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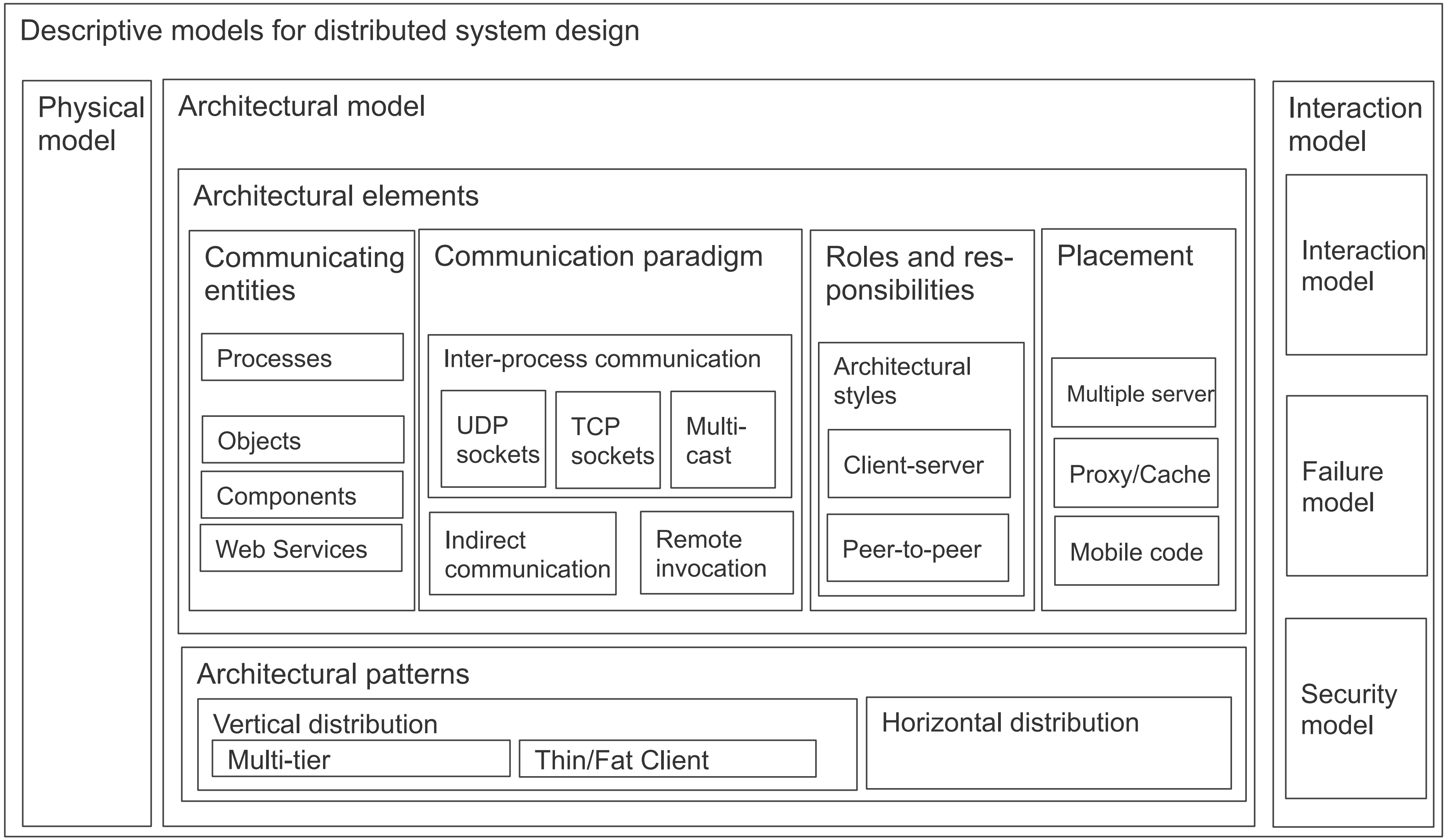
Ad hoc network programming

Nov 1st, 2011

Netzprogrammierung

(Algorithmen und Programmierung V)

Our topics last week



Our topics today

Internet Protocols, esp. TCP/IP layer

API for Internet protocols, esp. sockets vs. ports

UDP datagram communication

TCP stream communication

External data representation

Multicast communication

Ad hoc network programming

Internet protocols

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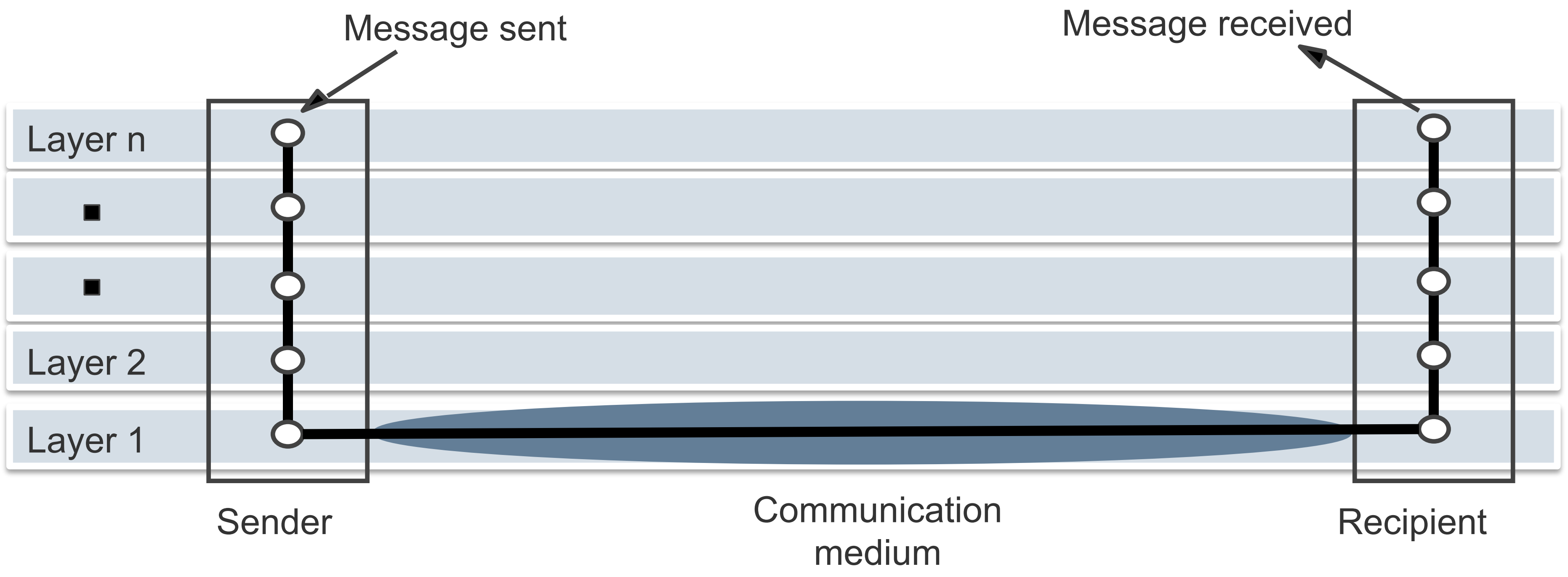
Protocols

Protocol refers to a set of **rules** and **formats** to be used for communication between processes in order to perform a given task.

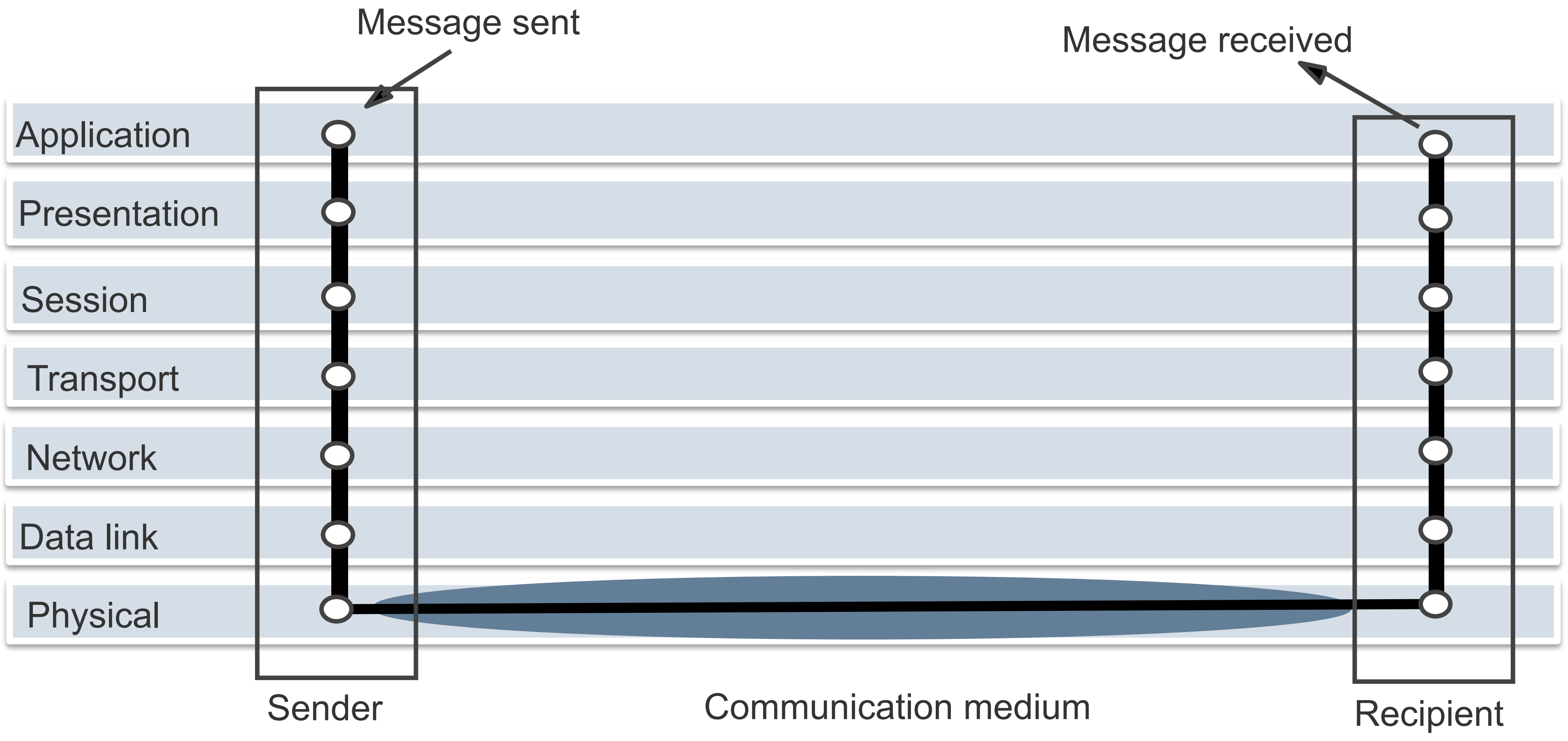
Specification of the sequence of messages that must be exchanged.

Specification of the format of the data in the messages.

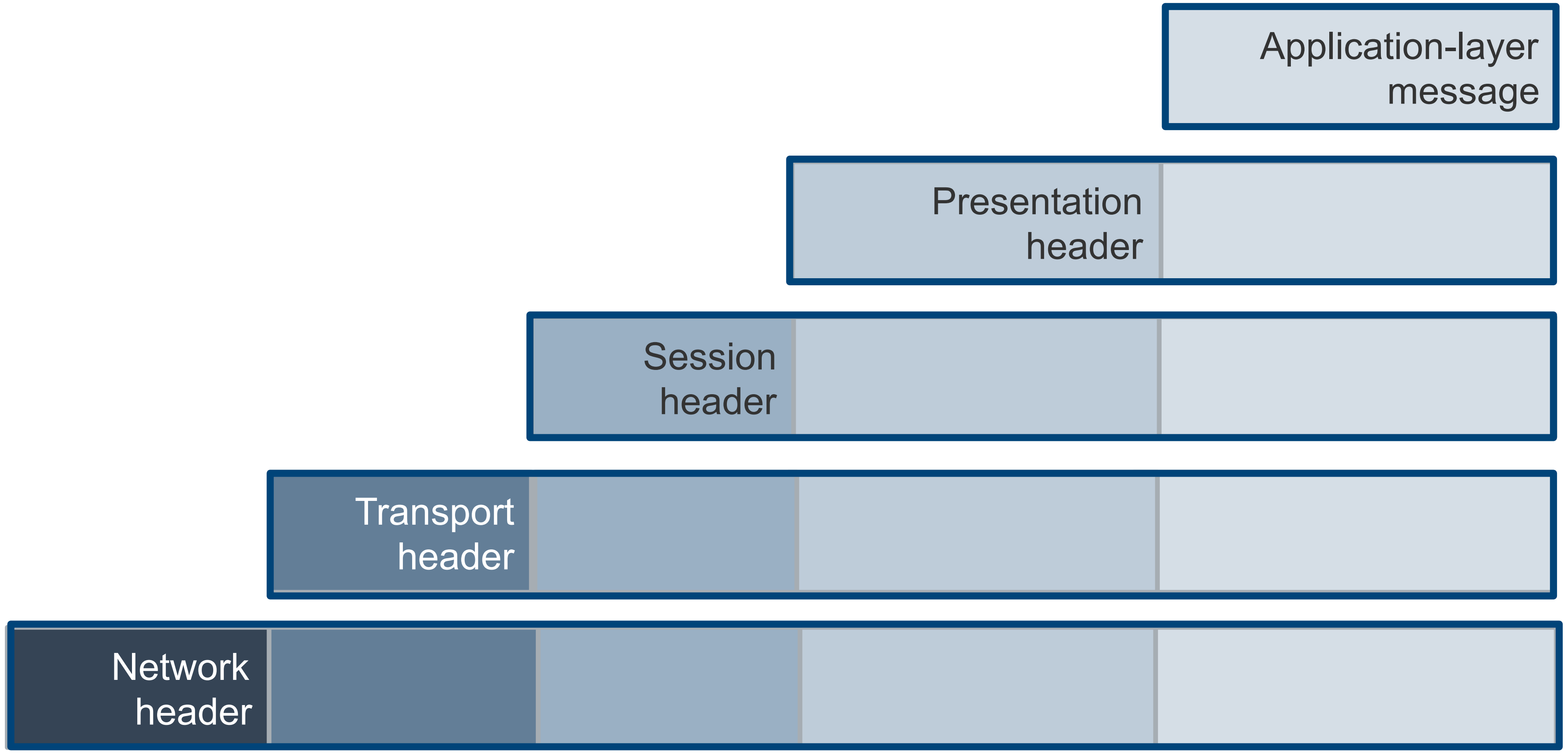
Conceptual layering of protocol software



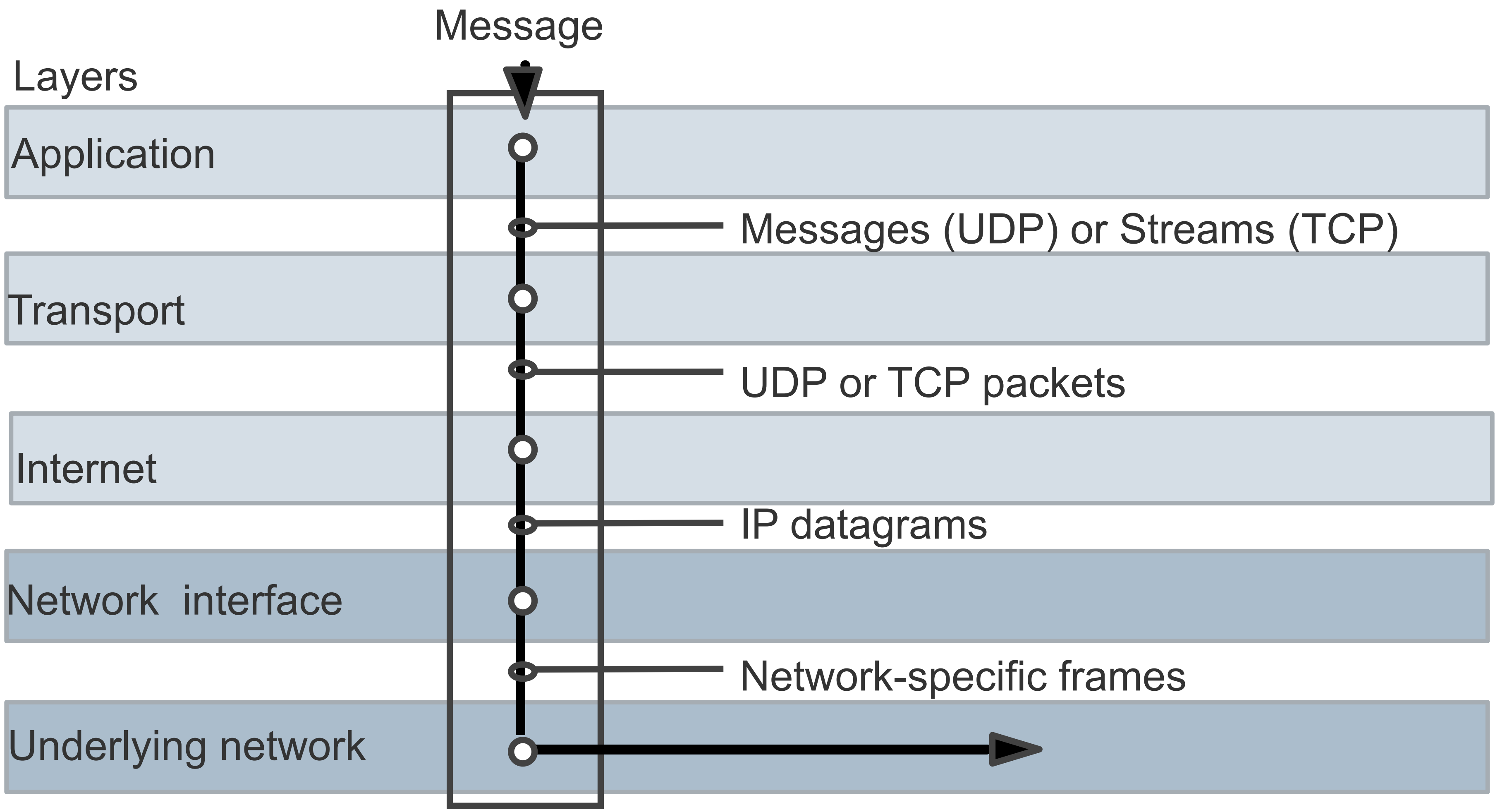
Review: Protocol layers in the ISO Open Systems Interconnection (OSI) model



Encapsulation as it is applied in layered protocols



TCP/IP layer


Message
Layers
Application
Messages (UDP) or Streams (TCP)
Transport
UDP or TCP packets
Internet
IP datagrams
Network interface
Network-specific frames
Underlying network

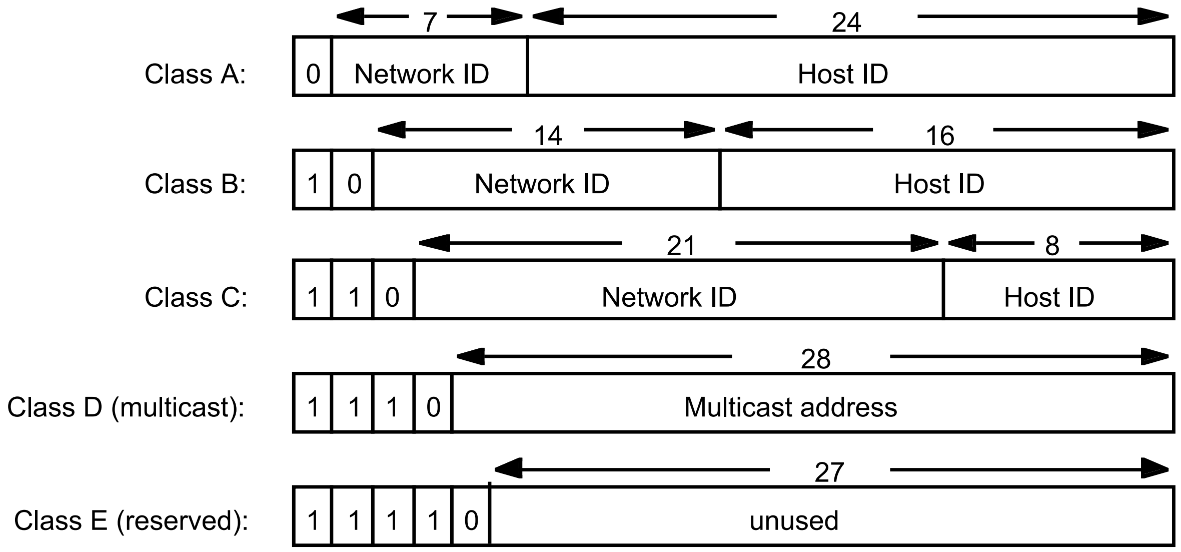
IPv4 addressing

Objective: schemes for naming and addressing hosts and for routing IP packets to their destinations.

Defined scheme assigns an IP address to each host in the Internet

- Network identifier – uniquely identifies the sub-network in the internet
- Host identifier - uniquely identifies the host’s connection

32-bit, written in a 4 Bytes in decimal notation, e.g. 130.149.27.12



Java API: package java.net

Java provides class `InetAddress` that represents Internet addresses

- Method static `InetAddress getByName(String host)`
- Can throw an `UnknownHostException`

- Example

```
w3c = InetAddress.getByName("www.w3c.org");
me = InetAddress.getByName("localhost");

System.out.println(InetAddress.getByName
("localhost"));
      localhost/127.0.0.1
System.out.println(InetAddress.getLocalHost());
      lounge.mi.fu-berlin.de/160.45.42.83
```

http://download.oracle.com/javase/6/docs/api/java/net/InetAddress.html

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API for Internet protocols

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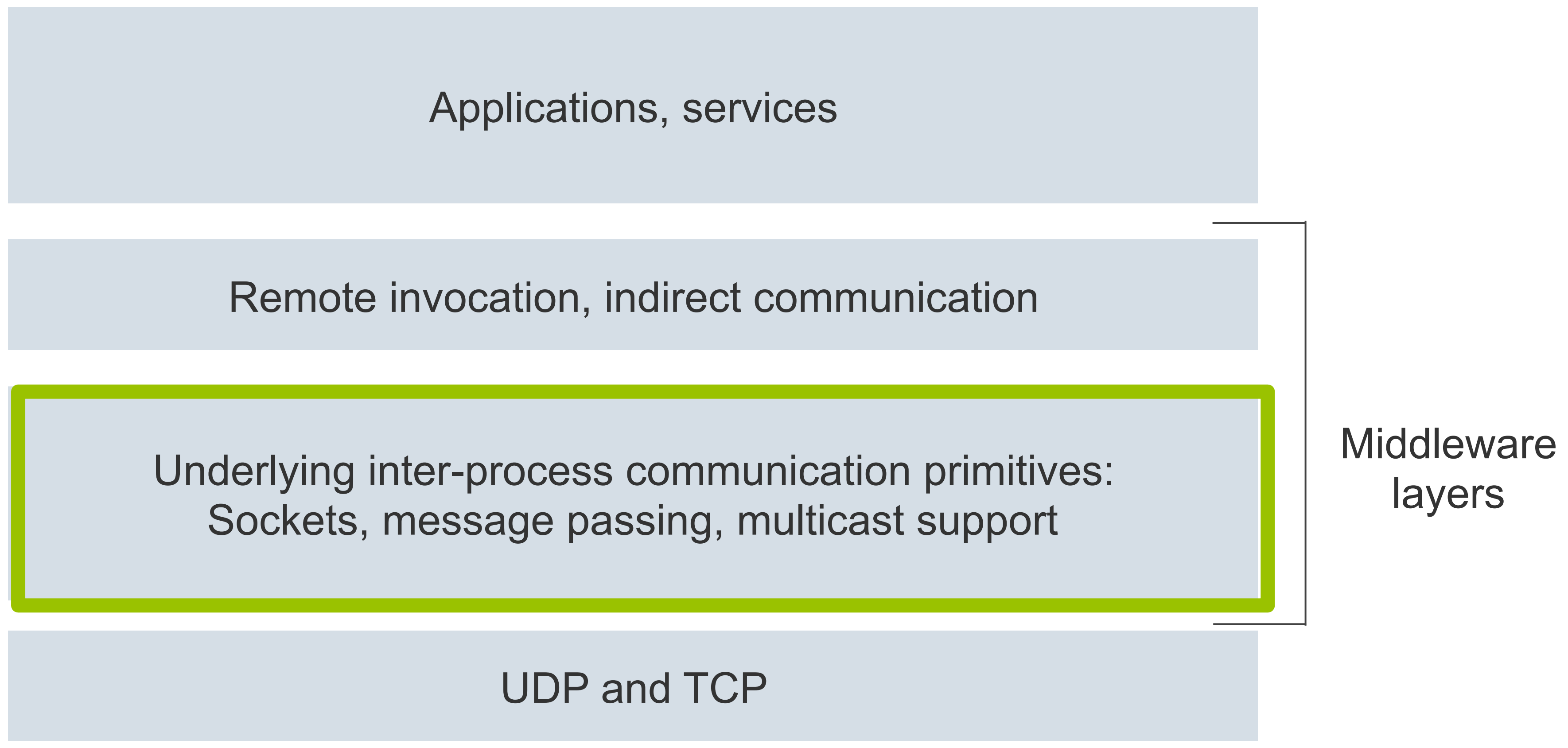
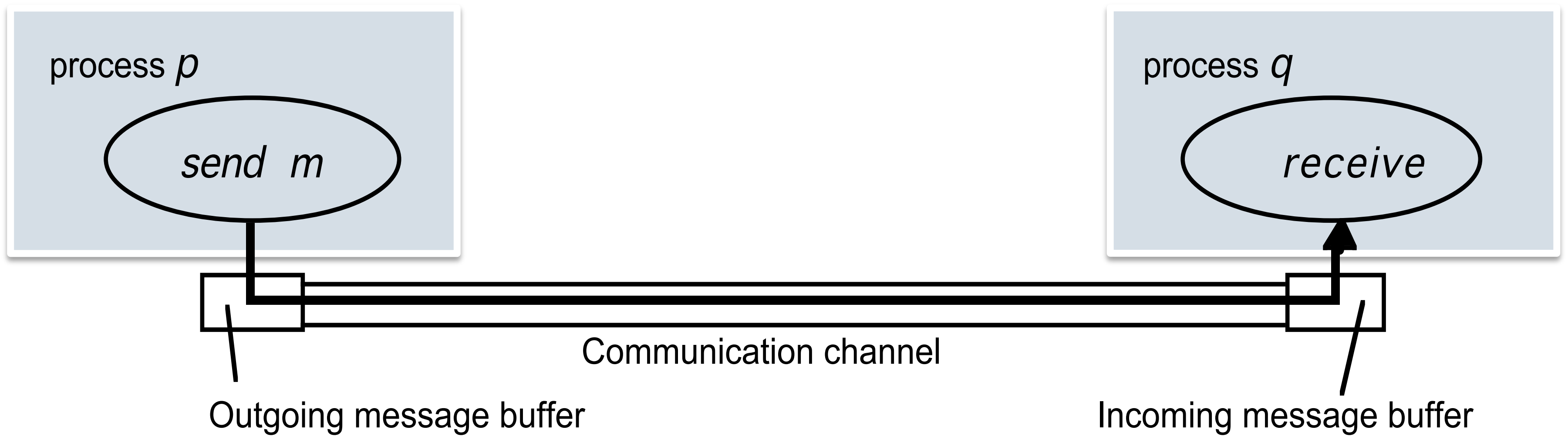
Middleware layers


Applications, services
Remote invocation, indirect communication
Underlying inter-process communication primitives: Sockets, message passing, multicast support
UDP and TCP
Middleware layers

Characteristics of inter-process communication

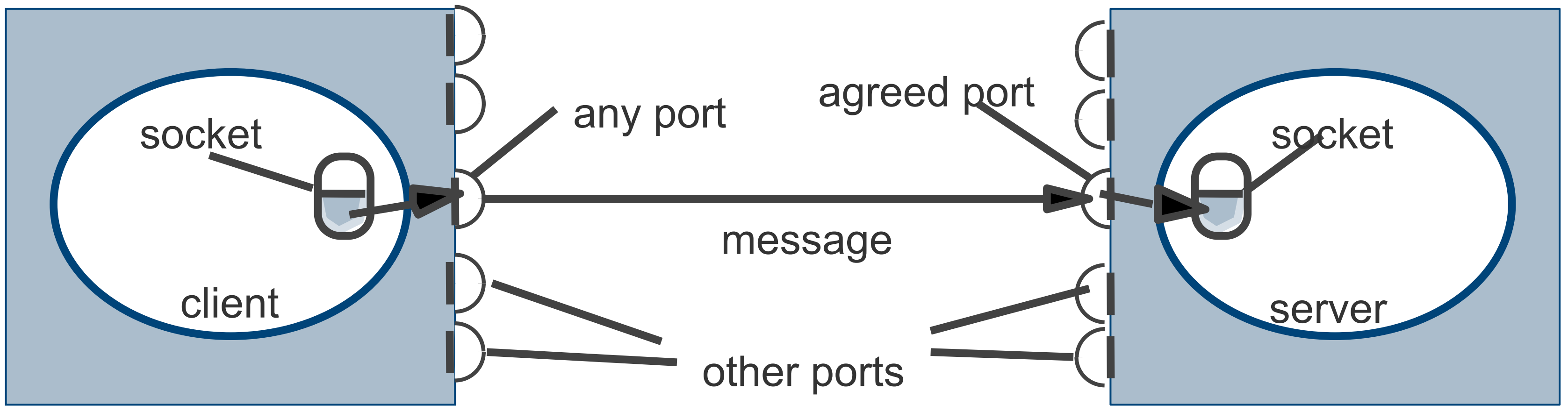


Synchronous communication: sending and receiving processes synchronize at every message = send and receive are blocking operation

Asynchronous communication: send and receive operations are non-blocking

Sockets

Interprocess communication consists of transmitting a message between a message between a socket in one process and a socket in another process



Internet address = 138.37.94.248

Internet address = 138.37.88.249

Socket address = IP address and port number

Sockets

- Sockets provide an interface for programming networks at the transport layer.
- Network communication using Sockets is very much similar to performing file I/O
- Socket-based communication is programming language independent.

Ports

- Port is represented by a positive (16-bit) integer value
- Some ports have been reserved to support common/well known services such as ftp (20 for data and 21 control)
- User level process/services generally use port number value >= 1024

Realizing process-to-process communication

UDP features

- UDP datagram encapsulated inside an IP package
- Header includes source and destination port numbers
- No guarantee of delivery
- Message size is limited
- Restricted to applications and services that do not require reliable delivery of single or multiple messages

TCP features

- Provides reliable delivery of arbitrarily long sequences of bytes via stream-based programming abstraction
- Connection-oriented service
- Before data is transferred, a bidirectional communication channel is established

UDP datagram communication

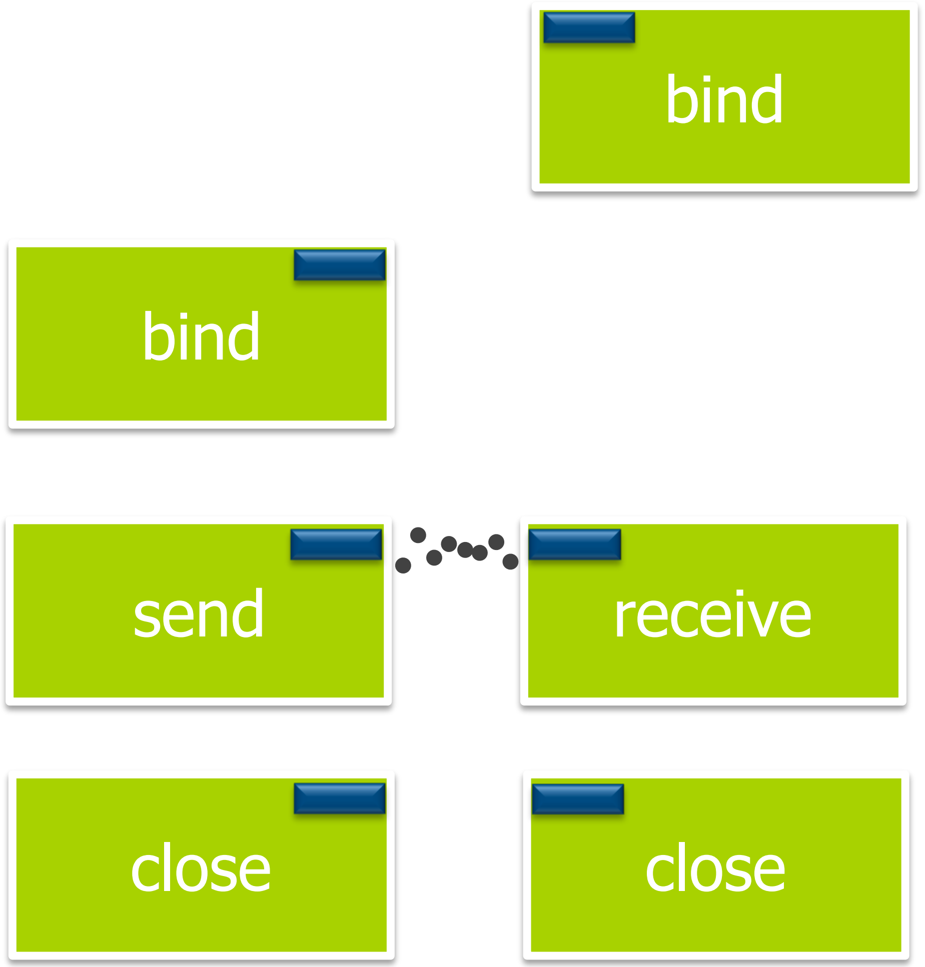
UDP Sockets

1. Client creates socket bound to a local port

2. Server binds its socket to a server port

3. Client/Server send and receive datagrams

4. Ports and sockets are closed



Issues related to datagram communication

Message size

- Receiving process needs to specify an array of bytes of a particular size in which to receive a message
- If the received message is to big it is truncated

Datagram communication is carried out with a non-blocking *send* and a blocking *receive* operation

Timeouts can be set, in order to avoid that the receive operation waits indefinitely

Receive method does not specify an origin of the messages. But it is possible to connect a datagram socket to a particular remote port and Internet address.

Failure model of UDP datagrams

Integrity

- Messages should not be corrupted or duplicated
- Use of checksum reduces probability that received message is corrupted

Failures

- Omission failures: messages maybe dropped occasionally because of checksum error or no buffer space is available at source/destination
- Ordering: Messages can sometimes be delivered out of order

Using UDP for applications

Advantage of UDP datagrams is that they do not suffer from overheads associated with guaranteed message delivery

Example 1: Domain Name System

- DNS primarily uses UDP on port number 53 to serve requests
- DNS queries consist of a single UDP request from the client followed by a single UDP reply from the server

Example 2: VOIP

- No reason to re-transmit packets with bad speech data
- Speech data must be processed at the same rate as it is sent - there is no time to retransmit packets with errors

UDP datagram communication

Java API for UDP diagrams

Java API for UDP diagrams

Datagram communication is provided by two classes `DatagramPacket` and `DatagramSocket`

`DatagramPacket`

- Constructor that makes an instance out of an array of bytes comprising a message
- Constructor for use when receiving a message, message can be retrieved by the method `getData`

`DatagramSocket`

- Constructor that takes port number as argument for use by processes
- No-argument constructor for choosing a free local port

Example: Java client (UDP)

Create input stream

Create client socket

Translate host-name to IP address using DNS

```
import java.io.*;
import java.net.*;
class UDPClient {
        public static void main(String args []) throws Exception {

        BufferedReader inFromUser =
          new BufferedReader(new InputStreamReader(System.in));

        DatagramSocket clientSocket = new DatagramSocket();

        InetAddress IPAddress =
          InetAddress.getByName("hostname");

        byte[] sendData = new byte[1024];
        byte[] receiveData = new byte[1024];
        String sentence = inFromUser.readLine();
        sendData = sentence.getBytes();
```

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Example: Java client (UDP) *(cont.)*

Create datagram with data-to-send, length, IP addr, port

```
DatagramPacket sendPacket =
   new DatagramPacket(sendData, sendData.length, IPAddress, 9876);
```

Send datagram to server

```
clientSocket.send(sendPacket);
```

```
DatagramPacket receivePacket =
   new DatagramPacket(receiveData, receiveData.length);
```

Read datagram from server

```
clientSocket.receive(receivePacket);

String modifiedSentence = new String(receivePacket.getData());

System.out.println("FROM SERVER:" + modifiedSentence);

clientSocket.close();
}
}
```

Example: Java server (UDP)

```
import java.io.*;
import java.net.*;

      class UDPServer {
        public static void main(String args []) throws Exception
          {
```

Create datagram socket at port 9876

```
            DatagramSocket serverSocket = new DatagramSocket(9876);

            byte[] receiveData = new byte[1024];
            byte[] sendData = new byte[1024];
            while(true) {
```

Create space for new datagram

```
              DatagramPacket receivePacket =
                    new DatagramPacket(receiveData, receiveData.length);
```

Receive datagram

```
              serverSocket.receive(receivePacket);
```

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Example: Java server (UDP) *(cont.)*

```
String sentence = new String(receivePacket.getData());

InetAddress IPAddress = receivePacket.getAddress();

int port = receivePacket.getPort();

String capitalizedSentence = sentence.toUpperCase();

sendData = capitalizedSentence.getBytes();

DatagramPacket sendPacket =
    new DatagramPacket(sendData, sendData.length,
    IPAddress, port);

serverSocket.send(sendPacket);
}
}
}
```

Get IP addr port #, of sender

Create datagram to send to client

Write out datagram to socket

End of while loop, loop back and wait for another datagram

TCP stream communication

Hiding network characteristics by TCP

Application can choose the **message size**, means how much data it writes to a stream or reads from it.

TCP protocol uses an **acknowledgement** scheme to avoid lost data.

TCP supports **flow control** that means if the writer is too fast for the reader, then the writer is blocked until the reader consumed sufficient data.

Message identifiers are used by each IP packet. The recipient can therefore detect and reject **duplicates** or can **reorder** message if needed.

Before a pair of communication processes communicate they **establish a connection**.

TCP Sockets

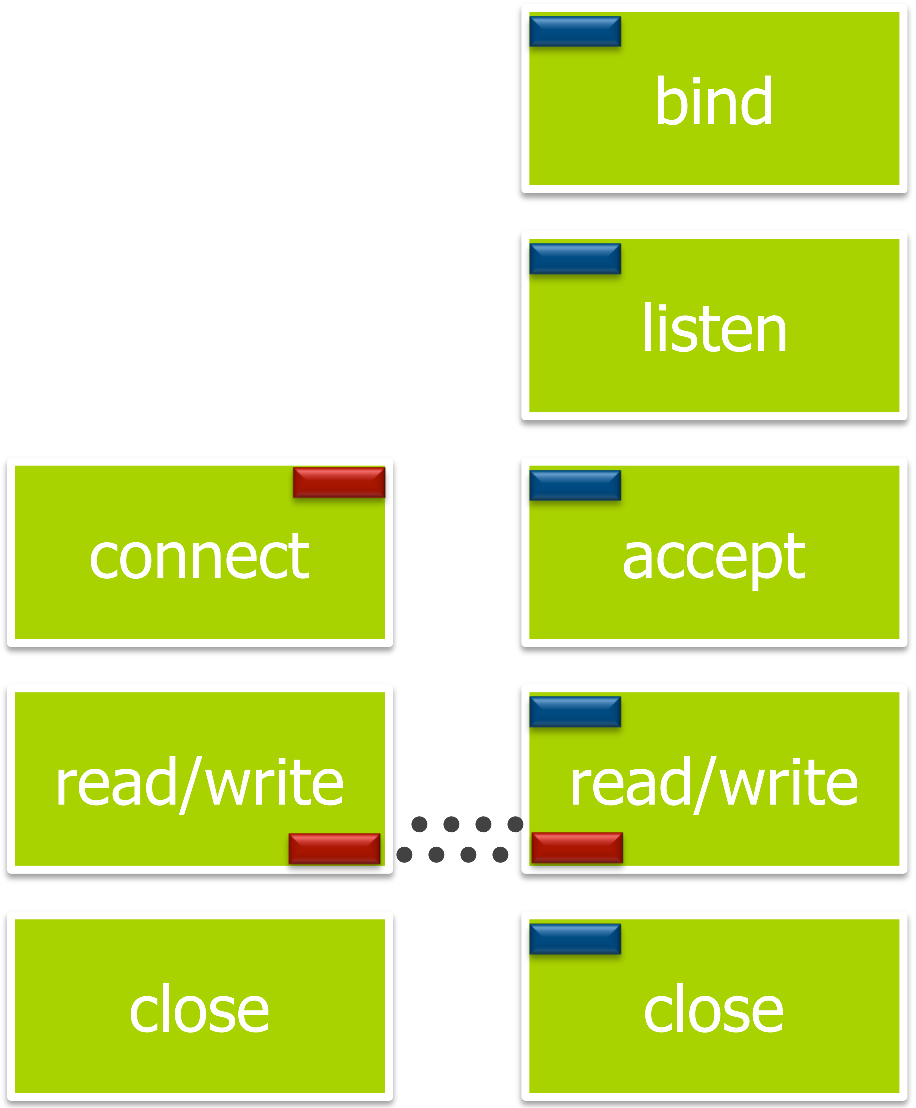
1. Server bind port

2. Server is ready and listening

3. Server is waiting for request, client sends request, server accepts

4. Client and server are connceted - bidirectional!

5. Connection is closed



Failure model of TCP

In order to realize **reliable communication**, TCP streams use **checksums** to detect and reject corrupt packages and **sequence numbers** to detect and reject duplicate packets.

To deal with lost packages TCP streams use **timeouts and retransmissions**.

A broken connection has the following effects

- The processes using the connection cannot distinguish between network failure and failure of the process at the other end of the connection
- The communication processes cannot tell whether the messages they have sent recently have been received or not.

Use of TCP

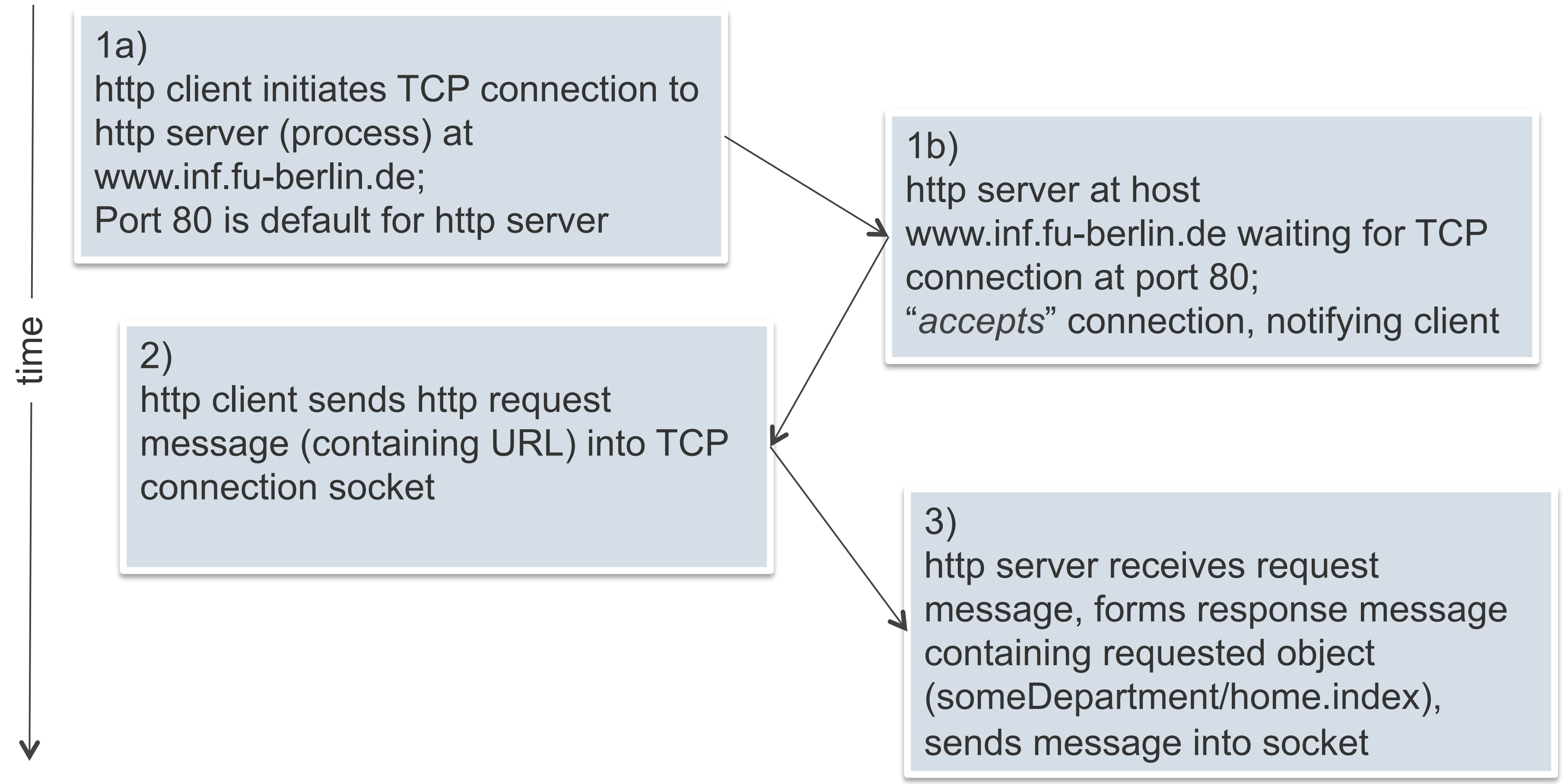
Many frequently used services run over TCP connections with reserved port numbers

- **HTTP** [RFC 2068]: The Hypertext Transfer Protocol is used for communication between web browser and web server.
- **FTP** [RFC 959]: The File Transfer Protocol allows directories on a remote computer t be browsed and files to be transferred from one computer to another over a connection.
- **Telnet** [RFC 854]: Telnet provides access by means of a terminal session to a remote computer.
- **SMTP** [RFC 821]: The Simple Mail Transfer Protocol is used to send mail between computer.

http://en.wikipedia.org/wiki/List_of_TCP_and_UDP_port_numbers

The HTTP protocol

Suppose you enter the URL: http://www.inf.fu-berlin.de/groups/index.html



1a)
http client initiates TCP connection to http server (process) at www.inf.fu-berlin.de;
Port 80 is default for http server

1b)
http server at host www.inf.fu-berlin.de waiting for TCP connection at port 80;
"*accepts*" connection, notifying client

2)
http client sends http request message (containing URL) into TCP connection socket

3)
http server receives request message, forms response message containing requested object (someDepartment/home.index), sends message into socket

The HTTP protocol *(cont.)*

time

4)
http server closes TCP connection

5)
http client receives response message containing html file, displays html. Parsing html file, finds 2 referenced jpeg objects

6)
steps 1-5 repeated for each jpeg objects

TCP stream communication

Java API for TCP

Java API for TCP streams

Java interface provides two classes `ServerSocket` and `Socket`

`ServerSocket`

- Class is intended to be used by server to create a socket at a server port for listening for connect requests from clients.

`Socket`

- Class is for use by a pair of processes with a connection
- The client uses a constructor to create a socket, specifying the DNS hostname and port of a server

Example: Java client (TCP)

```
import java.io.*;
import java.net.*;

class TCPClient {

      public static void main(String argv[]) throws Exception {

        String sentence;
        String modifiedSentence;

        BufferedReader inFromUser = new BufferedReader(new
          InputStreamReader(System.in));

        Socket clientSocket = new Socket ("hostname", 6789);
```

Create a input stream

Create client socket, connect to server

Example: Java client (TCP) *(cont.)*

Create output stream attached to socket

```
DataOutputStream outToServer =
  new DataOutputStream(clientSocket.getOutputStream());
```

Create input stream attached to socket

```
BufferedReader inFromServer =
  new BufferedReader(new InputStreamReader
  (clientSocket.getInputStream ()));
```

Send line to server

```
sentence = inFromUser.readLine();
outToServer.writeBytes(sentence + '\n');
```

Read line from server

```
modifiedSentence = inFromServer.readLine();

System.out.println("FROM SERVER: " + modifiedSentence);

clientSocket.close();

      }
    }
```

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Example: Java server (TCP)

```
import java.io.*;
import java.net.*;

class TCPServer {
        public static void main(String argv []) throws Exception {

          String clientSentence;
          String capitalizedSentence;

          ServerSocket welcomeSocket = new ServerSocket(6789);

            while(true) {
                Socket connectionSocket = welcomeSocket.accept();

                BufferedReader inFromClient = new BufferedReader(new
                InputStreamReader(connectionSocket.getInputStream()));
```

Create welcoming Socket at port 6789

Wait, on welcoming Socket for contact by client

Create input stream, attached to socket

Example: Java server (TCP) *(cont.)*

Create output stream, attached to socket

```
                DataOutputStream outToClient = new DataOutputStream
                                          (connectionSocket.getOutputStream());
```

Read in line from socket

```
                clientSentence = inFromClient.readLine();

                capitalizedSentence = clientSentence.toUpperCase() + '\n';
```

Write out line to socket

```
                outToClient.writeBytes (capitalizedSentence);
              }
           }
     }
```

End of while loop, loop back and wait for another client connection

External data representation and marshalling

What is the challenge?

Messages consist of sequences of bytes.

Interoperability Problems

- Big-endian, little-endian byte ordering
- Floating point representation
- Character encodings (ASCII, UTF-8, Unicode, EBCDIC)

So, we must either:

- Have both sides agree on an external representation or
- transmit in the sender's format along with an indication of the format used. The receiver converts to its form.

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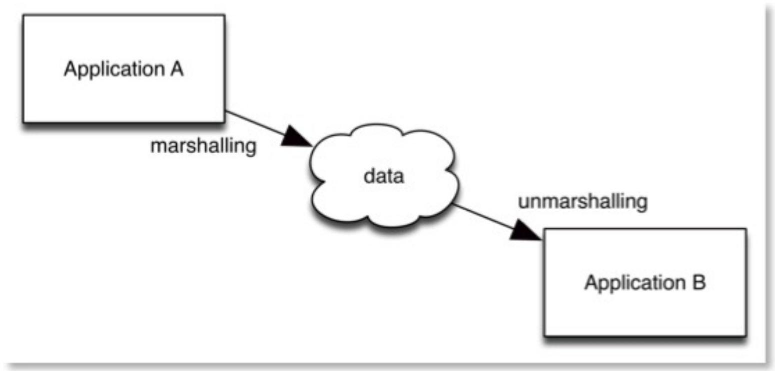
External Data Representation and Marshalling

External data representation

An agreed standard for the representation of data structures and primitive values

Marshalling

The process of taking a collection of data items and assembling them into a form suitable for transmission in a message



http://www.breti.org/tech/files/b400feb80f01f69e5cafca5160be5d65-67.html

Unmarshalling

Is the process of disassembling them on arrival into an equivalent representation at the destination

Approaches for external data representation

CORBA's common data representation

- Concerned with an external representation for the structured and primitive types that can be passed as the arguments and results of remote invocation in CORBA.

Java's object serialization

- Refers to the activity of flattening an object or even a connected set of objects that need to be transmitted or stored on a disk

XML

- Defines a textual format for representing structured data

Protocol buffer

JSON

Google Protocol Buffer

Protocol Buffer (PB) is a common serialization format for Google

Google adopts a minimal and efficient remote invocation service

The goal of Protocol Buffer is to provide a language- and platform-neutral way to specify and serialize data such that:

- Serialization process is efficient, extensible and simple to use
- Serialized data can be stored or transmitted over the network

More information here:
http://code.google.com/apis/protocolbuffers/docs/overview.html

Comparison of Protocol Buffer Language

Advantages of Protocol Buffer (PB)

- PB is 3-10 times smaller than an XML
- PB is 10-100 times faster than an XML

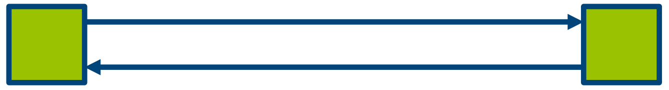
Can we compare PB with XML?

- PB works only on Google infrastructure, which is relatively closed system and does not address inter-operability
- XML is richer (it specifies self-describing data and meta-data). PB is not so rich. There are accessory programs that can create a full description. However, they are hardly used.

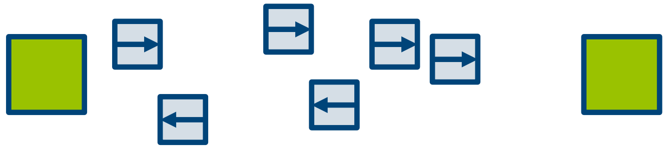
Multicast communication

Possiblities to communicate

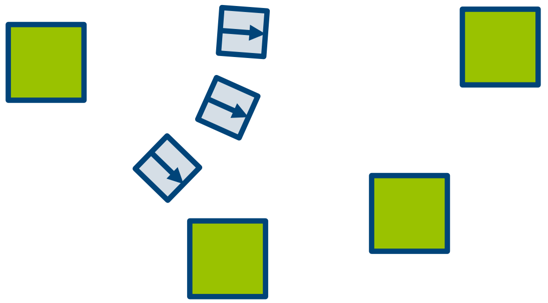
Connection-oriented 1:1
TCP



Connectionless 1:1
UDP



Connectionless 1:n
Multicast



Multicast messages

Multicast message provide a useful infrastructure for constructing distributed systems with the following characteristics

- Fault tolerance based on replicated services
- Discovering services in spontaneous networking
- Better performance through replicated data
- Propagation of event notifications

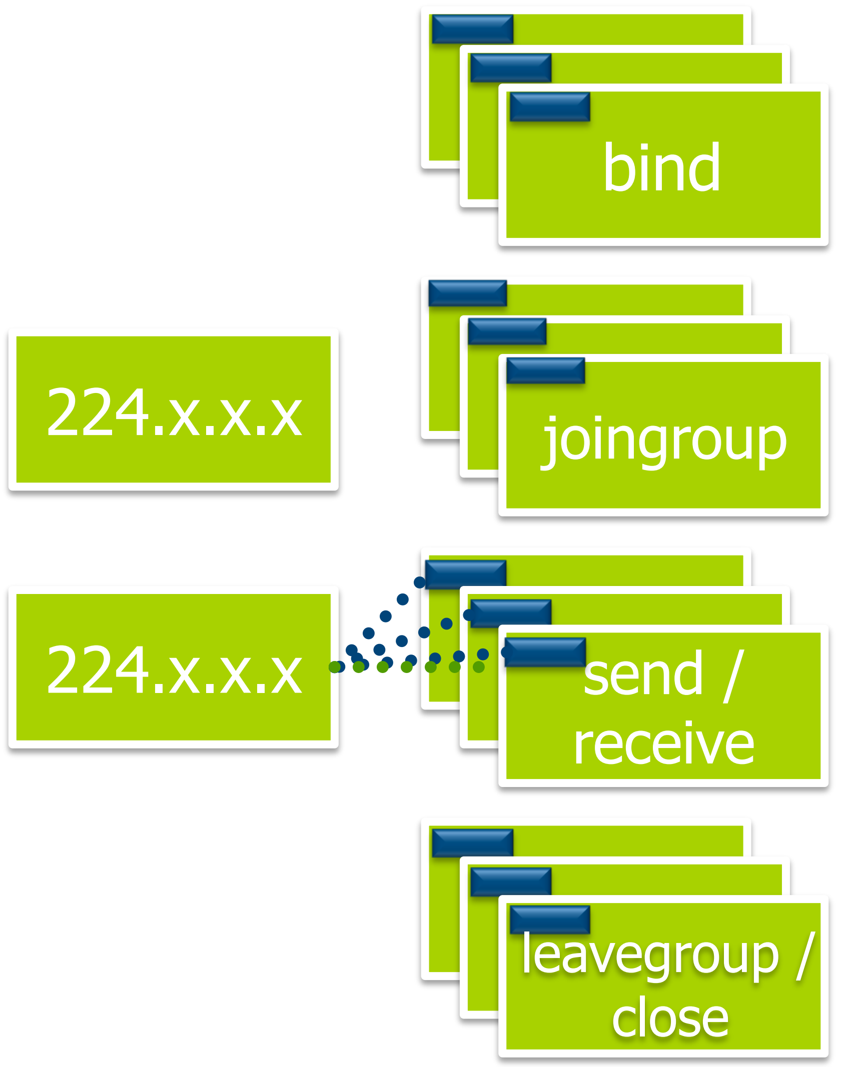
Multicast Sockets

1. Participants bind socket

2. Participants join group

3. Particpants receive
   messages from sender

4. Partcipants leave group and
   release socket



IP Multicast

Is built on top of the Internet Protocol (IP) and allow the sender to transmit a single IP packet to a set of computers that form a multicast group.

Multicast group is specified by a Class D Internet Address. Every IP datagram whose destination address starts with "1110" is an IP Multicast datagram.

IP packets can be multicast on a local and wider network. In order to limit the distance of operation, the sender can specify the number of routers that can be passed (i.e. time to live, or TTL)

Multicast addresses can be permanent (e.g. 224.0.1.1 is reserved for the Network Time Protocol (NTP))

Java API: java.net.MulticastSocket

```
public class MulticastSocket extends DatagramSocket {
public MulticastSocket()...
public MulticastSocket(int port)...
    // create socket and select port number explicitely or implicitely
public void setTimeToLive(int ttl) ...
    // define Time to Live – default is 1 !
public void joinGroup(InetAddress mcastaddr) throws ...
    // join group under the address mcastaddr
public void leaveGroup(InetAddress mcastaddr) throws ...
    // leave group
}
```

Please note: send, receive, ... are inherited from class DatagramSocket

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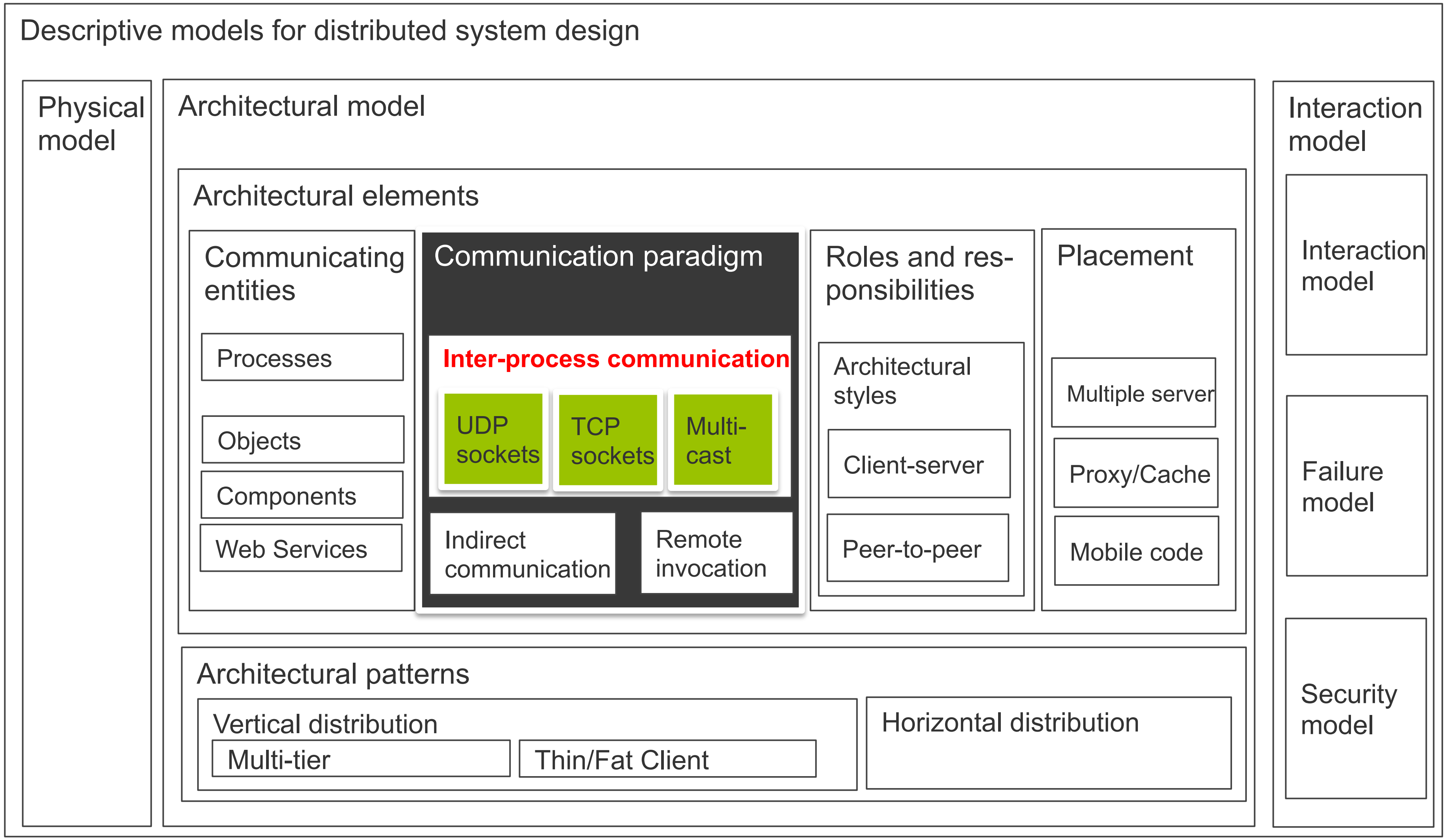
Our topics last week



Summary

- TCP/IP layer
- Characteristics of inter-process communication
- Sockets vs. ports
- UDP datagram communication
    - Characteristics, failure model, usage
    - Java API for UDP diagrams
- TCP stream communication
    - Characteristics, failure model, usage
    - Java API for TCP streams
- Approaches for external data representation (marshalling)
- Multicast communication

Next class

Structured communication (RCP)

References

Main resource for this lecture:

George Coulouris, Jean Dollimore, Tim Kindberg: *Distributed Systems: Concepts and Design*. 5th edition, Addison Wesley, 2011