ID2212 Network Programming with Java
Lecture 4

Networking with Sockets

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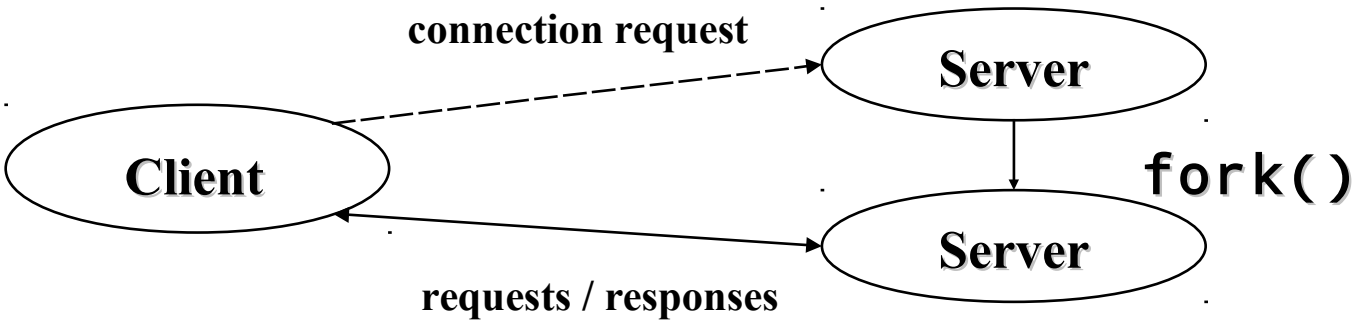
KTH/ICT/SCS
HT 2015

Outline

- **Review**
  - **Client-server architecture**
  - **Berkley Socket API in C**
- **Socket API in Java**
  - **Client Socket – connecting socket**
  - **Socket for Servers – listening socket**
  - **UDP sockets**
  - **Multicast**

Review: Client-Server Architecture

- The most commonly used model for distributed applications
  - Can be applied for a particular request-response interaction
- The *client* is the entity (process) accessing the remote resource and the *server* provides access to the resource.
- Request / response protocols



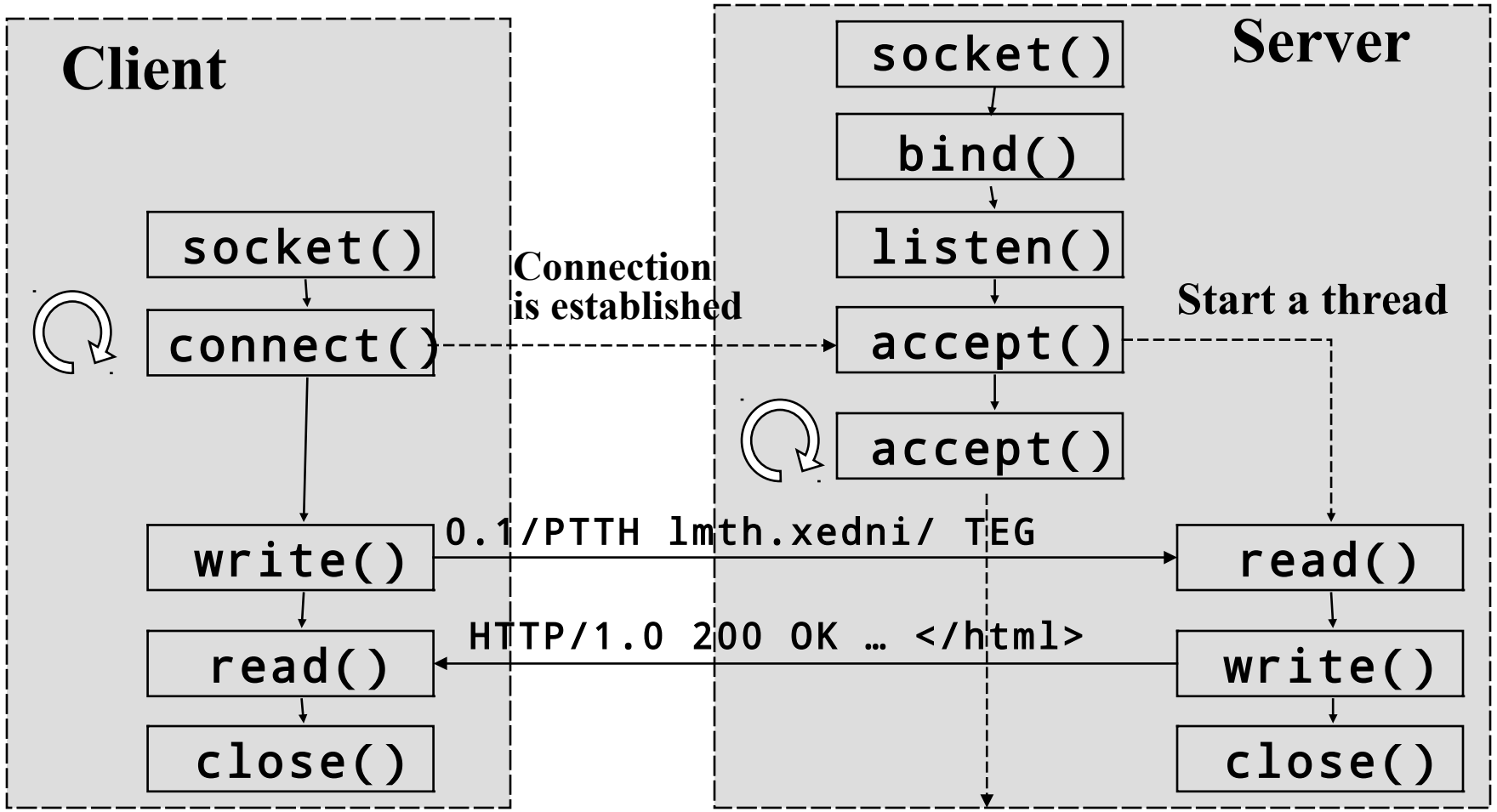
Review: Sockets

- *Socket* is an end-point of a virtual network connection between processes – much like a full-duplex channel
  - A socket address: IP address and a port number
  - A transport protocol used for communication over a socket
- *TCP socket* - stream-based, connection-oriented
- *UDP socket* - datagram-based, connectionless
- Sockets, a.k.a. *Berkeley sockets*, were introduced in 1981 as the Unix BSD 4.2 generic API for inter-process communication
  - Earlier, a part of the kernel (BSD Unix)
  - Now, a library (Solaris, MS-DOS, Windows, OS/2, MacOS)

Ports

- *Port* is an entry point to a process that resides on a host.
- 65,535 logical ports with integer numbers 1 - 65,535
- A port can be allocated to a particular service:
  - A server listens the port for incoming requests
  - A client connects to the port and requests the service
  - The server replies via the port.
- Ports with numbers 1-1023 are reserved for well-known services.
  - A list of services and allocated ports is stored in
    - /etc/services (Unix)
    - C:\Windows\services (Windows95)
    - C:\WINNT\system32\drivers\etc\services (WindowsNT)
    - C:\WINDOWS\system32\drivers\etc (Windows XP)

The Berkeley Socket API for the Client-Server Architecture



Sockets in `java.net`

- Two classes of TCP sockets
- `Socket` – connecting socket, a.k.a. client socket
  - Used to connect to another (remove) TCP socket specified by an IP address and a port number.
  - A connected TCP socket provides two sequenced byte streams, input and output streams, used to communicate with the remote process by reads and writes.
- `ServerSocket` – listening socket, a.k.a. server socket
  - Used to listen for connection requests, to accept connection and create a `Socket` object connected to the requester.

Sockets in `java.net` (cont'd)

- **Two classes of UDP sockets:**
- `DatagramSocket`
  - **used for sending and/or receiving datagrams represented by objects of the `DatagramPacket` class.**
- `MulticastSocket`
  - **is a subclass of `DatagramSocket` with capabilities for joining multicast groups on the Internet.**
  - **A multicast group is identified by an IP address of class D (multicast address (224-239.x.x.x)**

java.net.InetAddress

- Represents an IP address of a node on the Internet.
- Does not have public constructors.
- Getting an IP address:

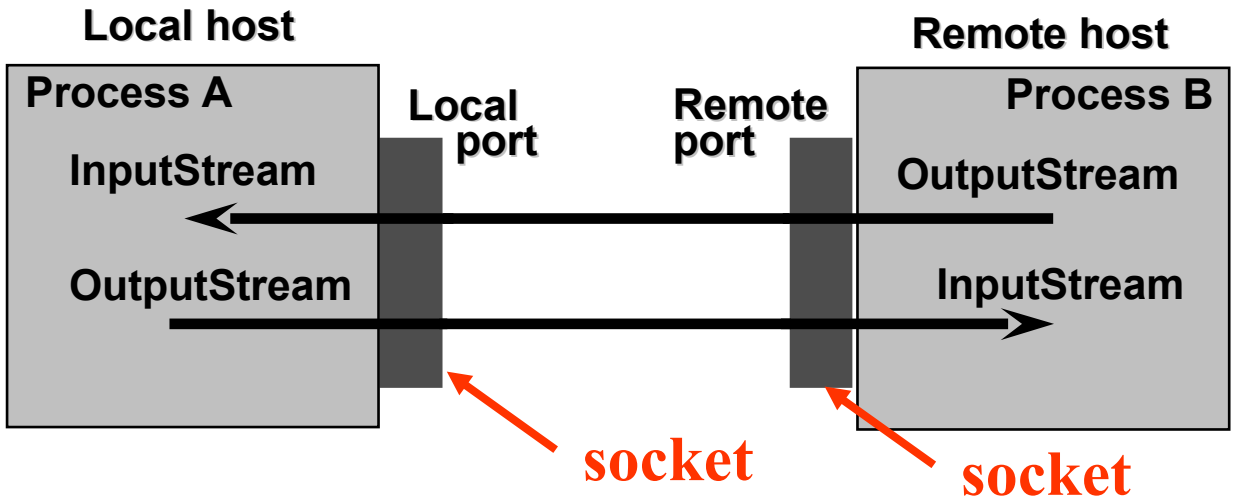
```
InetAddress ip1, ip2, localIP;
InetAddress[] ips;
try {
  // IP address of the local host
  localIP = InetAddress.getLocalHost();
  // IP address(es) of a remote host
  ip1 =
  InetAddress.getByName("it-gw.it.kth.se");
  ip2 =
  InetAddress.getByName("130.237.214.1");
  ips =
  InetAddress.getAllByName("130.237.214.1");
} catch ( UnknownHostException e ) {
  e.printStackTrace();
};
```

Client Sockets – Connecting Sockets

`java.net.Socket`

java.net.Socket

- **Implements a connecting TCP socket that provides connection to a specified host on a specified port.**
  - **When connected, provides input and output byte streams**



Socket Constructors

Socket(…)

- (String remoteHost, int remotePort)
- (InetAddress remoteAddr, int remotePort)
- (String remoteHost, int remotePort,
  InetAddress localAddr, int localPort)
- (InetAddress remoteAddr, int remotePort,
  InetAddress localAddr, int localPort)
- ( )
- (SocketImpl socketImplementation)

Socket's Attributes

- `setSoLinger(boolean, int)`
  - **Enable/disable SO_LINGER with the specified linger time (linger on close if data are present).**
    - **Note: Use `netstat` utility to check open connection.**
- `setSoTimeout(int)`
  - **Enable/disable SO_TIMEOUT with the specified time-out, in milliseconds.**
- `setTcpNoDelay(boolean)`
  - **Enable/disable TCP_NODELAY (disable/enable Nagle's algorithm).**

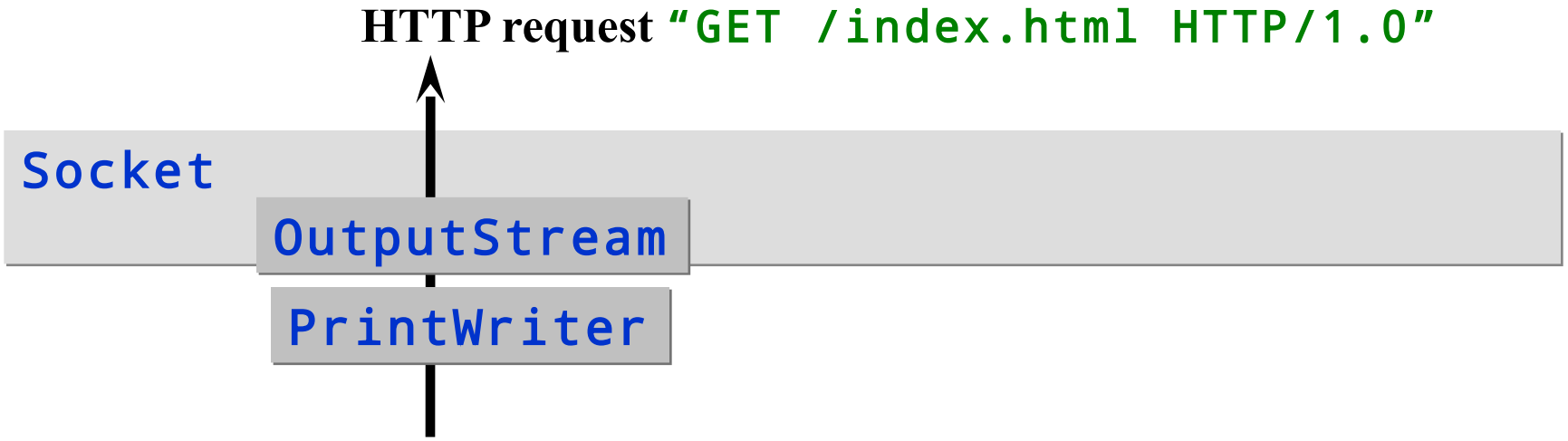
Communicating via a TCP Socket

- **Steps:**
  - **Establish a socket connection to the specified host on the specified port by create a connected `Socket` object.**
  - **Set socket's attributes.**
  - **Get an input stream of the socket connection for reading data.**
  - **Get an output stream of the connection for writing data.**
  - **Communicate via the input and output streams by reads and writes according to an application specific communication protocol.**
  - **Close the socket connection.**

Example: A Code Fragment from a HTTP Client

```
try {
    Socket socket = new Socket(host, port); // create a connected
socket
    socket.setSoTimeout( 10000 ); // set 10 sec timeout
    PrintWriter wr = new PrintWriter(socket.getOutputStream()); //
output stream
    wr.println("GET " + file + " HTTP/1.0"); // send GET request
    wr.println();
   wr.flush();
    BufferedReader rd = new BufferedReader( new
        InputStreamReader(socket.getInputStream())); // input
stream
    String str;
    while ((str = rd.readLine()) != null) // receive and print
response
      System.out.println(str);
    socket.close();  // close connection
  } catch (IOException e) {
    System.err.println(e);
  }
```

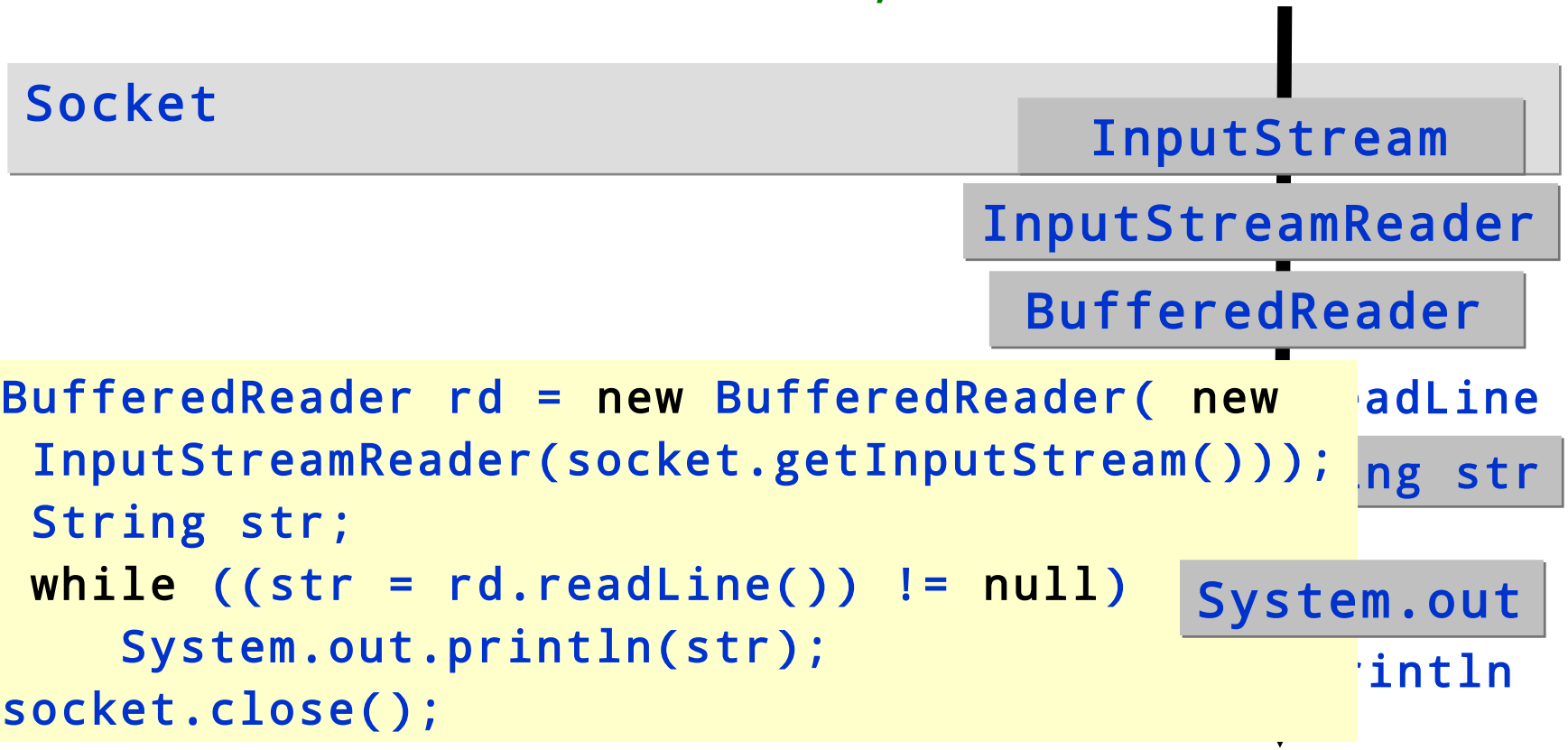
Communication in the `Httpc` Client (Example 3.6)




```
Socket socket = new Socket(host, port);
PrintWriter wr = new PrintWriter(socket.getOutputStream
wr.println("GET " + file + " HTTP/1.0");
wr.println();
wr.flush();
```

The `Httpc` Client (cont)

Reply: "`HTTP/1.1 200 OK`
`Date: Mon, 15 Nov 1999 11:23:29 GMT`



Parsing Textual Data by Tokenizers

- `java.io.StreamTokenizer` **supports splitting a character stream into "tokens".**

```
StreamTokenizer rd = new StreamTokenizer (
                     new BufferedReader(
                     new InputStreamReader(

   socket.getInputStream())));
```

- `java.util.StringTokenizer` **supports splitting a string into "tokens".**
  - `StringTokenizer(String)`
  - **Can be used to parse a text from the input stream accumulated into a** `StringBuffer` **object.**

Example: Usage of Stream Tokenizer

```
try {
      Socket socket = new Socket(host, port);
      socket.setSoTimeout( 10000 );
      PrintWriter wr = new PrintWriter( socket.getOutputStream() );
      wr.println( "GET " + file + " HTTP/1.0“ );
      wr.println();
      wr.flush();
      StreamTokenizer rd = new StreamTokenizer( new BufferedReader (
   new
          InputStreamReader(socket.getInputStream())));
      int num = 0, word = 0, i = 0;
      while ( rd.nextToken() != StreamTokenizer.TT_EOF)
        switch (rd.ttype) {
             case StreamTokenizer.TT_NUMBER: num++; break;
             case StreamTokenizer.TT_WORD: word++;
             if (++i % 5 == 0) System.out.println(rd.sval);
             else System.out.print(rd.sval + " ");
        }
        System.out.println();
        System.out.println("NUM = " + num);
        System.out.println("WORD = " + word);
        socket.close();
    } catch (IOException e) {
        System.err.println(e);
    }
```

Sockets for Servers – listening sockets

`java.net.ServerSocket`

java.net.ServerSocket

- **Implements a listening TCP socket, a.k.a. server socket**
  - **should be bound to some known local port (and known local IP address)**
  - **used to listen and accept connections from clients.**

`ServerSocket(…)`

`(int port)`

A port of 0 creates a socket on any free port.

`(int port, int backlog)`

Here `backlog` **is the maximum allowed length of queue of pending connection requests.**

`(int port, int backlog, InetAddress bindLocalAdd`

Accepting Connections

```
Socket clientSocket = serverSocket.accept();
```

- Blocks the current thread until a client connects
- Returns a connected `Socket` of the accepted connection.

- **For example:**

```
// create a server socket bound to the port 8080
ServerSocket serverSocket = new ServerSocket( 8080 );
while (true) {
    try {
        // wait for a client connection request
        Socket clientSocket = serverSocket.accept();
        // communicate with a client via clientSocket
        …
        // close the socket and wait for another
          connection
        clientSocket.close();
    } catch (SocketException e) { e.printStackTrace(); }
}
```

Handling Connections

- The server uses a `Socket` object to communicate with a connected client
  - The connection should be closed when service is done.
- The server shall handle the connection in a separate thread.
  - When a client connects, constructs a handler thread with the `Socket` object as a parameter of the handler constructor.
  - Starts the handler thread.
  - The parent thread continues waiting for the next connection requests.

Fragment of a Multithreaded Server

```
    ServerSocket serversocket = new ServerSocket( 8080 );
    while (true) {
       try {
                Socket socket = serversocket.accept();
                Handler handler =  new Handler( socket );
                handler.setPriority( handler.getPriority() + 1
           );
                handler.start();
       }
       catch (SocketException e) { e.printStackTrace(); }
    }
    . . .
}
class Handler extends Thread {
        private Socket socket;
        Handler(Socket socket) throws IOException { // thread
constructor
                this.socket = socket;
                ... }
        public void run() { // communicate with the client
via the socket
                ...
```

Working with Files. Status of a File

- Very often a server accesses files and/or databases.
- `java.io.File` allows obtaining the status of a file or directory:

```
String basedir =
  "/afs/it.kth.se/misc/info/www/documents";
File file = new File(basedir, "index.html");
```

- Useful methods
  - Get the status of the file:

    `exists(),length(),lastModified(),canRead(), canWrite(),getPath()`
  - Get a list of files in the directory:

    `list(),list(FilenameFilter)`
  - Manipulate a file, directory:

    `mkdir(),delete(),renameTo(File)`

Two APIs to Access Files. See `java.io`

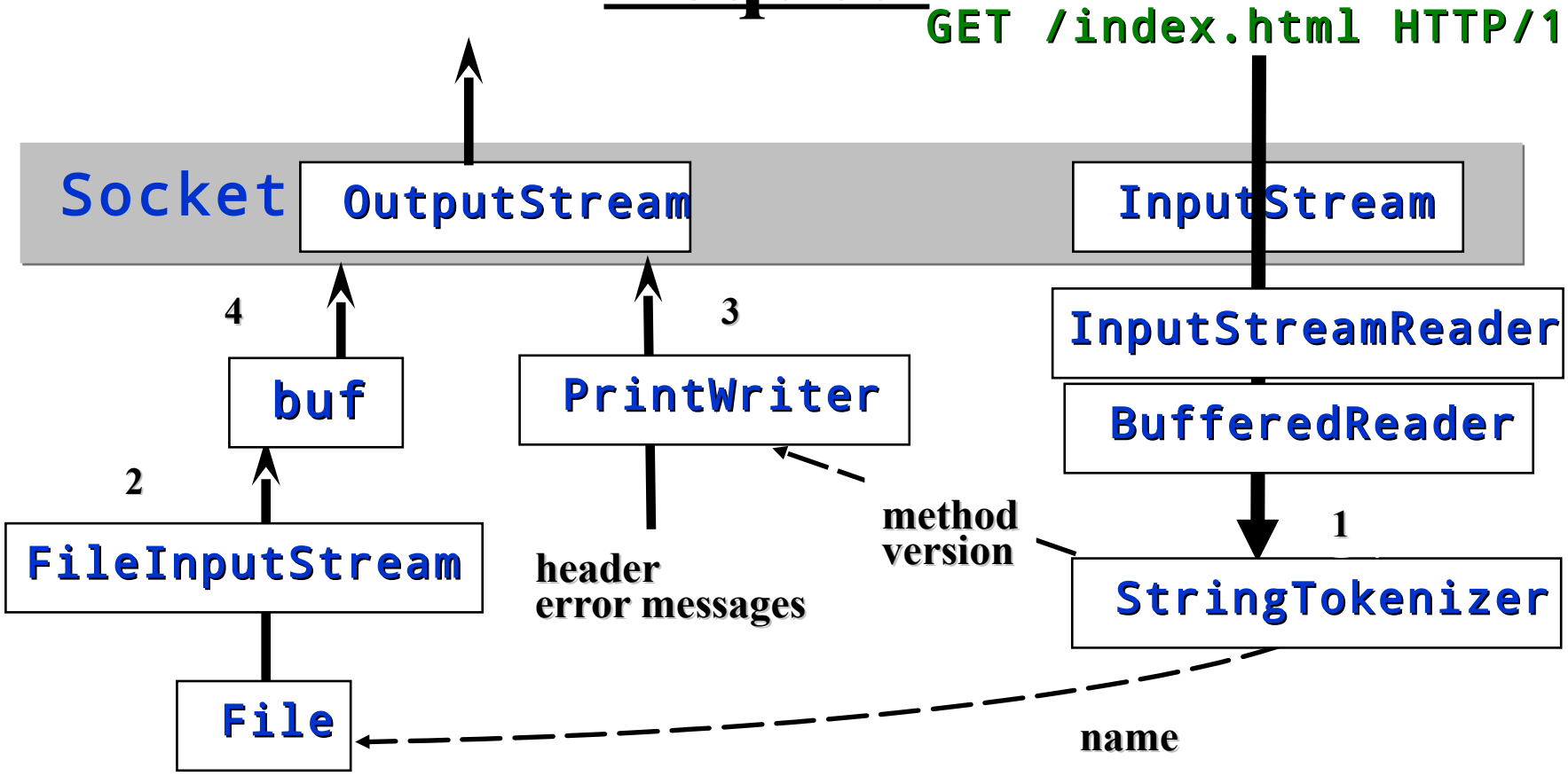
- **Sequential-access file:**
  - `FileInputStream` **and** `FileOutputStream`
    - **represent a file as a byte streams that can be wrapped by any specialized stream:**

```
DataInputStream in = new DataInputStream ( new
  FileInputStream("base.tsv"));
```

  - `FileReader` **and** `FileWriter` **are used to access text files.**

- **Random-access file (similar to file API in C):**
  - **An object of** `RandomAccessFile` **allows reading (or writing) data of various types from (or to) a file.**

Data flow in Httpd : GET Request



Connection Failures

- **Connection failures are signaled via exceptions thrown by methods of socket APIs (constructors, connect, accept, read, write, bind, etc.)**
- **Exceptions that indicate errors in the underlying protocol, such as a TCP error, are indicated by `SocketException` and its subclasses:**
  - `BindException`
    - **on failed attempt to bind a socket to a local address and port.**
  - `ConnectException`, `NoRouteToHostException`
    - **on failed attempt to connect a socket to a remote address and port.**

(cont'd) Connection Failures

- **The client can get exceptions**
  - `UnknownHostException`
    - **The IP address of a host could not be determined (getters of InetAddress)**
  - `IOException` **(subclass** `ProtocolException`**)**
    - **while creating the socket (Socket constructors) and communicating via the socket connection (getInputStream, getOutputStream, read/write, etc.)**
- **The server can get exceptions**
  - `IOException` **(subclass** `ProtocolException`**)**
    - **opening a server socket (ServerSocket constructors)**
    - **waiting for a connection and accepting the connection in accept()**
    - **closing the socket by close()**

JSSE (Java Secure Socket Extension)

- **A set of Java packages that enable secure Internet communications.**
  - **Implements a Java version of SSL (Secure Sockets Layer) and TLS (Transport Layer Security) protocols**
  - **Includes functionality for data encryption, server authentication, message integrity, and optional client authentication.**
  - `javax.net.ssl`
  - `javax.net`
  - `java.security.cert`
  - `com.sun.net.ssl`
- **JSSE on the Web:**

  http://www.oracle.com/technetwork/java/javase/tech/index-jsp-136007.html

  http://download.oracle.com/javase/8/docs/technotes/guides/security/

UDP Sockets. Multicast

`java.net.DatagramSocket`
`java.net.DatagramPacket`
`java.net.MulticastSocket`

UDP Sockets

- The `java.net.DatagramSocket` class
  - represents a UDP socket for sending and receiving datagrams – objects of the `java.net.DatagramPacket` class

- **Sending datagrams:**

```
DatagramSocket ds = new
    DatagramSocket();
byte buf[] = new byte[256];
// fill buf with data to be sent
…
// create a datagram
DatagramPacket dp = new
    DatagramPacket(
    buf, buf.length,
    InetAddress.getByName("dest.host.co
    m"),
    4711);
// send the datagram via the UDP
    socket
ds.send(dp);
```

- **Receiving datagrams:**

```
byte b[] = new byte[256];
DatagramPacket dp = new DatagramPacket(b,
    b.length);
/* Set timeout – the amount of time (in
    milliseconds) that receive() waits for
    datagram before throwing an
    InterruptedIOException. With the time
    out of 0, receive() never times out.
*/
ds.setSoTimeout(timeout)
ds.receive(dp); // receive a datagram
byte[] data = dp.getData(); // get data
InetAddress source = dp.getAddress(); //
    source
int port = dp.getPort(); // source port
```

IP Multicast

- ***IP multicast*** **is communication within a multicast group identified by a multicast IP address of the D class:**

  `224-239.x.x.x`

- ***A multicast group*** **is a set of computers sharing the same multicast address.**
  - **~80 of multicast addresses are permanently assigned by the IANA (Internet Assigned Number Authority).**
- **To receive datagrams directed to a multicast group, a computer joins the group (gets its IP address)**
  - **Informs a default router about its interest in receiving UDP packets directed to the group's IP address**

IP Multicast (cont'd)

- **Multicast is based on sending UDP datagrams to a multicast group.**
- **An IP header of a UDP packet includes the field *TTL (Time-To-Live)* that specifies the number of routers that the packet can pass through (in the range 0-255).**

MBONE. Videoconferencing on the Internet

- ***MBONE*** **(Multicast Backbone on the Internet) is the range of Class D addresses beginning with 224.2.x.x**
  - **Mbone is a part of the Internet formed of routers supporting the IP multicast extension.**
  - **Mbone is used for audio and video broadcasts over the Internet.**
- **The MBONE programs should be announced on 224.2.127.254 (port 9875).**

Multicast with Java

- `MulticastSocket` **is a subclass of** `DatagramSocket` **that represents a UDP socket with capabilities for joining multicast groups on the Internet.**
- **Communicating with a multicast group**
  - **Construct a multicast socket**
  - **Join a multicast group (for receiving)**
  - **Send/receive data to/from the multicast group**
  - **Leave the group**

Receiving from a Multicast Group

```
try {
   MulticastSocket ms = new MulticastSocket( 9875 );

   ms.joinGroup(InetAddress.getByName("224.2.127.254
   "));
    while (true) {
      ms.receive(dp);
      String s = new
   String(dp.getData(),0,0,dp.getLength());
      System.out.println(s);
   }
} catch (Exception se) {
   se.printStackTrace();
}
```

Sending to a Multicast Group

```
InetAddress iaddr =
   InetAddress.getByName( “224.17.17.17” );
DatagramPacket dp = new DatagramPacket(data,
   data.length,
                                    iaddr, port);
try {
      MulticastSocket ms = new MulticastSocket();
      ms.setTimeToLive( 16 ); // set TTL to 16
      ms.joinGroup(iaddr); // not necessary for sending
      ms.send(dp);
      ms.leaveGroup(iaddr); // not necessary for
      sending
      ms.close();
} catch (SocketException se) {
      se.printStackTrace();
} catch (IOException ioe) {
      ioe.printStackTrace();
}
```

Implication for A Course Project

- **Client-Server interaction using TCP**
  - **Client side:**
    - **Host and port of a server should be command line arguments**
    - **Do not bind a client socket to a fixed local port number**
    - **Do not forget to flush the socket output stream when sending a request**
    - **Remember that read from a socket input stream is blocking**
    - **Should set timeout for a socket and properly handle exceptions**
    - **Take into account long communication latency: User interface should be responsive, use multithreading: a thread for the user interface, a thread for the network interface.**
    - **A Client may create and listen a server socket (e.g. for callbacks). It should do this in a separate "server" thread**

Implication for the Course Project (cont'd)

- **Client Server interaction using TCP**
  - **Server side:**
    - **A server port should be a command line argument**
    - **A server should be scalable, i.e. it should be able to handle multiple requests simultaneously by using multithreading**
    - **Two approaches to multithreading:**
      - **(1) create a new thread for each client connected;**
      - **(2) assign a thread to a client from a pool of threads**
    - **While communicating with a client, do not forget to set timeout to a TCP socket, and flush output stream when needed**

Implication for the Course Project (cont'd)

- **Communication using UDP**
  - **The same UDP socket can be used for both, sending and receiving**
  - **A TCP socket and a UDP socket may be bound to the same port number**
  - **Sending a datagram, set a proper TTL**
  - **Remember that receive is a blocking call**
    - **Set timeout and handle exceptions properly**
  - **You may get source address (IP address and port) from a datagram received**

Implication for the Course Project (cont'd)

- **Problem with request-response interaction using UDP:**
  - **if `receive` is interrupted because of timeout, you may treat this as there is no response to the sent request and send a new request. However, next `receive` may receive a response on the old request rather than the one sent recently.**
  - **Your application should be able to handle this situation.**

Implication for the Course Project (cont'd)

- **Communication with a multicast group**
  - **A multicast address(es) and port(s) should be command line arguments.**
  - **To send to a multicast group, it is not needed to join the group**
    - **You may use DatagramSocket for sending to the group**
  - **Responses to one member of a group should be sent directly to the member (to it's IP) rather than to the entire group**
  - **When your application waits for a response from the multicast group, it should be able to handle two extreme cases**
    - **No response**
    - **Too many responses**
  - **You should also solve the problem of receiving old responses (see previous slide).**