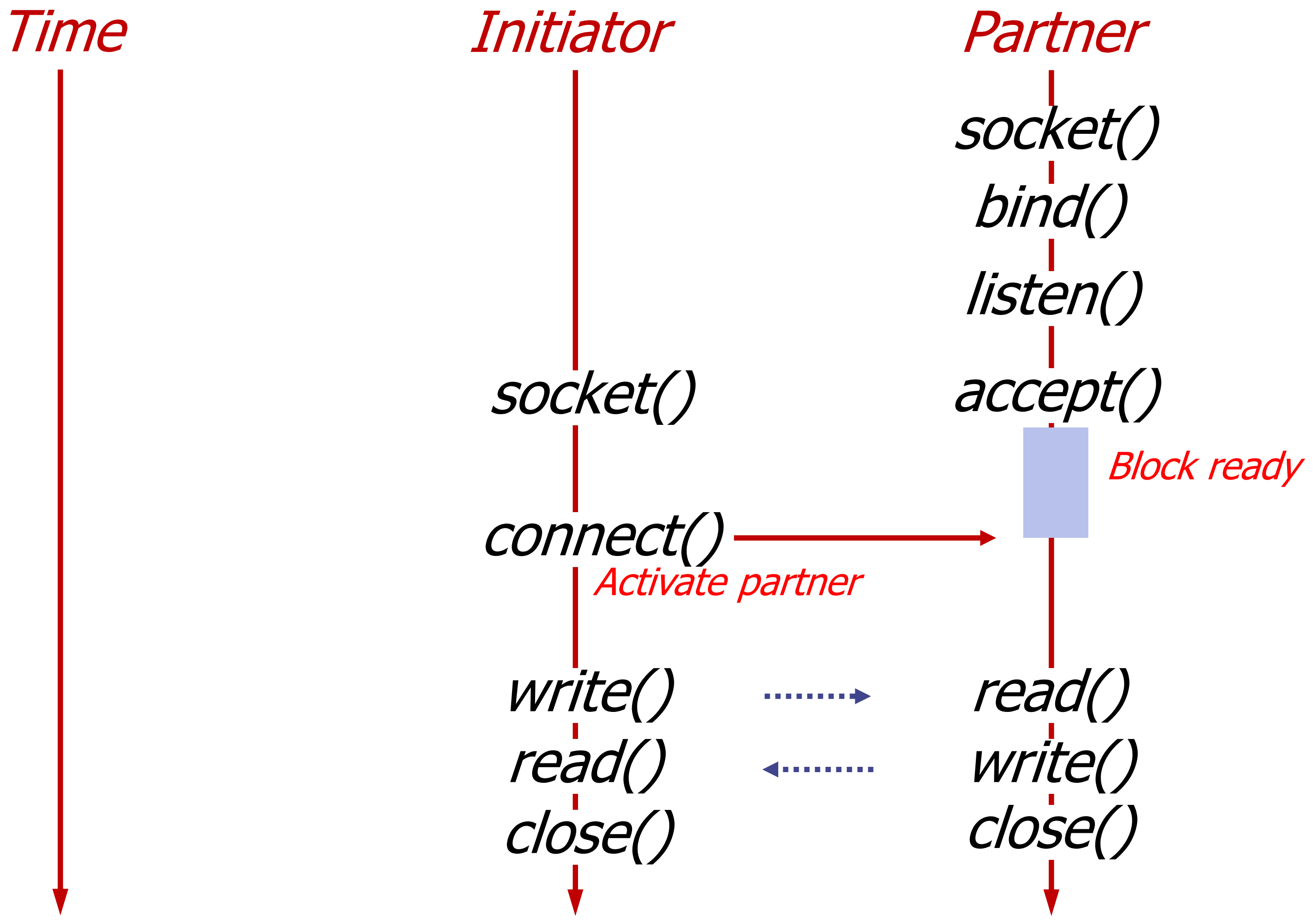
Receiver

- `int s = socket (…);`
- **bind** (s, local_addr, …);
- **recv** (s,
```
      buffer,
      max_buff_length,
      0);
```
- Will wait until data is available on socket `s` and put the data into `buffer`

Java API for Datagram Comms [wonkwang]

- Class *DatagramSocket*
  - *socket constructor* (returns free port if no arg)
  - *send DatagramPacket* (non-blocking)
  - *receive DatagramPacket* (blocking)
  - *setSoTimeout*
    (receive blocks for time *T* and throws *InterruptedIOException*)
  - *Connect*
    (throws *SocketException* if port unknown or in use)
  - *close DatagramSocket*

Stream sockets



Byte streams over a connection-oriented socket [Karl]

- For reliable byte streams, sockets have to be connected first
- Receiver has to accept connection

Initiator *(client)*

- `int s =` **`socket`** `(…);`
- **`connect`** `(s, destination_addr, addr_length);`
- **`send`** `(s,buffer, datasize, 0);`
- Arbitrary `recv()/send()`
- **`close`** `(s);`

- Connected sockets use a `send` without address information

Partner *(server)*

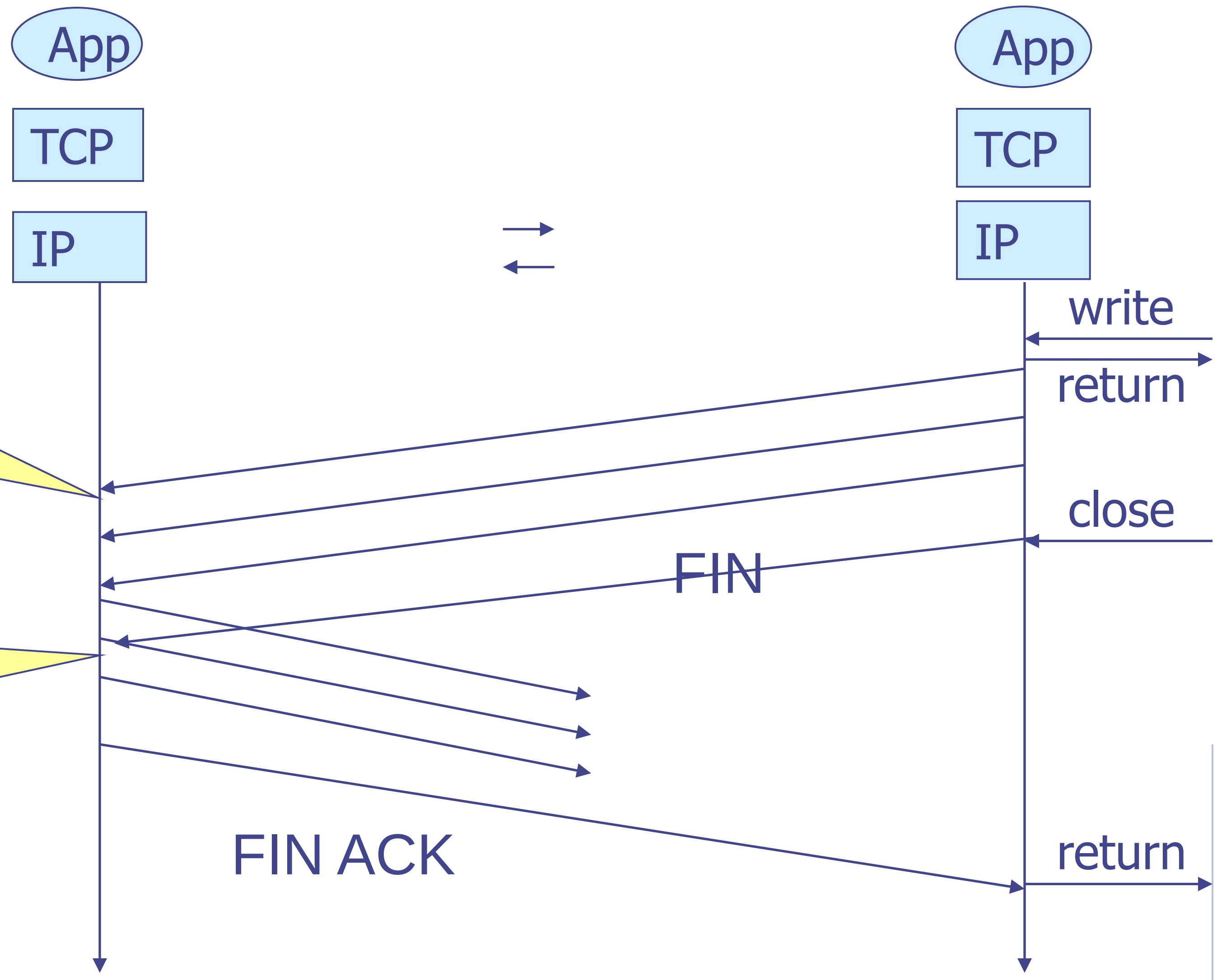
- `int s =` **`socket`** `(…);`
- **`bind`** `(s, local_addr, …);`
- **`listen`** `(s, …);`
- `int newsock =` **`accept`** `(s, *remote_addr, …);`
- **`recv`** `(newsock, buffer, max_buff_length, 0);`
- Arbitrary `recv()/send()`
- **`close`** `(newsock);`

Java API for Data Stream Communications

- Class *ServerSocket*
  - *socket constructor* (for listening at a server port)
  - *getInputStream, getOutputStream*
  - *DataInputStream, DataOutputStream*

    (automatic marshaling/unmarshaling)
  - *close* to close a socket
    (raises *UnknownHost, IOException*, etc)

Reliability of sockets

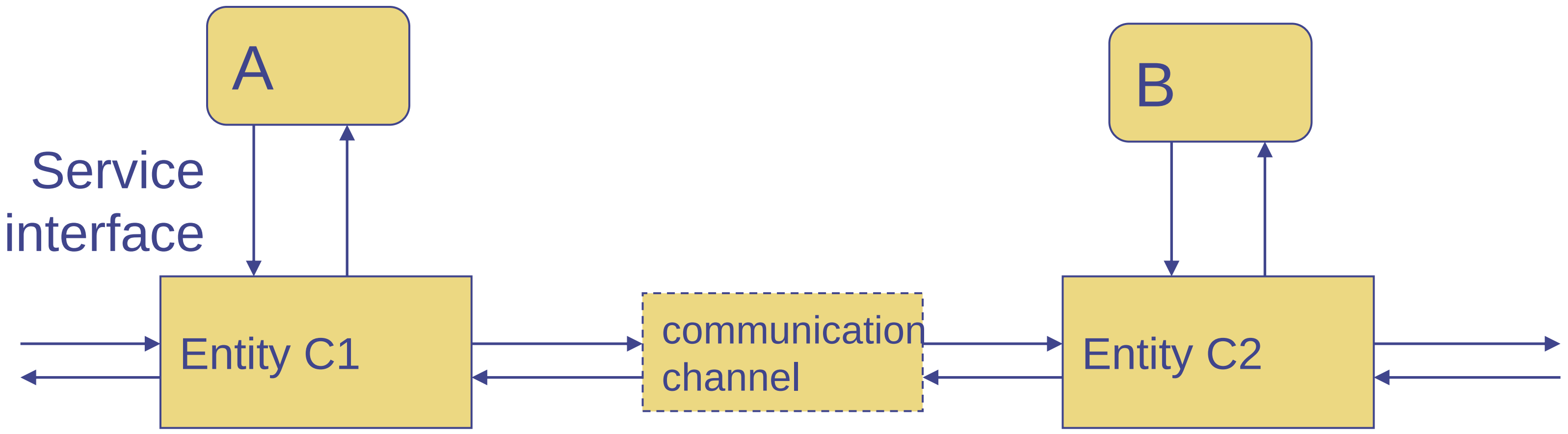


TCP data packets are acknowledged according to the receivers´s policy

The FIN is not acknowledged until all data are received by the end-system

Communication: a service offered to the users…

- A, B **use** a **communication service** provided by a pair of Communicating Entities (short: **entities**)



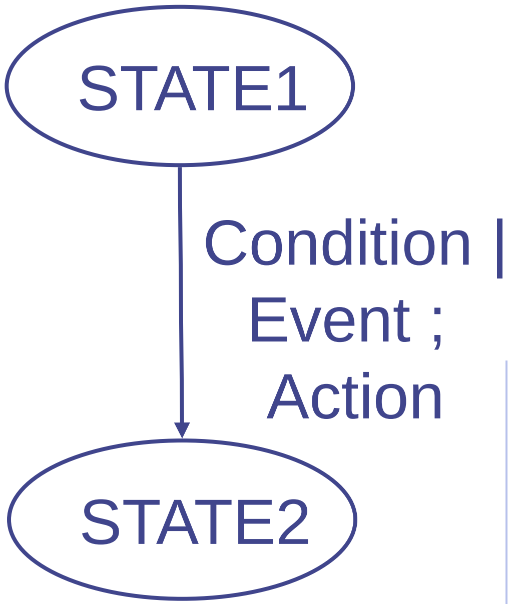
- Entities exchange messages
  - A message contains **"an envelope" (**a.k.a HEADER – an organization part**)**
  - **and –mostly - "the payload" (a.k.a user's data!)**

Protocols

- Cooperation between the entities needs rules
  - How can we ensure that each participant is able to communicate with each other participant?
    - Standardized, overreaching protocols after a general discussion open for everyone
    - Manufacturers must implement the protocol for their device, operating system, application, …
- Transmission protocols = Rules for communication in network
- Analogy: Hand shake

Protocol Specification

- Formal behavior
  - Rules which constitute the protocol have to be precisely specified
- One popular method: (Extended) Finite State Machine (FSM)
  - Protocol instance/protocol engine at each entity with several states
    - Connected – waiting…
  - Events/transitions between states
    - Message arrivals
    - Real time / timer events
  - Transition can have conditions
- Actions during transition are
  - Send new message
  - Set timer, delete timer, …



Protocol Specifications - FSMs

- Finite State Machines (FSM)
  - $\sum = (S, E, D, S_0)$
  - $S = \{s^j\}$: countable state space
  - $E = \{e^j\}$: countable set of events
  - D: transition function
  - D: S X E -> [S ,A]
    - ϕ: undefined transition (zero element)
  - $A = \{a^j\}$: countable set of actions
  - S_0: initial state
  - $E^f(s)$: feasible event set for state S

Just for those who like it a bit more formal!

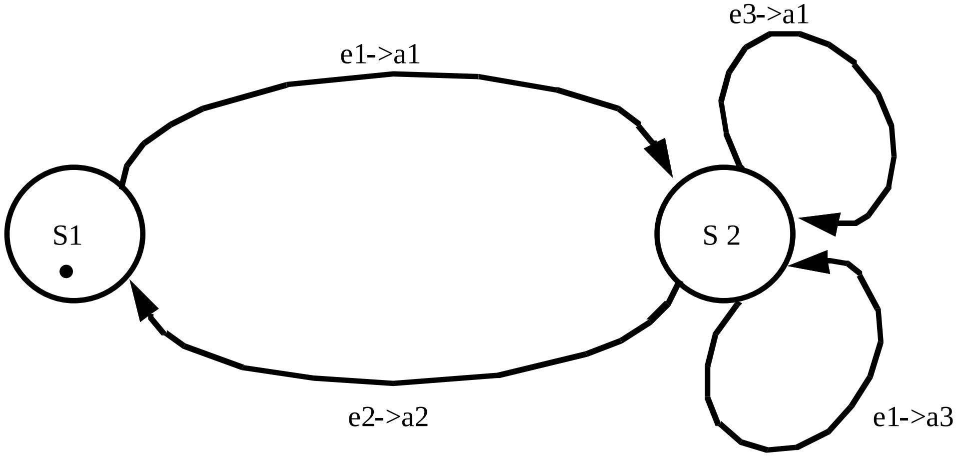
Send_and_Wait Specification

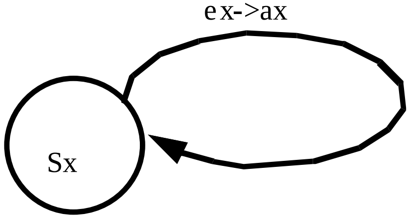
- Example - Send and Wait
  - s^1 - idle — e^1 - data to send **(+*Transmission Request*)**
  - s^2 - waiting — e^2 - get acknowledge
  - $s^0 = s^1$ — e^3 - timer expired
  - a^1 = <send data, set timer>
  - a^2 = <acknowledge transfer, clear timer> (**Conf**)
  - a^3 = <response: busy> (+*Transmission* ***Confirmation***)

- Transition function

	State	
Event	$S^{\mathbf{1}}$	$S^{\mathbf{2}}$
e^1	a^1,s^2	a^3,s^2
e^2	0	a^2,s^1
e^3	0	a^1,s^2

Protocol Specification: Graph usage





Receiver side specification

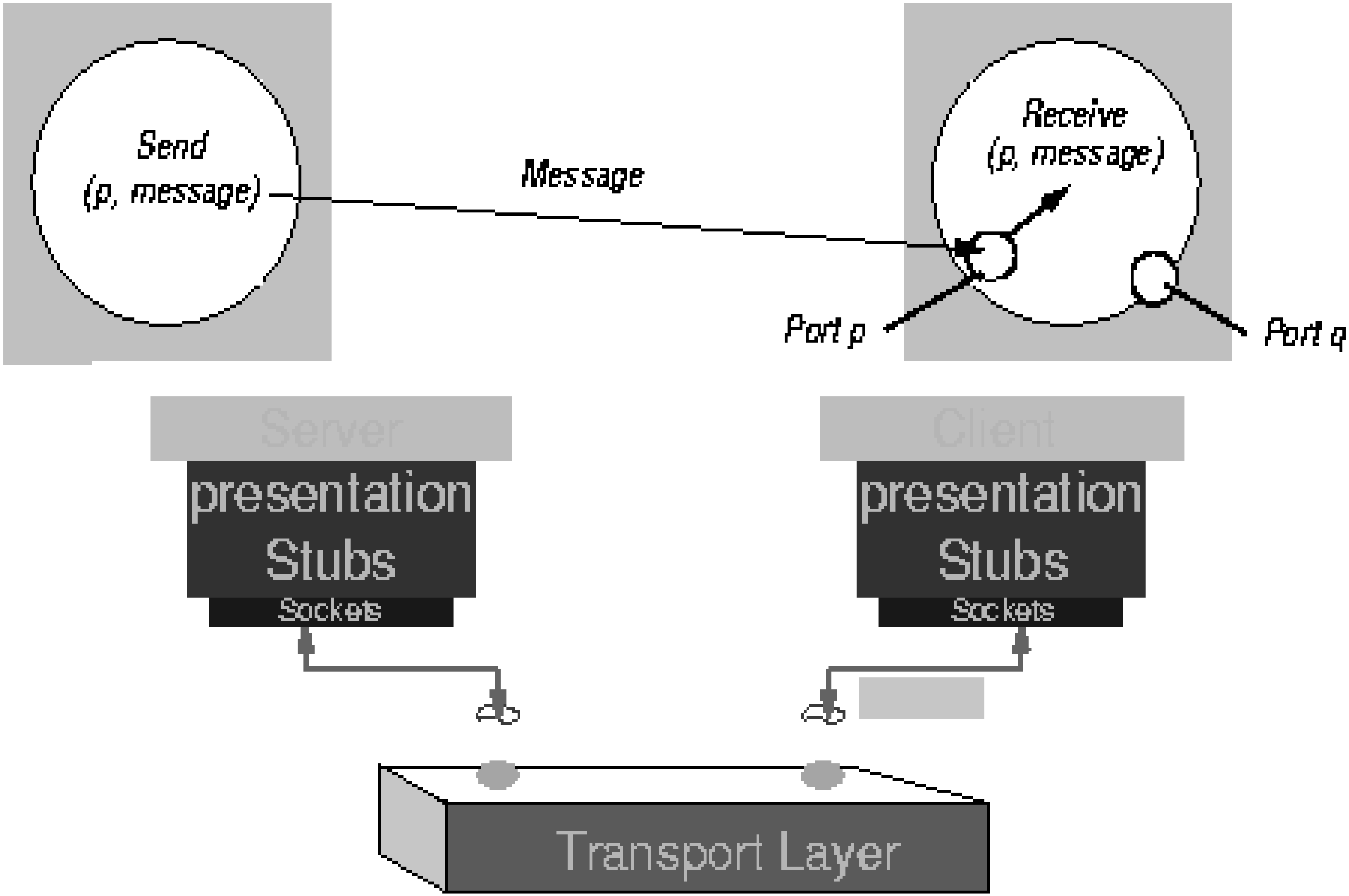
- S^x - idle
- e^x - data arrived
- a^x - acknowledge **(+*Transmission Indication***)
- Note:
  - Timers count is irrelevant
  - Infinite loop if permanent transmission errors!
  - Duplication if acknowledge gets lost

Streams of Bits/bytes can be transmitted: so what?

How do we know what is the INFORMATION inside?

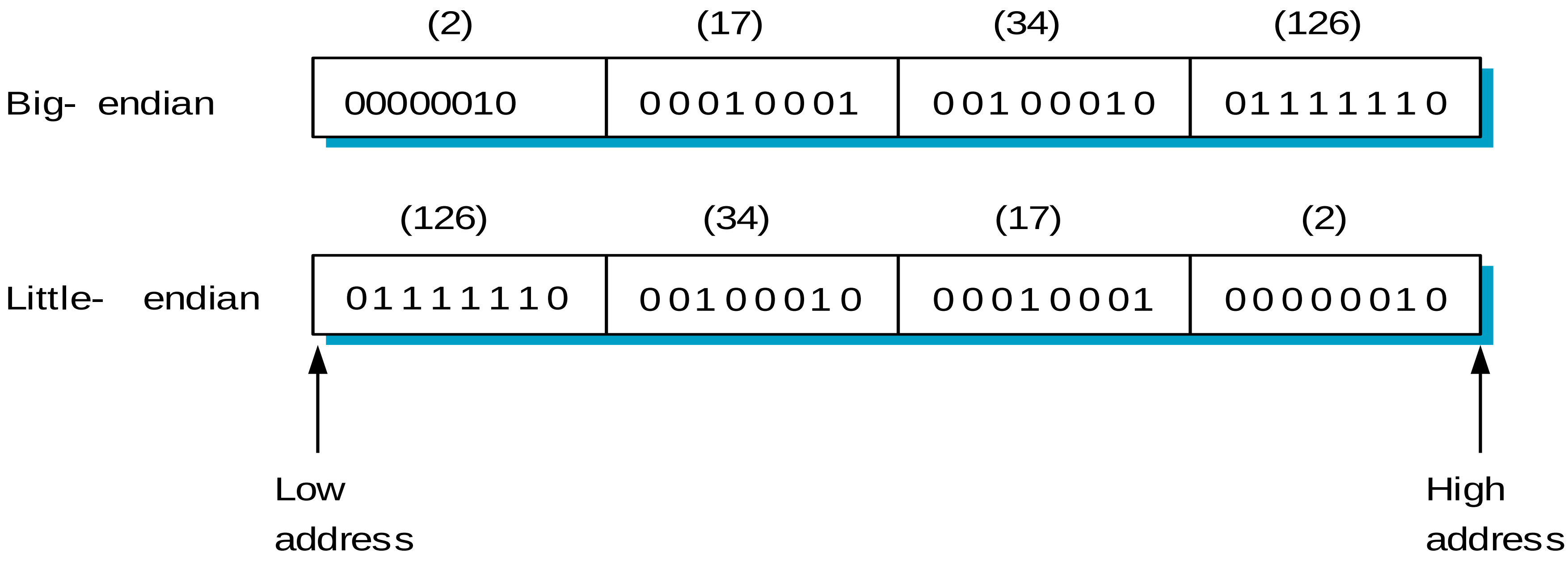
Inter-Process Communication

[wonkwang, modified]



Simple example

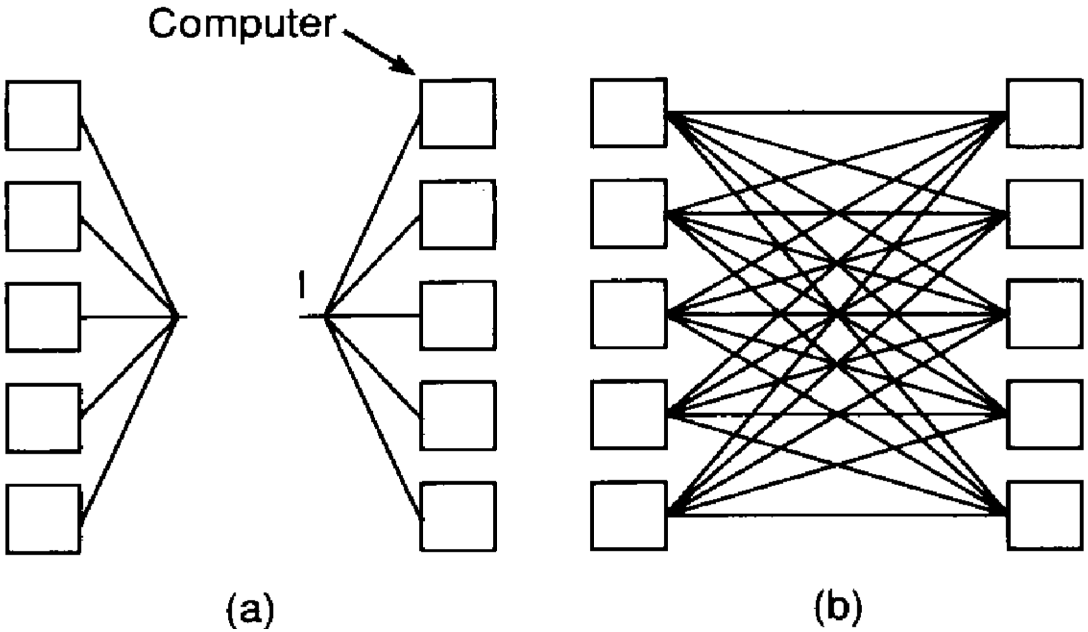
- Representation of base types
  - floating point: IEEE 754 versus non-standard
  - integer: big-endian versus little-endian (e.g., 34,677,374)



  - on a 680x0 CPU, the 32 bit integer number 255 is stored as:
    00000000 00000000 00000000 11111111
    but an Intel 80x86-CPU stores this as:
    11111111 00000000 00000000 00000000

Taxonomy

- Data types
  - base types (e.g., ints, floats); must convert
  - flat types (e.g., structures, arrays); must pack
  - complex types (e.g., pointers); must linearize



- Conversion Strategy
  - canonical intermediate form
  - receiver-makes-right (an *N* x *N* solution)

Data Conversion

- Two different types of rules are needed:
  - Abstract syntax: a station must define what datatypes are to be transmitted
  - Transfer syntax: it must be defined how these datatypes are transmitted, i.e. which representation has to be used.

Tagged versus untagged data

type = INT	len = 4		value =	417892	

Abstract Syntax Notation.1 - ASN.1

- Each transmitted data value belongs to an associated data type.
- For the lower layers of the OSI-RM, only a fixed set of data types is needed (frame formats), for applications with their complex data types ASN.1 provides rules for the definition and usage of data types.
- ASN.1 distinguishes between a data type (as the set of all possible values of this type) and values of this type (e.g. ‘1’ is a value of data type Integer).
- Basic ideas of ASN.1:
  - Every data type has a globally unique name (type identifier)
  - Every data type is stored in a library with its name and a description of its structure (written in ASN.1)
  - A value is transmitted with its type identifier and some additional information (e.g. length of a string).

Definition of Datatypes using ASN.1 (1)

- A data type definition is called „abstract syntax“; it uses a Pascal-like syntax.
- Lexical rules:
  - Lowercase letters and uppercase letters are different
  - A type identifier must start with an uppercase letter
  - Keywords are written in uppercase letters
- ASN.1 offers some predefined simple types:
  - BOOLEAN (Values: True, False)
  - INTEGER (natural numbers without upper bound)
  - ENUMERATED (association between identifier and Integer value)
  - REAL (floating point values without upper or lower bound)
  - BIT STRING (unbounded sequence of bits)
  - OCTET STRING (unbounded sequence of bytes/ octets)
  - NULL (special value denoting absence of a value)
  - OBJECT IDENTIFIER (denoting type names or other ASN.1-objects)

Definition of Datatypes using ASN.1 (2)

- Examples:
  - MonthsPerYear ::= INTEGER
    MonthsPerYear ::= INTEGER (1..12)
    Answer ::= ENUMERATED (correct(0), wrong(1),noAnswer(3))
- With the following type constructors new types can be built from existing ones:
  - SET: the order of transmission of the elements of a set is not specified. The number of elements is unbounded, their types can differ
  - SET OF: like SET, but all elements are of the same type.
  - SEQUENCE: the elements of a sequence are transmitted in the defined order. They can be of different types. The number of elements is unbounded.
  - SEQUENCE OF: like SEQUENCE, but all elements are of the same type
  - CHOICE: the type of a given value is chosen from a list of types (like a Pascal variant record)
  - ANY: unspecified type

ASN.1 Transfer Syntax (1)

- Some coding rules (the „transfer syntax“) specifies how a value of a given type is transmitted. A value to be transmitted is coded in four parts:
  - identification (type field or tags)
  - length of data field in bytes
  - data field
  - termination flag, if length is unknown.
- The coding of data depends on their type:
  - integer numbers are transmitted in High-Endian Two’s complement representation, using the minimal number of bytes: numbers smaller 128 are encoded in one byte, numbers smaller than 32767 are encoded in two bytes, ...
  - Booleans: 0 is false, every value not equal 0 is true.
  - for a sequence type first a type identification of the sequence itself is transmitted, followed by each member of the sequence.
  - Similar rules apply to the transfer of set types