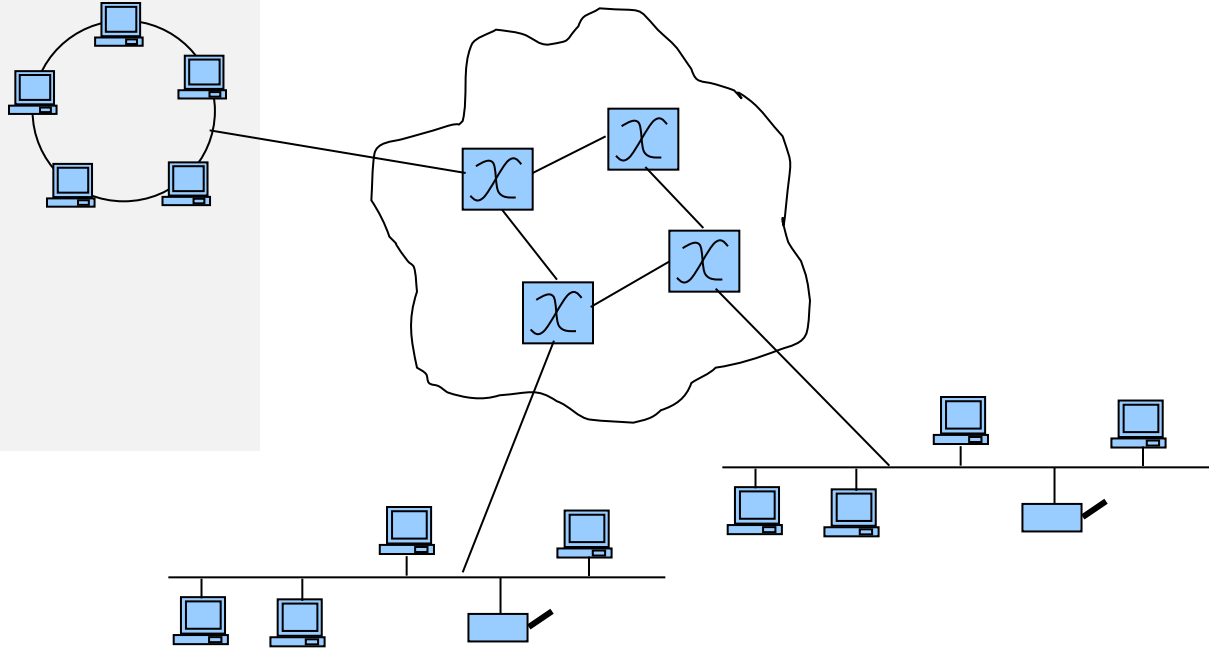


Networking

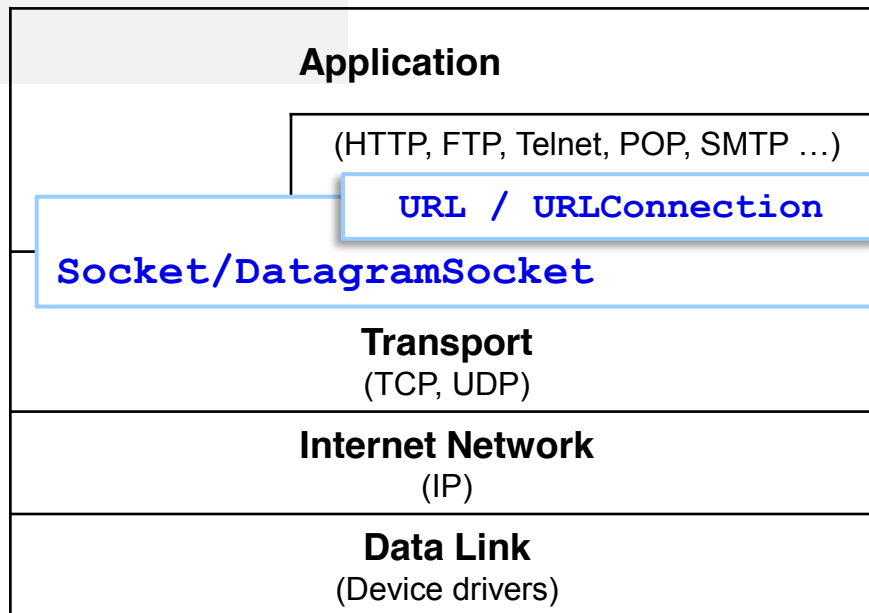
Internet



- Each computer has a unique identifier – ***IP Address***
- Data are delivered in small units – ***Packets***
- Definition of packet formats and delivery – ***Internet Protocol (IP)***

Networking Basics

- Java is the first language to provide a powerful cross-platform network support for writing programs that
 - communicate with other programs on the network
 - use and interact with the resources on the Internet and Web



*Java programming
at the Application layer*

Transport Protocols

- Java provides classes for networking for both TCP and UDP protocols

TCP

- Transmission Control Protocol
- TCP is a connection-based protocol that provides a *reliable flow of data* between two computers
- e.g. HTTP, FTP, Telnet

Java classes:

`Socket`, `ServerSocket`,
`URL`, `URLConnection`

UDP

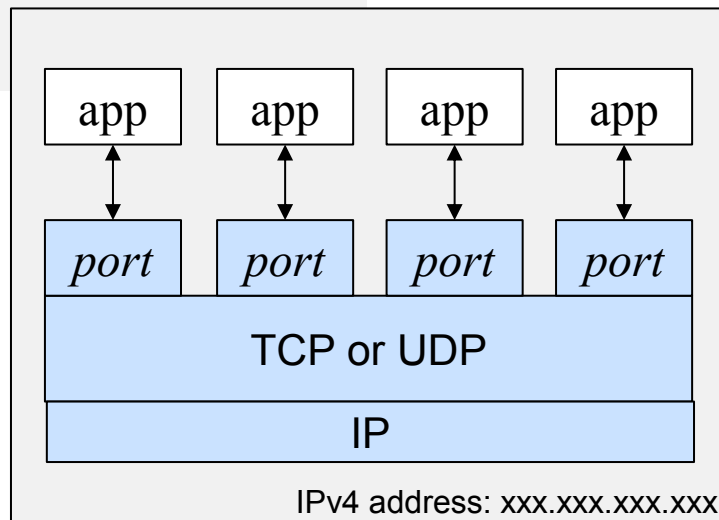
- User Datagram Protocol
- UDP is a protocol that sends *independent packets of data*, called *datagrams*, from one computer to another with no guarantees about arrival
- UDP is not connection-based like TCP
- e.g. clock server

Java classes:

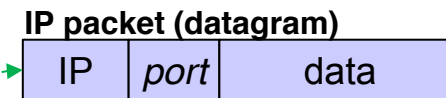
`DatagramPacket`,
`DatagramSocket`,
`MulticastSocket`

Ports

- *Ports* are used by TCP and UDP protocols to identify a particular process (application) to forward incoming data that transmitted through a single physical connection to the network



- Ports: 0 to 65,535
- Restricted: 0 to 1023 reserved for *well-known services*, such as HTTP (80), FTP (21), Telnet (23), ssh (22) SMTP (25), etc.



xxx.xxx.xxx.xxx

Hostname-to-IP/reverse name resolution

- local machine configuration (hosts)
- Domain Naming Service (DNS)
- Network Information Services (NIS)

*Hostname
Domain name*

IP Address

- Most widely deployed IP is IP version 4 (IPv4)
- IPv4 uses 32-bit (4-byte) addresses in the well known dotted decimal format: xxx.xxx.xxx.xxx
 - IP version 6 (IPv6) has been in commercial deployment since 2006, which uses 128-bit (8 groups of 4-hexadecimal) addresses

Reserved IP addresses

Classless Range	Address Range	Description
10.0.0.0/8	10.0.0.0-10.255.255.255	Private network
127.0.0.0/8	127.0.0.0-127.255.255.255	Loopback
172.16.0.0/12	172.16.0.0-172.31.255.255	Private network
192.168.0.0/16	192.168.0.0-192.168.255.255	Private network
224.0.0.0/4	224.0.0.0-239.255.255.255	IP multicast
255.255.255.255	255.255.255.255	Broadcast

Sockets

- A socket is one end-point of a two-way communication link between two programs running on the network
- A socket is bound to a port number so that the TCP layer can identify the application that data is destined to be sent
- Socket classes are used to represent the platform-independent connection between a client program (**Socket**) and a server program (**ServerSocket**)
- **ServerSocket**:
 - a socket that servers (listening applications) can use to listen for and accept connections to clients
- **Socket**:
 - implements one side of a two-way connection between your Java program and another program on the network

Stream (TCP) Programming

Server host

Client host

1. Create a server socket on a port

```
ServerSocket serverSocket =  
    new ServerSocket(port);
```

2. Create a socket to listen to a connecting client

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

4. Obtain I/O streams

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

3. Create a socket to connect to the server

```
Socket socket =  
    new Socket(serverHost, port);
```

4. Obtain I/O streams

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


Example: Data Transmission through Sockets

Server

```
int port = 8000;
DataInputStream in;
DataOutputStream out;
ServerSocket server;
Socket socket;

server = new ServerSocket(port);
socket = server.accept();

in = new DataInputStream
    (socket.getInputStream());
out = new DataOutputStream
    (socket.getOutputStream());

System.out.println(in.readDouble());
out.writeDouble(aNumber);
```

Client

```
int port = 8000;
String host = "localhost";
DataInputStream in;
DataOutputStream out;
Socket socket;

socket = new Socket(host, port);

in = new DataInputStream
    (socket.getInputStream());
out = new DataOutputStream
    (socket.getOutputStream());

out.writeDouble(aNumber);
System.out.println(in.readDouble());
```

Basic Steps of Socket Programming

- 1 Open a socket
- 2 Open an input stream and output stream to the socket
- 3 Read from and write to the stream
according to the server's PROTOCOL
- 4 Close the streams
- 5 Close the socket

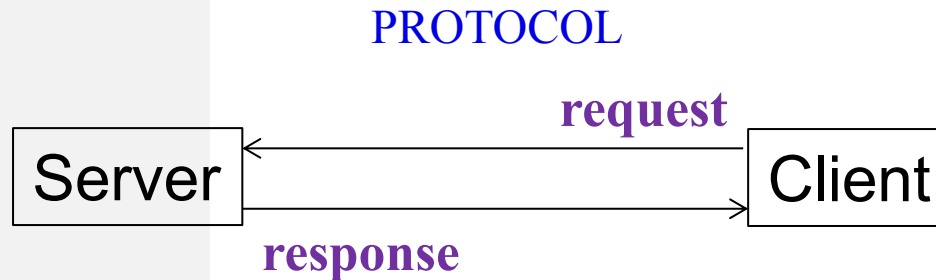
You need to define your application-specific protocol

Protocol examples:

HTTP: **GET**, **POST**, **OPTIONS** ...

FTP: **LIST**, **CWD**, **RETR** (get) ...

Communication Protocol



- Decide on the different commands (requests) and data to exchange for each server operation
- Associate keyword or numeric codes with each command to identify possible responses

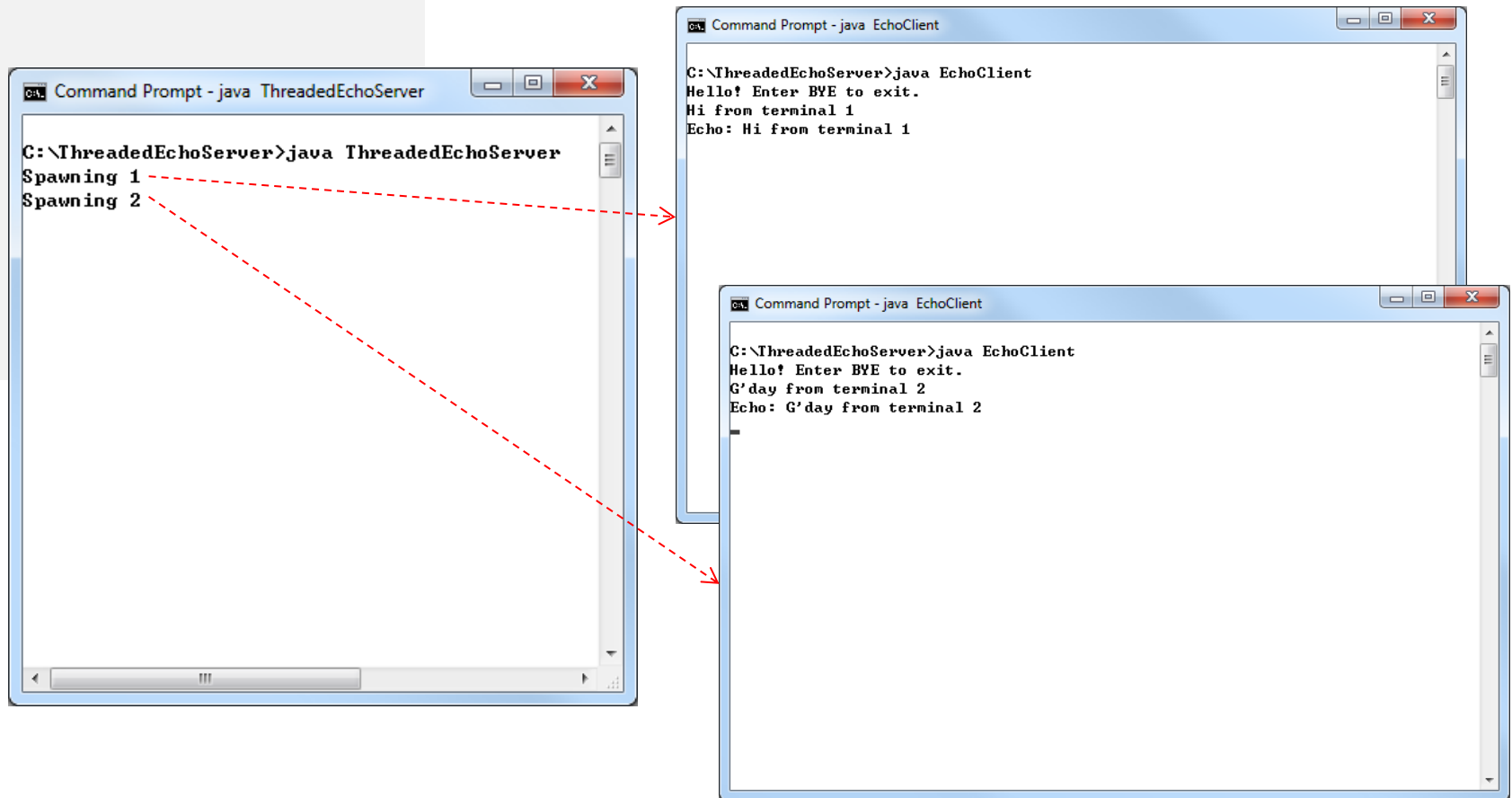
Threaded Servers

- Serving multiple clients (Listener Mechanism)

```
while(true) {
    Socket incoming = serverSocket.accept();
    Runnable clientHandler = new ClientHandler(incoming);
    new Thread(clientHandler).start();
}

class ClientHandler implements Runnable {
    ...
    public void run(){
        try {
            InputStream inStream = incoming.getInputStream();
            OutputStream outStream = incoming.getOutputStream();
            /* processing input and send response */
            // synchronization is necessary for safety of shared data
            incoming.close();
        } catch {
            // handle exception
        }
    }
}
```

Example: Threaded Echo Server



Example: Threaded Echo Server

Server main loop

```
public class ThreadedEchoServer {  
    public static void main(String[] args ) {  
        try {  
  
            int i = 1;  
            ServerSocket s = new ServerSocket(8000);  
  
            while (true) {  
                Socket incoming = s.accept();  
                System.out.println("Spawning " + i);  
                Runnable r = new ThreadedEchoHandler(incoming);  
                Thread t = new Thread(r);  
                t.start();  
                i++;  
            }  
        } catch (IOException e) {  
            e.printStackTrace();  
        }  
    }  
}
```

Example: Threaded Echo Server

Server Client Handler

```
class ThreadedEchoHandler implements Runnable
{
    . . .
    public void run() {
        try{
            try {
                InputStream inStream = incoming.getInputStream();
                OutputStream outStream = incoming.getOutputStream();
                Scanner in = new Scanner(inStream);
                PrintWriter out = new PrintWriter(outStream, true /*autoFlush*/);
                out.println( "Hello! Enter BYE to exit." );
                // echo client input
                boolean done = false;
                while (!done && in.hasNextLine()) {
                    String line = in.nextLine();
                    out.println("Echo: " + line);
                    if (line.trim().equals("BYE")) ← Echo server protocol to disconnect
                        done = true;
                }
            } finally {
                incoming.close();
            }
        }
    }
}
```

Example: Echo Client

```
public class EchoClient {
    public static void main(String[] args) throws IOException {
        try {
            Socket echoSocket = new Socket (
                InetAddress.getLocalHost().getHostName(), 8000);
            PrintWriter out = new PrintWriter(echoSocket.getOutputStream(), true);
            Scanner in = new Scanner(echoSocket.getInputStream());
            System.out.println(in.nextLine());
            Scanner stdIn = new Scanner(System.in);
            String userInput;
            while ((userInput = stdIn.nextLine()) != null) {
                out.println(userInput);
                if(! "BYE".equals(userInput)) System.out.println(in.nextLine());
                else break;
            }
            out.close();
            in.close();
            echoSocket.close();
        } catch (Exception e) {
            e.printStackTrace();
        }
    }
}
```


Serializable Objects for Socket

- Send and receive objects on socket streams

```
ObjectInputStream  
ObjectOutputStream
```

- The objects must be **Serializable**
 - To enable transmission of objects on socket streams

```
class MyClass implements Serializable
```

Example: Sending and Receiving Objects

Student class

```
public class StudentAddress implements Serializable {  
  
    private String name;  
    private String street;  
    private String city;  
    private String state;  
    private String zip;  
  
    public StudentAddress(String name, String street, String city,  
        String state, String zip) {  
        this.name = name;  
        this.street = street;  
        this.city = city;  
        this.state = state;  
        this.zip = zip;  
    }  
  
    public String getName() {  
        return name;  
    }  
  
    public String getStreet() {  
        return street;  
    }  
  
    . . .  
}
```

Example: Sending and Receiving Objects

Student Client

```
// Establish connection with the server
```

```
Socket socket = new Socket(host, 8000);
```

```
// Create an output stream to the server
```

```
ObjectOutputStream toServer =  
    new ObjectOutputStream(socket.getOutputStream());
```

```
// Get text field
```

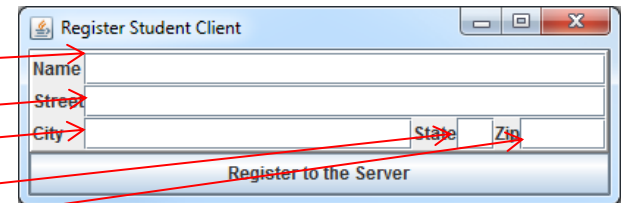
```
String name = jtfName.getText().trim();
```

```
String street = jtfStreet.getText().trim();
```

```
String city = jtfCity.getText().trim();
```

```
String state = jtfState.getText().trim();
```

```
String zip = jtfZip.getText().trim();
```



```
// Create a Student object and send to the server
```

```
StudentAddress s = new StudentAddress(name, street, city, state, zip);
```

```
toServer.writeObject(s);
```

Example: Sending and Receiving Objects

Student Server

```
// Create a server socket
ServerSocket serverSocket = new ServerSocket(8000);

// Create an object output stream
outputToFile = new ObjectOutputStream(
    new FileOutputStream("student.dat", true));

while (true) {
    // Listen for a new connection request
    Socket socket = serverSocket.accept();

    // Create an input stream from the socket
    inputFromClient = new ObjectInputStream(socket.getInputStream());

    // Read from input
    Object object = inputFromClient.readObject();

    // cast the object and print student information
    StudentAddress student = (StudentAddress) object;
    System.out.println("Student name: " + student.getName());
    System.out.println("Student Address: " + student.getStreet() + ", " + . . .);
}
```

Reading and Writing at Sockets

- Java to Java
 - Text:
 - `Scanner/PrintWriter` or `BufferedReader/BufferedWriter`
 - Java sends Unicode characters
 - Primitive data:
 - `DataInputStream/DataOutputStream`
 - Java `int`, `double`, UTF-8 data for Web
 - Objects:
 - `ObjectInputStream/ObjectOutputStream`
 - Often this is the best way
- Java to unknown
 - `DataInputStream/DataOutputStream`
 - Send data as text using `byte` transfers
 - Not all languages handle characters as Unicode characters

Socket Timeouts

- Reading from a socket blocks !

1. Set the timeout

```
Socket socket = new Socket(...);  
socket.setSoTimeout ( milliseconds );  
  
// all read/write throws SocketTimeoutException
```

2. Catch the exception

```
try {  
    InputStream in = soccket.getInputStream();  
    ...  
} catch (InterruptedException) {  
    // react to timeout  
}
```

- The Socket constructor can block indefinitely until connected

```
Socket socket = new Socket();  
socket.connect(new InetSocketAddress(hostname, port), timeout);
```

Interruptible Sockets

- Enable users to cancel a socket connection that does not appear to produce results
- Use **SocketChannel**
 - when a thread is interrupted during an open, read or write operation, the operation does not clock, but is terminated with an exception

```
SocketChannel channel = SocketChannel.open(  
    new InetSocketAddress(host, port));  
  
try {  
    Scanner in = new Scanner (channel);  
    OutputStream outputStream = Channels.newOutputStream(channel);  
    while(!Thread.currentThread().isInterrupted())  
        // read and write to the socket (channel)  
} catch {...}  
} finally {  
    channel.close()  
}
```

Internet Address

- Convert between host name and Internet address
 - **InetAddress** encapsulates the IP address (IPv4 and IPv6)

```
InetAddress address = InetAddress.getByName("www.uow.edu.au");
```

InetAddress
<pre><code>+<u>getByName</u>(String host): InetAddress +<u>getAllByName</u>(String host): InetAddress[] +<u>getLocalHost</u>(): InetAddress +getLocalHost(): String +getAddress(): byte[] +getHostAddress(): String +getHostName(): String</code></pre>

Selected methods are shown

Example: HTTP Session

Example conversation between HTTP client and Web server on a socket at port 80

Client request

```
GET /index.html HTTP/1.1\r\n
Host: www.uow.edu.au\r\n
\r\n
```

Server response

```
HTTP/1.0 200 OK
Date: Sun, 13 May 2012 12:19:04 GMT
Server: Apache/2.2.19 (Unix) mod_ssl/2.2.19
      OpenSSL/0.9.7d DAV/2
Content-Type: text/html
Content-Length: 50415
Age: 1289
X-Cache: HIT from kami.its.uow.edu.au
Via: 1.1 kami.its.uow.edu.au:80
      (squid/2.7.STABLE6)
Connection: close

<!DOCTYPE html>
<html>
<head><meta charset="UTF-8">
. . .
```

URL (Uniform Resource Locator)

- URL address
 - a pointer to a "resource" on the World Wide Web

`http://www.uow.edu.au/index.html`

Application Protocol Domain Name Data Object

- URL class
 - `URL` (and `URLConnection`) objects encapsulates much of complexity of retrieving information from a remote site
 - Higher level than making a socket connections and issuing HTTP requests

```
URL url = new URL(urlString);
```

```
URL url = new URL(URL baseUrl, String relativeURL);
```

- Guaranteed protocols: http, https, ftp, file, and jar

URL and URLConnection Classes

- Retrieving contents of resources directly from a URL

```
URL url = new URL(urlString); // create a URL object for the file
InputStream inStream = url.openStream(); // open an input stream
Scanner in = new Scanner(inStream);
```

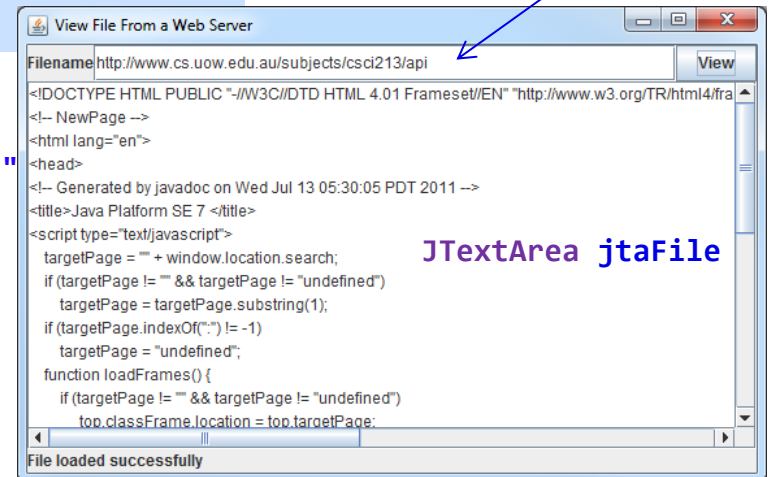
- Using URLConnection class for additional information about a web resource

```
URLConnection conn = url.openConnection();
// 1. set request properties eg. setConnectionTimeout() etc.
conn.setDoInput(true);
conn.setDoOutput(true);
// 2. open a connection
conn.connect();
// 3. query header information with, if required
Map header = conn.getHeaderField();
// 4. get I/O streams from the connection
InputStream in = conn.getInputStream(); //also can use getContent()
PrintWriter out = new PrintWriter(conn.getOutputStream());
```

Example: Retrieving Files from Web

```
private void showFile() {
    Scanner input = null; // Use Scanner for getting text input
    URL url = null;
    try {
        // Obtain URL from the text field
        url = new URL(jtfURL.getText().trim());
        // Create a Scanner for input stream
        input = new Scanner(url.openStream());
        // Read a line and append the line to the text area
        while (input.hasNext()) {
            jtaFile.append(input.nextLine() + "\n");
        }
        jlblStatus.setText("File loaded successfully");
    } catch (MalformedURLException ex) {
        jlblStatus.setText("URL " + url + " not found.");
    } catch (IOException e) {
        jlblStatus.setText(e.getMessage());
    } finally {
        if (input != null) input.close();
    }
}
```

JTextField jtfURL



JTextArea jtaFile

JEditorPane

- The GUI component **JEditorPane** can be used to display plain **text**, **HTML**, and **RTF** files automatically
 - you don't have to write code to explicitly read data from the files
 - **JEditorPane** is a subclass of **JTextComponent**
 - Supports frames, hyperlinks, images and CSS but not JavaScript and plugins. Supports can be added by recognizing relevant parts of HTML
- To display the content of a file described by a URL

```
public void setPage(URL url) throws IOException
```

- **JEditorPane** generates **HyperlinkEvent** when a hyperlink in the editor pane is clicked
 - Through this event, you can get the URL of the hyperlink and display it using the **setPage(url)** method

Example: Displaying HTML

```
// JEditor pane to view HTML files
```

```
private JEditorPane jep = new JEditorPane();
```

```
add(new JScrollPane(jep), BorderLayout.CENTER);
```

```
...
```

```
//Get the page from the URL text field
```

```
public void actionPerformed(ActionEvent e)
```

```
try {
```

```
    // Get the URL from text field
```

```
    URL url = new URL(jtfURL.getText().trim());
```

```
    // Display the HTML file
```

```
    jep.setPage(url);
```

```
}
```

```
...
```

```
//Get the page by following the link in the pages
```

```
public void hyperlinkUpdate(HyperlinkEvent e) {
```

```
    if (e.getEventType() == HyperlinkEvent.EventType.ACTIVATED) {
```

```
        try {
```

```
            jep.setPage(e.getURL());
```

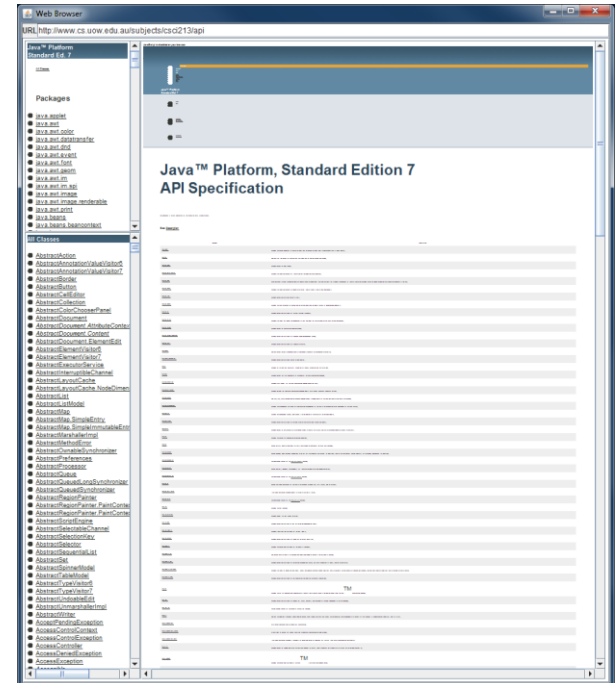
```
        } catch (IOException ex) {
```

```
            System.out.println(ex);
```

```
        }
```

```
    }
```

```
}
```



Datagram (UDP) Programming

- A **datagram** is an independent, self-contained message sent over the network whose *arrival*, *arrival time*, and *content* are not guaranteed
- The clients and servers do not have and do not need a dedicated point-to-point channel
- Two Java classes: **DatagramPacket** and **DatagramSocket** to support UDP programming
- Datagram packets can be broadcast to multiple recipients all listening to a **MulticastSocket**.

Send and Receive Datagrams

- To send data, you put the data in a **DatagramPacket** and send the packet using a **DatagramSocket**
 - The address and port to send a **DatagramPacket** is included in **DatagramPacket**
 - The **DatagramSocket** needs only to know the port to send
 - A single **DatagramSocket** can send data to and receive data from many independent hosts
- To receive data, you receive a **DatagramPacket** object from a **DatagramSocket** and then read the contents of the packet
 - Receiving **DatagramSocket** does not need to know the host, needs only to know the port to listen
 - Get the address and port of the sender from received **DatagramPacket**
 - `getAddress()`
 - `GetPort()`

Datagram Sockets

- A client socket can be anonymous
 - constructing a `DatagramSocket` without port and the actual port is assigned by the system and placed in the outgoing datagrams that a server can use to respond)
- A server socket must specify the port to listen so that a client can send requests
- There's no distinction between client sockets and server sockets, as there is with TCP

Construct DatagramPacket

- **DatagramPacket** for receiving datagrams

```
public DatagramPacket(byte[] buffer, int length)
```

- Most native UDP implementations don't support more than 8,192 bytes of data per datagram
- The theoretical limit for an IPv4 datagram is 65,507 bytes of data, and a DatagramPacket with a 65,507-byte buffer can receive any possible IPv4 datagram without losing data. IPv6 datagrams raise the theoretical limit to 65,536 bytes
- Almost all UDP datagrams you're likely to encounter will have 8K of data or fewer

- **DatagramPacket** for sending datagrams

```
public DatagramPacket(byte[] data, int length,  
                      InetAddress destination, int port)
```

Read Content of Datagrams

- The `getData()` method returns a byte array containing the data from the datagram
- Receiving text

```
public String(byte[] buffer, String encoding)
```

```
e.g. String s = new String(dp.getData( ), "ASCII");
```

- Receiving data
 - to convert the byte array returned by `getData()` into a `ByteArrayInputStream` first and then chain it to desired I/O stream

```
public ByteArrayInputStream(byte[] buffer, int offset, int length)
```

```
e.g. InputStream in = new ByteArrayInputStream(dp.getData( ),  
                                              dp.getOffset(), dp.getLength( ));  
    DataInputStream din = new DataInputStream(in);  
    int aNumber = din.readInt();
```

Example: Client and Server

Steps for Server

The server continuously receives datagram packets over a datagram socket. Each datagram packet received by the server indicates a client request for a quotation. When the server receives a datagram, it replies by sending a datagram packet that contains a one-line "quote of the moment" back to the client.

```
// Create a DatagramSocket
```

```
DatagramSocket socket = new DatagramSocket(port);
```

```
// receive requests from clients
```

```
byte[] buf = new byte[256];
```

```
DatagramPacket packet = new DatagramPacket(buf, buf.length);
```

```
socket.receive(packet);
```

packet

```
// sends the response to the client over the DatagramSocket
```

```
InetAddress address = packet.getAddress();
```

```
int port = packet.getPort();
```

```
packet = new DatagramPacket(buf, buf.length, address, port);
```

```
socket.send(packet);
```

packet

Example: Client and Server

Steps for Client

The client application sends a single datagram packet to the server indicating that the client would like to receive a quote of the moment. The client then waits for the server to send a datagram packet in response.

```
// Create a DatagramSocket without a port number
DatagramSocket socket = new DatagramSocket();
```

```
// send a request to the server
```

```
byte[] buf = new byte[256];
```

```
InetAddress address = InetAddress.getByName(hostname);
```

```
DatagramPacket packet = new DatagramPacket(buf, buf.length, address, port);
```

```
socket.send(packet);
```

The packet contains the address and port

```
// get a response to the server over the DatagramSocket
```

```
packet = new DatagramPacket(buf, buf.length);
```

```
socket.receive(packet);
```

```
// form a string from bytes
```

```
String receivedString = new String(packet.getData(), 0, packet.getLength());
```

Stream Socket vs. Datagram Socket

Stream Socket

- A dedicated point-to-point channel between a client and server.
- Use TCP (Transmission Control Protocol) for data transmission.
- Lossless and reliable.
- Sent and received in the same order.

Datagram Socket

- No dedicated point-to-point channel between a client and server.
- Use UDP (User Datagram Protocol) for data transmission.
- May lose data and not 100% reliable.
- Data may not be received in the same order as sent.

IP Multicast

- IP multicast is the delivery of a message to a group of destination computers simultaneously in a single transmission from the source over IP network
- Many tasks require a multicast model of communication
 - IP multicast is widely used in networks such as enterprise and multimedia content delivery networks like IPTV
- A **MulticastSocket** is a (UDP) **DatagramSocket**, with additional capabilities for joining "groups" of other multicast hosts on the internet
- A **multicast group** is specified by a **multicast IP** address (**224.0.0.1-239.255.255.255**) and by a standard UDP port number
- All datagram packets have a Time-To-Live (TTL) value
 - TTL is the maximum number of routers that the datagram is allowed to cross; when it reaches the maximum, it is discarded

Joining a Multicast Group

```
// 1. create a multicast group with a multicast IP address
InetAddress groupAdd = InetAddress.getByName("224.xxx.xxx.xxx");
                                                    // any multicast IP

// 2. create a MulticastSocket with a desired port
MulticastSocket s = new MulticastSocket(port);      // any available port

// 3. join the group
s.joinGroup(groupAdd);

// Ready to send DatagramPacket using the group address
// to all subscribing recipients within the TTL range of the packet
```


Example: Broadcasting to Multiple Recipients

Steps for Server

Instead of sending quotes to a specific client that makes a request, the new server now needs to broadcast quotes at a regular interval.

```
byte[] buf = quoteString.getBytes();    // string to send in byte

// don't wait for request...just broadcast a quote to a group
InetAddress group = InetAddress.getByName("230.xxx.xxx.0");

DatagramPacket packet = new DatagramPacket(buf, buf.length, group, port);
socket.send(packet);

sleep((long)Math.random() * FIVE_SECONDS);
```

Example: Broadcasting to Multiple Recipients

Steps for Client

The client needs to be modified so that it passively listens for quotes and does so on a **MulticastSocket**.

```
// Create a MulticastSocket with the port number and become a member of the group
MulticastSocket socket = new MulticastSocket(port);
InetAddress group = InetAddress.getByName("230.xxx.xxx.0");
socket.joinGroup(group);
```

```
// passively receive a quote without requesting
byte[] buf = new byte[256];
DatagramPacket packet = new DatagramPacket(buf, buf.length);
socket.receive(packet);
```

```
// form a string from bytes
String receivedString = new String(packet.getData(), 0, packet.getLength());
```

```
socket.leaveGroup(group);
socket.close();
```

The server can also use a **MulticastSocket**. The socket used by the server to send the **DatagramPacket** is not important. What's important when broadcasting packets is the *addressing information* contained in the **DatagramPacket**, and the socket used by the client to listen for it

Resources

- Besides *Core Java* books and *Oracle Java Tutorials* recommended for the subject, some materials covered on this topic can be found in the following book:

Y. Daniel Liang, *Introduction to Java Programming*,
Comprehensive Version, 9th ed, Prentice Hall, 2012