Network Programming

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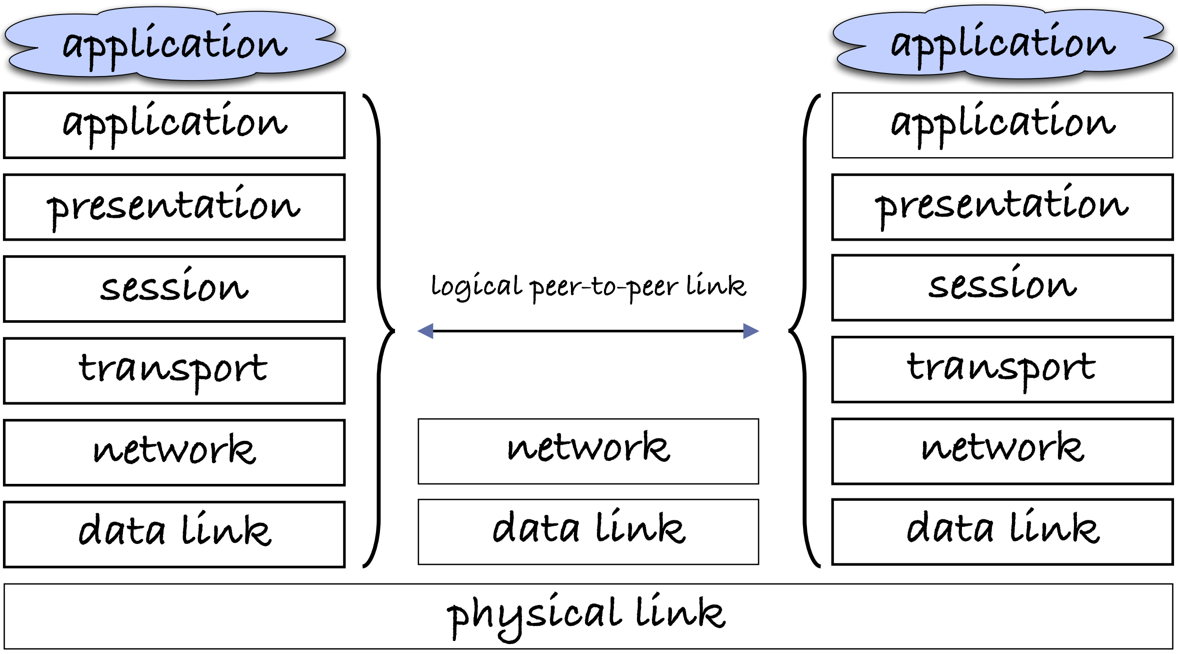
Network programming

- □ Network programming is not distributed programming (somewhat lower-level)
- □ They both rely on:
  - □ computers as processing & storage resources
  - □ a network and a common protocol stack
- □ But network programming lacks:
  - □ naming and location transparency
  - □ an integrated programming & operating model
    (usually achieved thanks to a middleware)

The OSI model (1)



application

application

presentation

session

transport

network

data link

logical peer-to-peer link

network

data link

application

application

presentation

session

transport

network

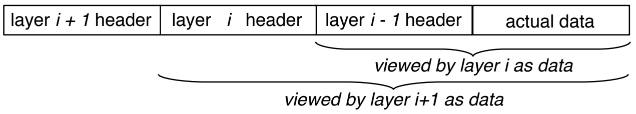
data link

physical link

The OSI model (2)

Physical link	physical medium, electrical/optical signal processing.
Data link	grouping of bits into blocks, error detection/correction, local address format, medium access layer.
Network	global address format, routing of data packets (no flow control).
Transport	end-to-end connection, flow control, retransmission, order.
Session	failure detection & reconnection in case of crashes.
Presentation	standard data representation (e.g., marshaling convention).
Application	basic application-level functionality (http, ftp, smtp, etc.).

Data encapsulation:



The Internet: some history

- ❑ In the middle of the cold war, early 1970s, the Department of Defense (DOD) decides to build a set of tools for interconnecting computer networks.
- ❑ The responsibility of this task falls on the Advance Research Project Agency (ARPA), which develops the ARPAnet protocol suite. A key design issue of ARPAnet was to resist to the massive destruction resulting from a nuclear attack.
  - ⇒ Fully distributed architecture (no single point of failure)
- ❑ In the 1980s, the ARPAnet technology, also named TCP/IP (after its two main building blocks), spreads into the academic community (also very distributed), which had developed it.

TCP/IP

TCP = Transmission Control Protocol

IP = Internet Protocol

- ❑ It Is cornerstone of the Internet
- ❑ It is de facto standard
- ❑ It is an often misunderstood technology
- ❑ It is an old yet alive protocol suite

The OSI model & TCP/IP

Internet Protocol (IP) ⇔ Network Layer (OSI nº 3)

- □ Packet oriented
- □ Routing with best-effort guarantee
- □ Error detection
- □ Datagram fragmentation

Transmission Control Protocol (TCP) ⇔ Transport Layer (OSI nº 4)

- □ Stream oriented
- □ Reliability guarantee
- □ FIFO order guarantee

Host addressing with IP (1)

□ An IP address is used by the IP protocol (Network Layer) to name hosts (computers) and routers.

□ An IP address consists of 32-bits (4 bytes) and is usually written in dotted decimal format, e.g., 130.223.171.8

Class	First byte	Networks		Hosts		Address format	
A	1-126	$2^7 - 2$ =	126	$2^{24} - 2$ =	16'777'214	net id	host id
B	128-191	2^{14} =	16'384	$2^{16} - 2$ =	65'534	net id	host id
C	192-223	2^{21} =	2'097'152	$2^8 - 2$ =	254	net id	host id
D	224-239	-		-		multicast	
E	240-247	-		-		reserved	

Host addressing with IP (2)

□ Address 127.x.y.z is the loopback address (local)

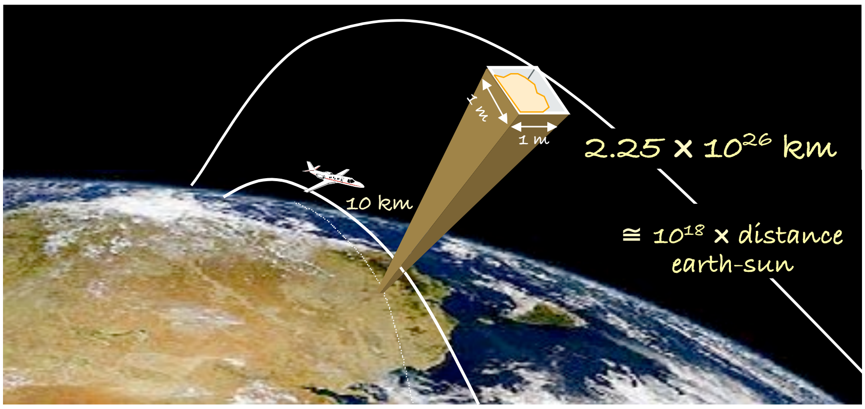
Class	Format
A	0NNNNNNN.HHHHHHHH.HHHHHHHH.HHHHHHHH
B	10NNNNNN.NNNNNNNN.HHHHHHHH.HHHHHHHH
C	110NNNNN.NNNNNNNN.NNNNNNNN.HHHHHHHH
D	1110MMMM.MMMMMMMM.MMMMMMMM.MMMMMMMM
E	1111RRRR.RRRRRRRR.RRRRRRRR.RRRRRRRR

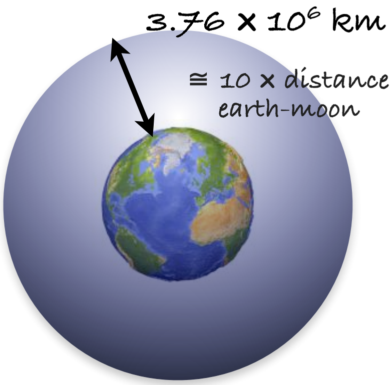
N	network ID bits	M	multicast address bit
H	host ID bits	R	reserved bits

Towards IPv6

Addresses encoded on 128 bits

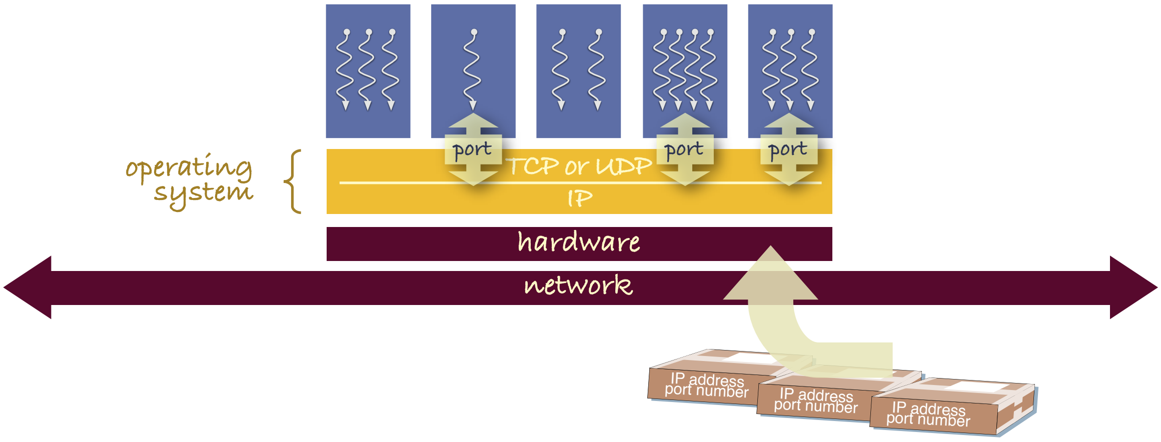
⇒ $2^{128} > 3.4 \times 10^{38}$ addresses are available





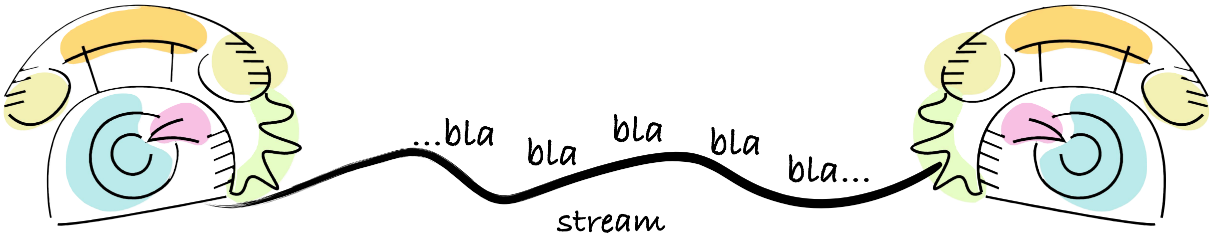
Naming applications

Within a single host, applications are named (addressed) using ports. At the operating system level, this is known as port multiplexing.

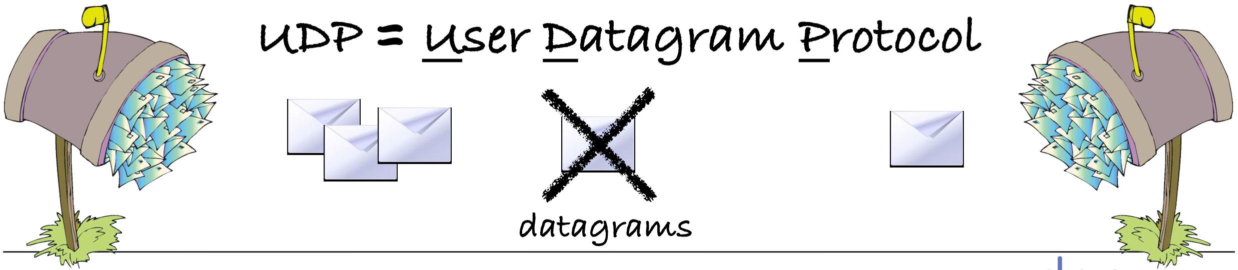


TCP *versus* UDP (1)

TCP = Transmission Control Protocol



UDP = User Datagram Protocol



TCP *versus* UDP (2)

TCP and UDP exhibit dual features:

	connection oriented	reliable channels	fifo ordering	message boundaries
TCP	YES	YES	YES	NO
UDP	NO	NO	NO	YES

The Socket abstraction

- □ Sockets are programming abstractions that represent bidirectional communication endpoints between two or more processes
- □ There exists two types of sockets : TCP sockets and UDP sockets
- □ In Java, sockets are instances of various classes found in the java.net package

TCP Sockets

- ☐ Because TCP is connection-oriented, we have two classes for TCP sockets in Java:

Client

```
public class Socket {
    ...
    public
    Socket(String host, int port) {...}
    public
    OutputStream getOutputStream() {...}
    public
    InputStream getInputStream() {...}
    public
    void close() {...}
    ...
}
```

Server

```
public class ServerSocket {
    ...
    public
    ServerSocket(int port) {...}
    public
    Socket accept() {...}
    ...
}
```

- ☐ This captures the asymmetry when establishing a communication channel

TCP sockets: server side

```
public class DictionaryServer {
    private static Dictionary dico= new Hashtable();
    public static void main(String[] args) {
        ServerSocket connectionServer= null; Socket clientSession= null;
        PrintWriter out= null; BufferedReader in= null;
        dico.put("inheritance", "héritage"); dico.put("distributed", "réparti"); // Etc...
        try {
            connectionServer = new ServerSocket(4444);
            clientSession = connectionServer.accept();
            out = new PrintWriter(clientSession.getOutputStream(), true);
            in = new BufferedReader(new InputStreamReader(clientSession.getInputStream()));
            String word, mot;

            while ( (word = in.readLine()) != null ) {
                mot= (String) dico.get(word);
                if (mot == null) mot= "sorry, no translation available for \"" + word + "\" !";
                out.println(mot);
            }
            out.close(); in.close(); connectionServer.close(); clientSession.close();
        } catch (IOException e) {
            System.out.println(e); System.exit(1);
        }
    }
}
```

TCP sockets: client side

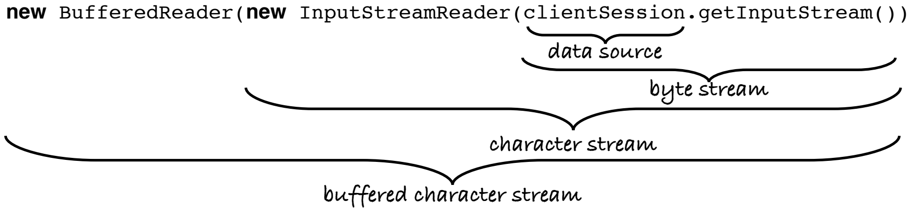
```
public class DictionaryClient {
    public static void main(String[] args) {
        Socket mySession= null; PrintWriter out= null;
        BufferedReader in= null; BufferedReader stdIn= null;
        try {
            if (args.length < 1) { System.out.println("Hostname missing."); System.exit(1); }
            mySession = new Socket(args[0], 4444);
            out = new PrintWriter(mySession.getOutputStream(), true);
            in = new BufferedReader(new InputStreamReader(mySession.getInputStream()));
            stdIn = new BufferedReader(new InputStreamReader(System.in));
            String fromServer, fromUser;

            System.out.println("Go on, ask the dictionary server!");
            while ( !(fromUser = stdIn.readLine()).equals("quit") ) {
                out.println(fromUser);
                fromServer= in.readLine();
                System.out.println("-> " + fromServer);
            }
            out.close(); in.close(); stdIn.close(); mySession.close();
        } catch (UnknownHostException e) {
            System.err.println("Host Unknown: " + args[0]); System.exit(1);
        } catch (IOException e) {
            System.err.println("No connection to: " + args[0]); System.exit(1);
        }
    }
}
```

Streams in Java (1)

- ☐ Streams offer a unified programming abstraction for reading and writing data
- ☐ Streams can encapsulate various types of data sources, e.g., files, byte arrays in memory, sockets, etc.
- ☐ Streams can encapsulate other streams to stack up processing of the data
- ☐ In Java, streams are instances of various classes found in the java.io package

Streams in Java (2)

```
…
Socket clientSession= connectionServer.accept();
BufferedReader in= new BufferedReader(new InputStreamReader(clientSession.getInputStream()));
…
```



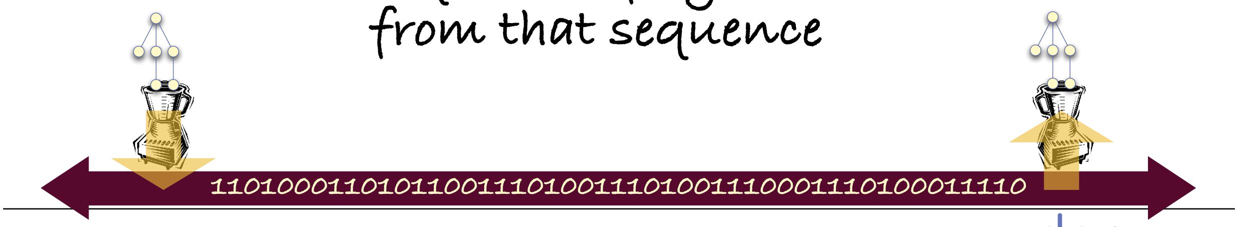
- □ Printer and writer classes are special streams manipulating only characters
- □ Standard operating systems-level input and output streams are also accessed via Java streams (System.in & System.out)

Objects through the wire (1)

<u>Fact:</u> the network knows nothing about objects, only about bytes

<u>Problem:</u> how can we send a complete object graph across the network?

<u>Solution:</u> almost any Java object can be automatically transformed into a sequence of bytes and recreated from that sequence



Objects through the wire (2)

- □ The process of transforming an object graph into a byte sequence is known as serialization or marshaling
- □ By implementing the java.io.Serializable interface, an object becomes serializable
- □ Two special stream classes allow for writing and reading objects :

```
ObjectOutputStream out = new ObjectOutputStream(clientSession.getOutputStream());
out.writeObject(myCollection);

ObjectInputStream in= new ObjectInputStream(clientSession.getInputStream());
Collection yourCollection = (Collection) in.readObject();
```

UDP Sockets

- □ Because UDP is connectionless, we have only one class for UDP sockets in Java:

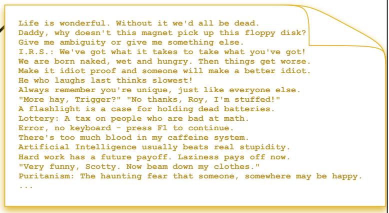
```
public class DatagramSocket {
    ...
    public
    DatagramSocket() {...}    // Let the system choose a port
    public
    DatagramSocket(int port) {...}
    public
    void send(DatagramPacket packet) {...}
    public
    void receive(DatagramPacket packet) {...}
    public
    void close() {...}
    ...
}
```

```
public class DatagramPacket {
    ...
    public
    DatagramPacket(...) {...}
    public
    byte[] getData() {...}
    public
    InetAddress getAddress() {...}
    ...
}
```

- □ However, the DatagramPacket is also a key class when working with UDP sockets

UDP sockets: server side

```
public class QuoteServer   {
    public static void main(String[] args) throws Exception {
        DatagramSocket socket = null;
        BufferedReader in = null;
        socket = new DatagramSocket(4445);
        in = new BufferedReader(new FileReader("one-liners.txt"));
        String quote = null;
        boolean moreQuotes= true;

        while (moreQuotes) {
            byte[] buf= new byte[256];
            DatagramPacket packet = new DatagramPacket(buf, buf.length);
            socket.receive(packet);
            quote = in.readLine();
            if (quote == null)  { moreQuotes= false; buf= ("No more, bye!").getBytes();}
            else { buf = quote.getBytes(); }
            InetAddress address = packet.getAddress();
            int port = packet.getPort();
            packet = new DatagramPacket(buf, buf.length, address, port);
            socket.send(packet);
        }
        socket.close();
    }
}
```

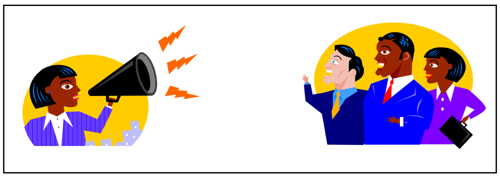


```
Life is wonderful. Without it we'd all be dead.
Daddy, why doesn't this magnet pick up this floppy disk?
Give me ambiguity or give me something else.
I.R.S.: We've got what it takes to take what you've got!
We are born naked, wet and hungry. Then things get worse.
Make it idiot proof and someone will make a better idiot.
He who laughs last thinks slowest!
Always remember you're unique, just like everyone else.
"More hay, Trigger?" "No thanks, Roy, I'm stuffed!"
A flashlight is a case for holding dead batteries.
Lottery: A tax on people who are bad at math.
Error, no keyboard - press F1 to continue.
There's too much blood in my caffeine system.
Artificial Intelligence usually beats real stupidity.
Hard work has a future payoff. Laziness pays off now.
"Very funny, Scotty. Now beam down my clothes."
Puritanism: The haunting fear that someone, somewhere may be happy.
...
```

UDP sockets: client side

```
public class QuoteClient {
    public static void main(String[] args) throws Exception {
        if (args.length != 1) { System.out.println("Missing hostname"); System.exit(1); }
        DatagramSocket socket = new DatagramSocket();
        InetAddress address = InetAddress.getByName(args[0]);
        BufferedReader stdIn = new BufferedReader(new InputStreamReader(System.in));
        System.out.println("Go on, ask for a quote by typing return!");
        while ( !stdIn.readLine().equals("quit") ) {
            byte[] buf = new byte[256];
            DatagramPacket packet = new DatagramPacket(buf, buf.length, address, 4445);
            socket.send(packet);
            packet = new DatagramPacket(buf, buf.length);
            socket.receive(packet);
            String received = new String(packet.getData());
            System.out.println("-> " + received);
        }
        socket.close();
    }
}
```

UDP Multicast



- A multicast allows for one-to-many communication in an anonymous way
- A multicast address is an address between 224.0.0.0 and 239.255.255.255, and defines a so-called multicast group
- In Java, multicast is available thanks to a the MulticastSocket class:
  - Methods joinGroup() and leaveGroup() allow a receiver to respectively join and leave a multicast group
  - Method setTimeToLive() allows a sender to restrict the number of hubs its sent messages are going through

UDP Multicast: sender

```
public class MulticastQuoteSender   {
    public static void main(String[] args) throws Exception {
        MulticastSocket socket = null;
        BufferedReader in = null;
        socket = new MulticastSocket();
        socket.setTimeToLive(1);
        in = new BufferedReader(new FileReader("one-liners.txt"));
        String quote = null;
        boolean moreQuotes= true;

        while (moreQuotes) {
            Thread.currentThread().sleep(500);
            byte[] buf = new byte[256];
            quote = in.readLine();
            if (quote == null)  { moreQuotes= false; buf= ("No more, bye!").getBytes();}
            else { buf = quote.getBytes(); }
            InetAddress group = InetAddress.getByName("230.0.0.1");
            DatagramPacket packet = new DatagramPacket(buf, buf.length, group, 4446);
            socket.send(packet);
        }
        socket.close();
    }
}
```

UDP Multicast: receiver

```
public class MulticastQuoteReceiver {
    public static void main(String[] args) throws Exception {
        try {
        MulticastSocket socket = new MulticastSocket(4446);
        InetAddress group = InetAddress.getByName("230.0.0.1");
        socket.joinGroup(group);
        while (true) {
            byte[] buf = new byte[256];
            DatagramPacket packet = new DatagramPacket(buf, buf.length);
            System.out.print("Waiting for the next quote: ");
            socket.receive(packet);
            String received = new String(packet.getData());
            System.out.println(received);
            if ( received.indexOf("bye") != -1 ) break;
        }
        socket.leaveGroup(group);
        socket.close();
        } catch (Exception e) {
            e.printStackTrace();
        }
    }
}
```