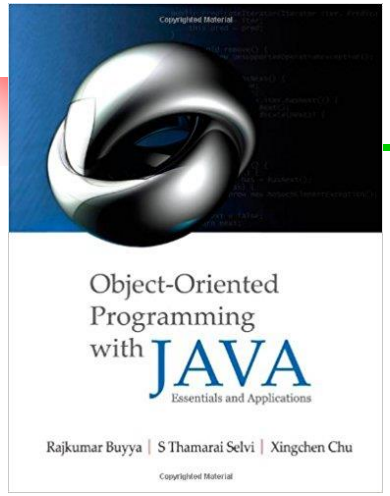
Inter-Process Communication (IPC): Network Programming using TCP Java Sockets



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Agenda

- Introduction
- Networking Basics
- Understanding Ports and Sockets
- Java Sockets
  - Implementing a Server
  - Implementing a Client
- Sample Examples
- Conclusions

Introduction

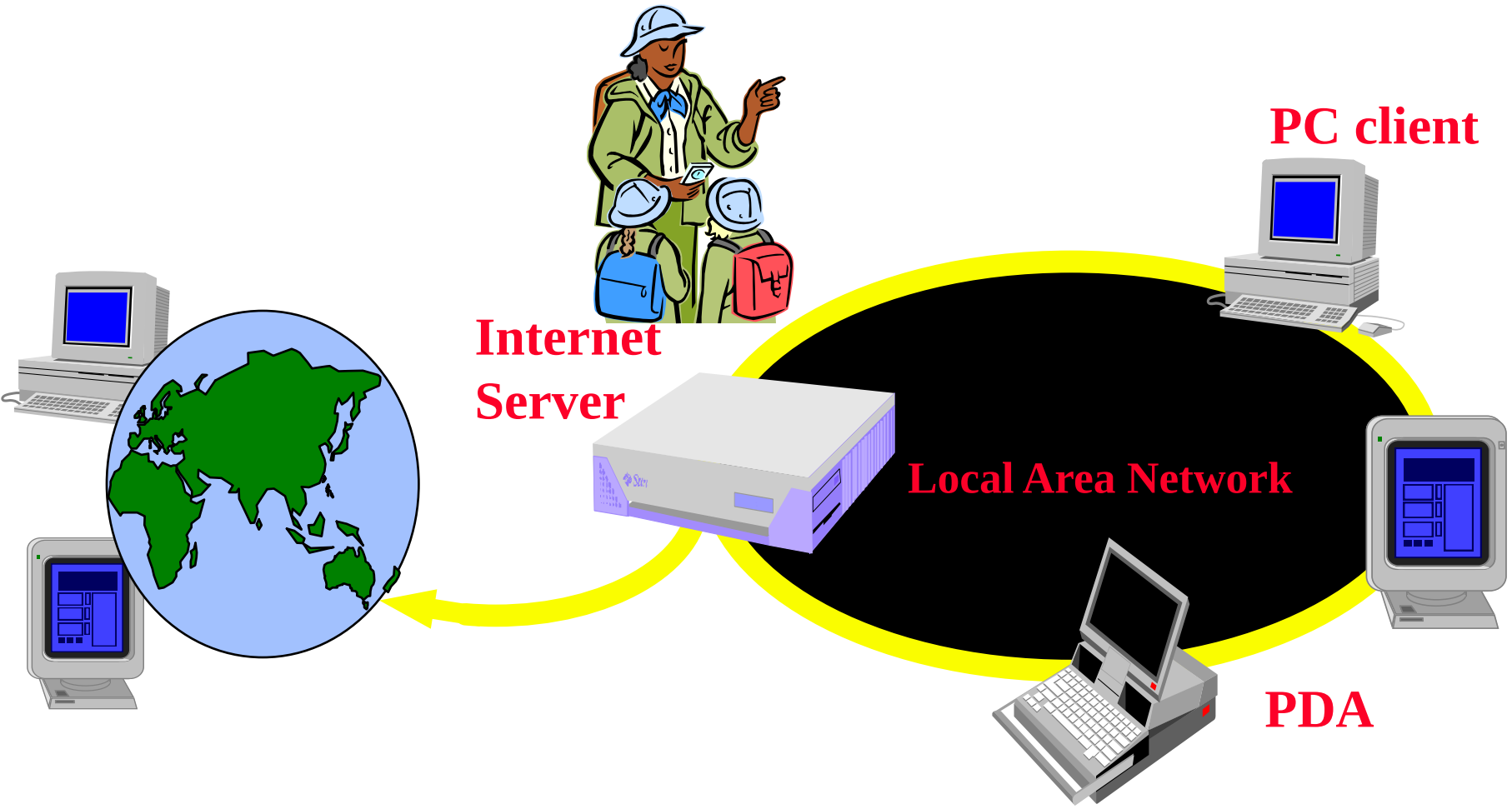
- Internet and WWW have emerged as global ubiquitous media for communication and are changing the way we conduct science, engineering, and commerce
- They are also changing the way we learn, live, enjoy, communicate, interact, engage, etc. It appears like the modern life activities are getting completely centered around the Internet

facebook

skype™
For Business

WeChat

Internet Applications Serving Local and Remote Users

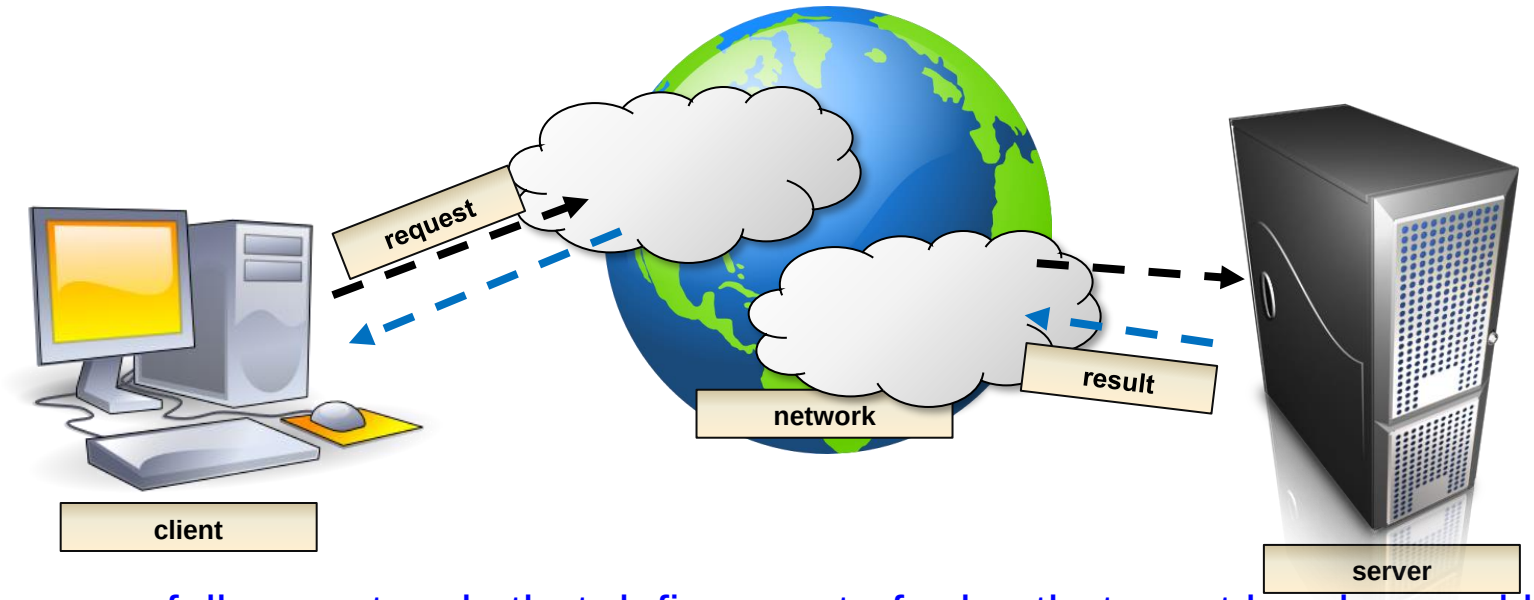


Increasing Demand for Internet Applications

- To take advantage of opportunities presented by the Internet, businesses are continuously seeking new and innovative ways and means for offering their services via the Internet.
- This created a huge demand for software designers with skills to create new Internet-enabled applications or migrate existing/legacy applications to the Internet platform.
- Object-oriented Java technologies—Sockets, threads, RMI, clustering, Web services—have emerged as leading solutions for creating portable, efficient, and maintainable large and complex Internet applications.

Elements of Client-Server Computing/Communication

a client, a server, and network



- Processes follow protocols that define a set of rules that must be observed by participants:
  - How the data exchange is encoded?
  - How events (sending, receiving) are synchronized (ordered) so that participants can send and receive data in a coordinated manner?
- In face-to-face communication, humans beings follow unspoken protocols based on eye contact, body language, gesture.

The Characteristics of Interprocess Communication

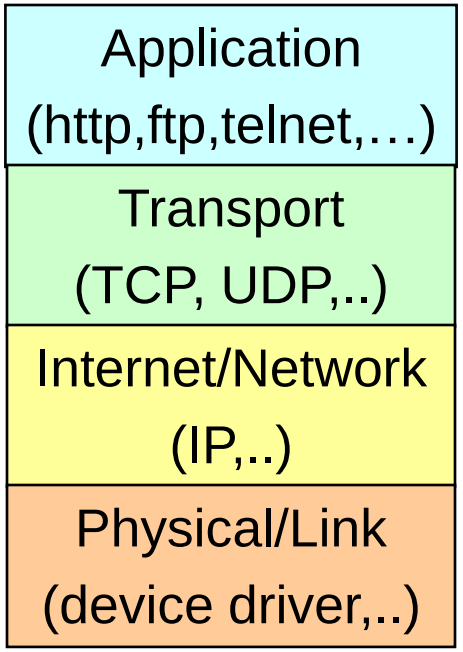
- Message Communication Operations. Message passing between a pair of processes can be supported by two message communication operations, send and receive.
- Synchronous and asynchronous communication. A queue is associated with each message destination. Sending processes cause messages to be added to remote queues and receiving processes remove messages from local queues.
  - Synchronous
  - Asynchronous

The Characteristics of Interprocess Communication

- Reliability. A point-to-point message service can be described as reliable if messages are guaranteed to be delivered despite a 'reasonable' number of packets being dropped or lost **(unreliable?)**
- Ordering. Some applications require that messages be delivered in *sender order*

Networking Basics

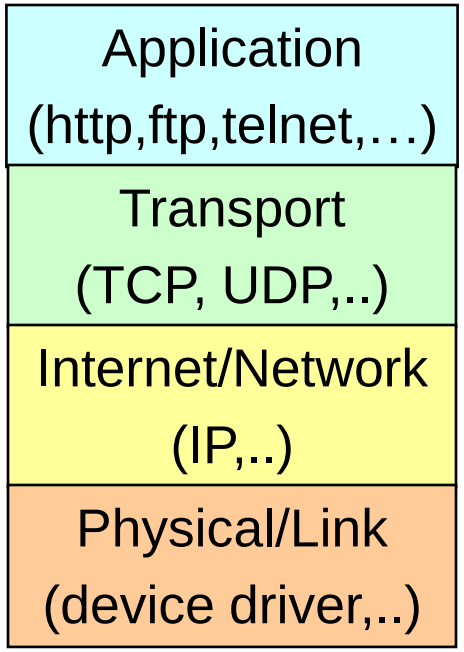
- Physical/Link Layer
  - Functionalities for transmission of signals representing a stream of data from one computer to another
- Internet/Network Layer
  - IP (Internet Protocols) – a packet of data to be addressed to a remote computer and delivered
- TCP/IP Stack



Networking Basics

- Transport Layer
  - Functionalities for delivering data packets to a specific process on a remote computer
  - TCP (Transmission Control Protocol)
  - UDP (User Datagram Protocol)
  - Programming Interface:
    - Sockets
- Applications Layer
  - Message exchange between standard or user applications:
    - HTTP, FTP, Telnet, **Skype,…**

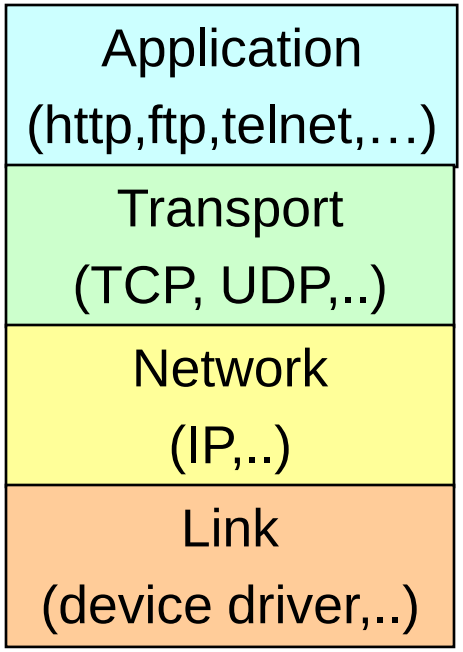
- TCP/IP Stack



Networking Basics

- UDP (User Datagram Protocol) is a connectionless communication protocol that sends independent packets of data, called *datagrams*, from one computer to another with no guarantees about arrival or order of arrival
- Similar to sending multiple emails/letters to friends, each containing part of a message.
- Example applications:
  - Live streaming (event/sports broadcasting)

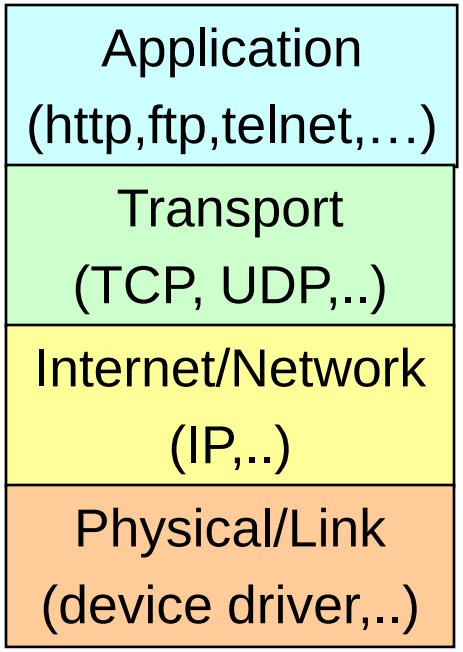
- TCP/IP Stack



Networking Basics

- TCP (Transmission Control Protocol) is a connection-oriented communication protocol that provides a reliable flow of data between two computers.
- Analogy: Speaking on Phone

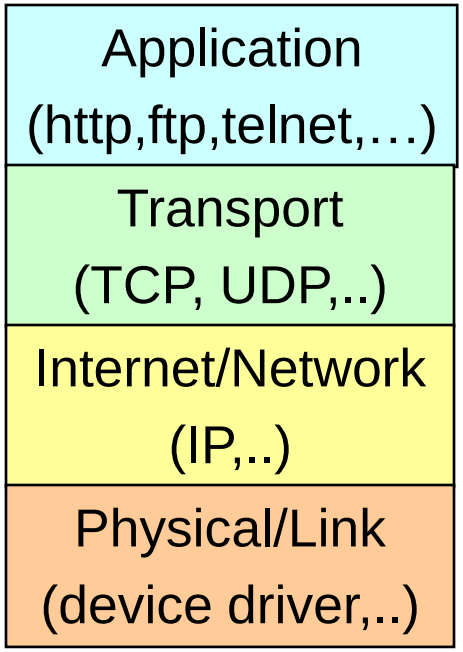
- TCP/IP Stack



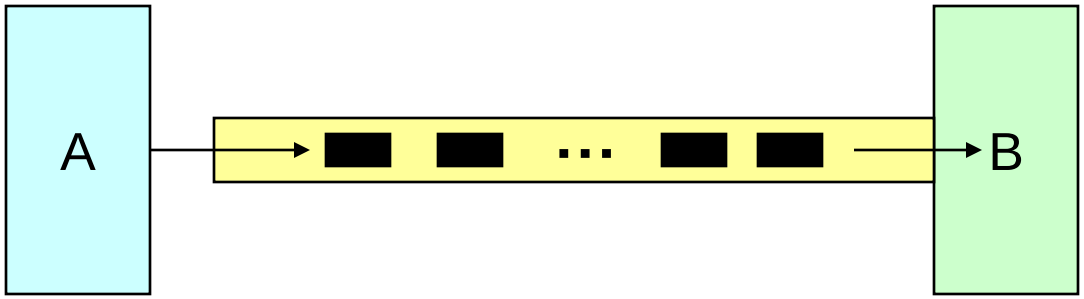
Networking Basics

- TCP (Transmission Control Protocol)
- Mechanisms to meet reliability guarantees:
  - Sequencing
  - Retransmission
- Example applications:
  - HTTP, FTP, Telnet
  - **Skype** uses **TCP** for call signalling, and both **UDP** and **TCP** for transporting media traffic.

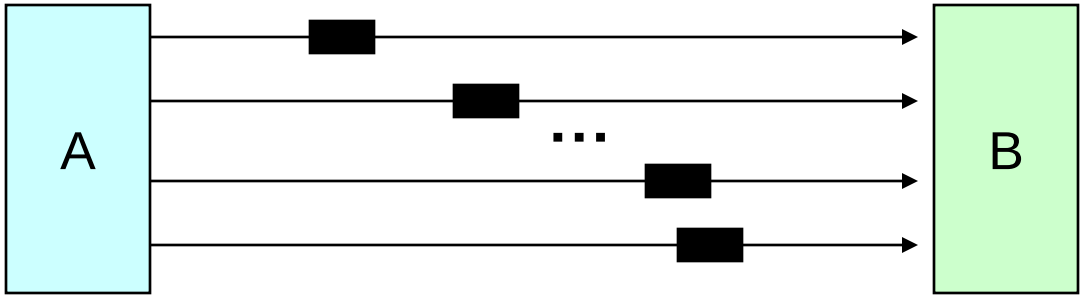
- TCP/IP Stack



TCP Vs UDP Communication



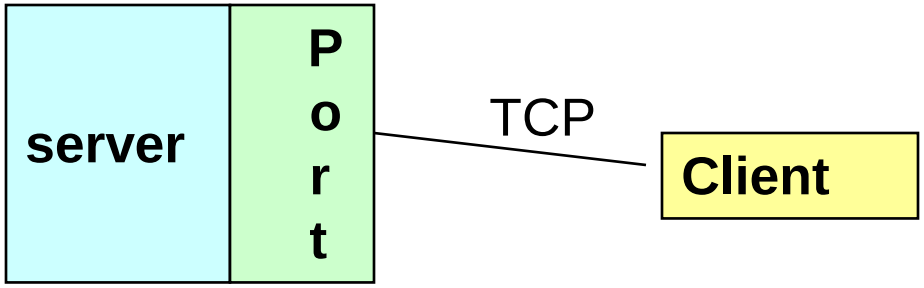
- Connection-Oriented Communication

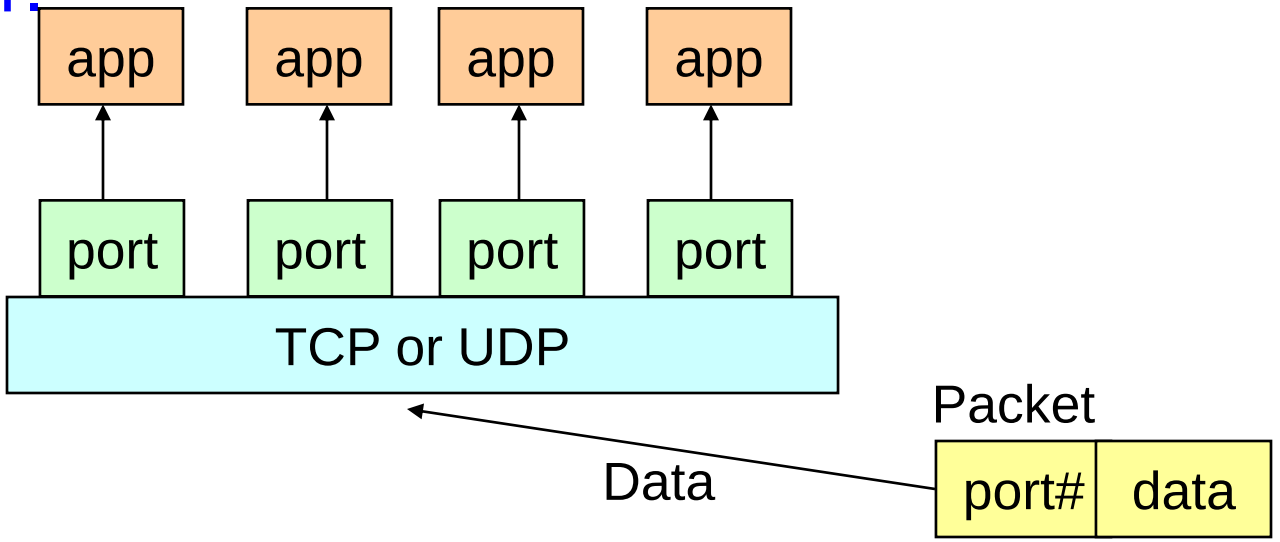


- Connectionless Communication

Understanding Ports

- The **TCP and UDP** protocols use ***ports*** to map incoming data to **a particular *process*** running on a computer.





Understanding Ports

- Port is represented by a positive (16-bit) integer value
- Some ports have been reserved to support common/well known services:
  - ftp 21/tcp
  - telnet 23/tcp
  - smtp 25/tcp
  - login 513/tcp
- User-level processes/services generally use port number value >= 1024

Hosts Identification and Service Ports

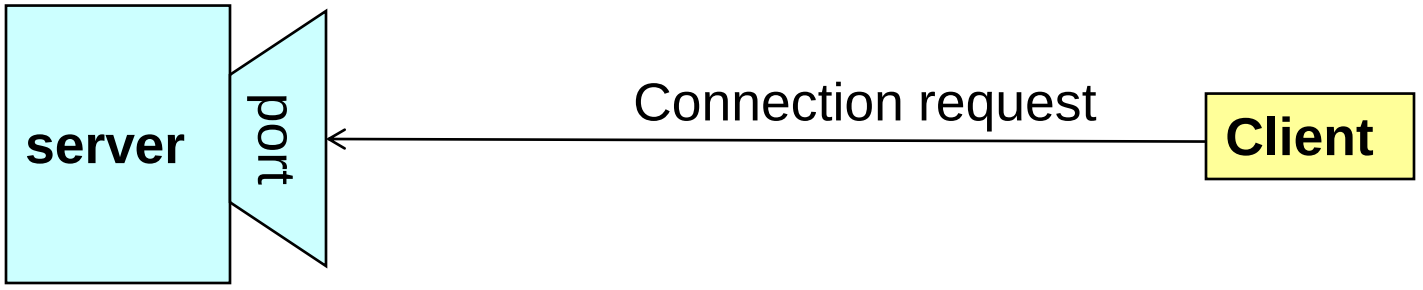
- Every computer on the Internet is identified by a unique, 4-byte IP address (e.g. 128.250.25.158) [User friendly?]
- IP addresses are mapped to names like www.google.com.
- Computers often need to communicate and provide more than one type of service or to talk to multiple hosts/computers at a time (Examples?)
- Hence, the need for ports! (How?)
- IP versus port number?
- Sockets or ports?

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
  - In fact, 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 is programming language independent.
  - That means, a socket program written in Java language can also communicate to a program written in Java or non-Java socket program

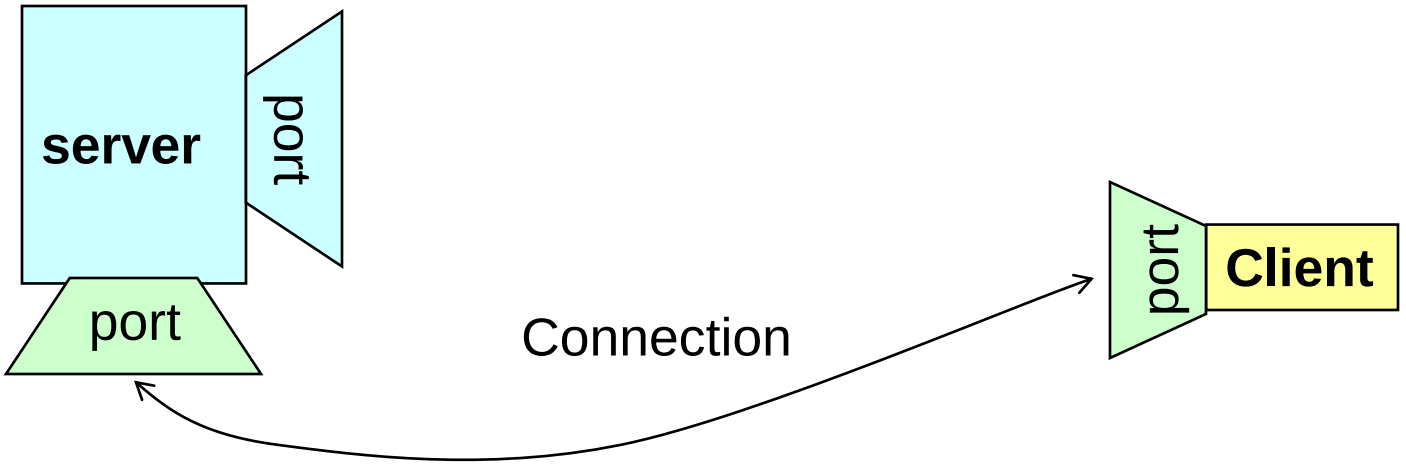
Socket Communication

- A server (program) runs on a specific computer and has a socket that is bound to a specific port. The server waits and listens to the socket for a client to make a connection request.



Socket Communication

- **If everything goes well, the server accepts the connection.** Upon acceptance, the server gets a new socket bounds to a different port. It needs a new socket (consequently a different port number) so that it can continue to listen to the original socket for connection requests while serving the connected client.



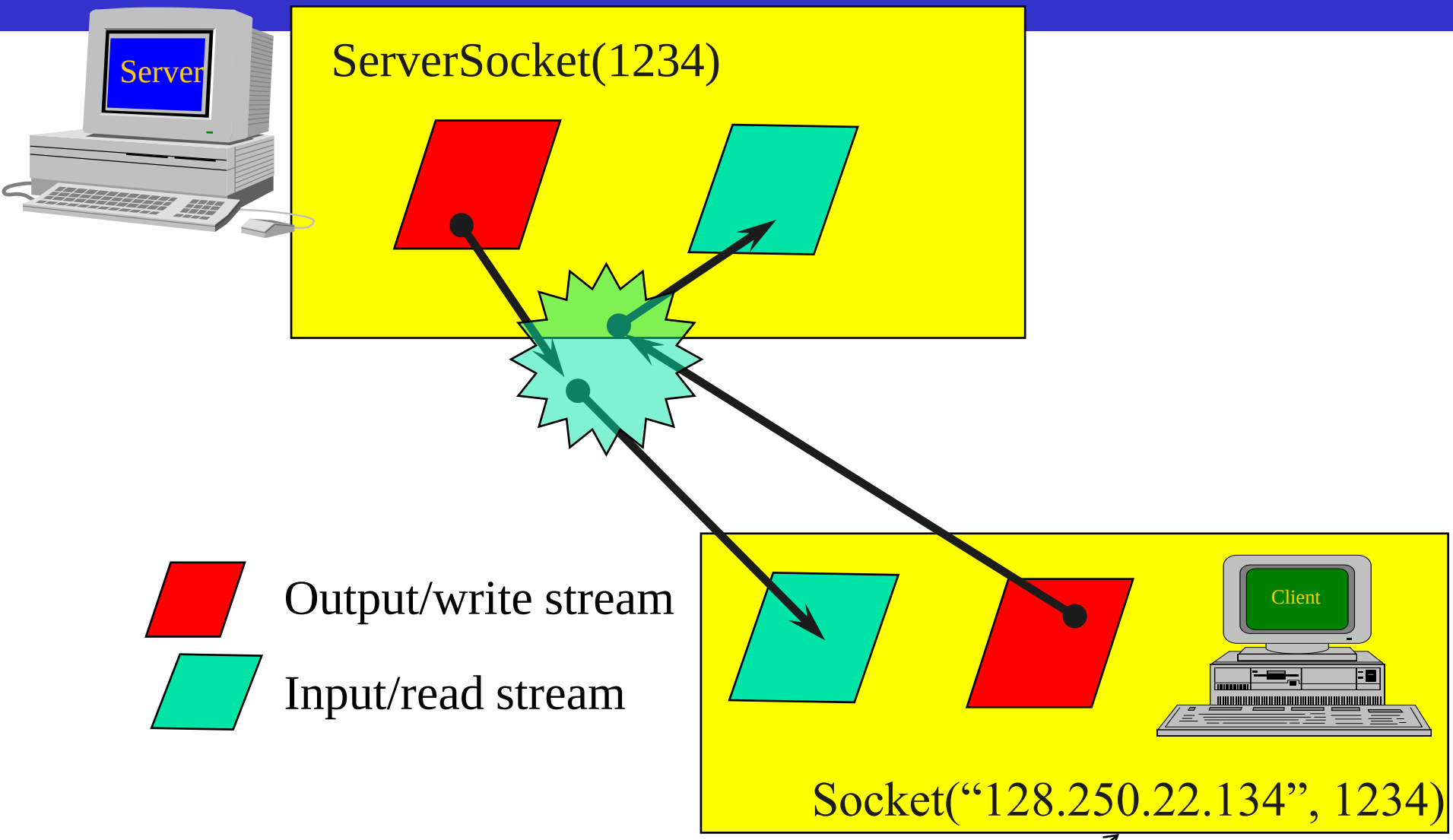
Sockets and Java Socket Classes

- A socket is an endpoint 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 destined to be sent.

TCP/IP Socket Programming

- Java's .net package provides two classes:
  - Socket – for implementing a client
  - ServerSocket – for implementing a server

TCP/IP Socket Programming



It can be host_name like "jarrett.cis.unimelb.edu.au"

TCP/IP: Implementing a Server

1. Open the Server Socket:

```
ServerSocket server;
  DataOutputStream os;
  DataInputStream is;
  server = new ServerSocket( PORT );
```

2. Wait for the Client Request:

```
Socket client = server.accept();
```

3. Create I/O streams for communicating to the client

```
is = new DataInputStream(
client.getInputStream() );
  os = new DataOutputStream(
client.getOutputStream() );
```

TCP/IP: Implementing a Server

4. Perform communication with client

Receive from client:

```
String line = is.readLine();
```

Send to client:

```
os.writeBytes("Hello\n");
```

5. Close sockets: `client.close();`

For multithreaded server:

```
while(true) {
```

i. wait for client requests (step 2 above)

ii. create a thread with "client" socket as parameter (the thread creates streams (as in step(3) and does communication as stated in (4). Remove thread once service is provided.

```
}
```

TCP/IP: A simple server (simplified code)

```
// SimpleServer.java: a simple server program
import java.net.*;
import java.io.*;
public class SimpleServer {
  public static void main(String args[])
  throws IOException {
    // Register service on port 1234
    ServerSocket s = new ServerSocket(1234);
    Socket s1=s.accept(); // Wait and accept a
  connection
```

TCP/IP: A simple server (simplified code)

```
// Get a communication stream associated with
  the socket
    OutputStream s1out = s1.getOutputStream();
    DataOutputStream dos = new
  DataOutputStream (s1out);
    // Send a string!
    dos.writeUTF("Hi there");
    // Close the connection, but not the
  server socket
    dos.close();
    s1out.close();
    s1.close();
  }
```

TCP/IP: Implementing a Client

1. Create a Socket Object:

```
client = new Socket( server, port_id );
```

2. Create I/O streams for communicating with the server.

```
is = new
DataInputStream(client.getInputStream() );
 os = new DataOutputStream(
client.getOutputStream() );
```

3. Perform I/O or communication with the server:
   - **Receive data from the server:**

```
String line = is.readLine();
```

   - **Send data to the server:**

```
os.writeBytes("Hello\n");
```

4. Close the socket when done:

```
client.close();
```

TCP/IP: A simple client (simplified code)

```
// SimpleClient.java: a simple client
  program
import java.net.*;
import java.io.*;
public class SimpleClient {
  public static void main(String args[])
  throws IOException {
    // Open your connection to a server, at
  port 1234
    Socket s1 = new
  Socket("jarrett.cis.unimelb.edu.au",1234)
  ;
```

TCP/IP: A simple client (simplified code)

```
// Get an input file handle from the socket
  and read the input
     InputStream s1In = s1.getInputStream();
     DataInputStream dis = new
  DataInputStream(s1In);
     String st = new String (dis.readUTF());
     System.out.println(st);
     // When done, just close the connection
  and exit
     dis.close();
     s1In.close();
     s1.close();
```

Run

A. Run Server on mundroo.cs.mu.oz.au
   - [raj@mundroo] java SimpleServer &

B. Run Client on any machine (including mundroo):
   - [raj@mundroo] java SimpleClient
     Hi there

C. If you run client when server is not up:
   - [raj@mundroo] sockets [1:147] java SimpleClient

Exception in thread "main" java.net.ConnectException: **Connection refused**
    at java.net.PlainSocketImpl.socketConnect(Native Method)
    at java.net.PlainSocketImpl.doConnect(PlainSocketImpl.java:320)
    at java.net.PlainSocketImpl.connectToAddress(PlainSocketImpl.java:133)
    at java.net.PlainSocketImpl.connect(PlainSocketImpl.java:120)
    at java.net.Socket.<init>(Socket.java:273)
    at java.net.Socket.<init>(Socket.java:100)

Socket Exceptions

```
try {
    Socket client = new Socket(host, port);
    handleConnection(client);
}
catch(UnknownHostException uhe) {
    System.out.println("Unknown host: " + host);
    uhe.printStackTrace();
}
catch(IOException ioe) {
System.out.println("IOException: " + ioe);
    ioe.printStackTrace();
}
```

ServerSocket & Exceptions

- public **ServerSocket**(int port) throws IOException
  - Creates a server socket on a specified port
  - A port of 0 creates a socket on any free port. You can use **getLocalPort**() to identify the (assigned) port on which this socket is listening
  - The maximum queue length for incoming connection indications (a request to connect) is set to 50. If a connection indication arrives when the queue is full, the connection is refused
- Throws:
  - IOException - if an I/O error occurs when opening the socket
  - SecurityException - if a security manager exists and its checkListen method doesn't allow the operation

Server in Loop: Always up

```
// SimpleServerLoop.java: a simple server program that
   runs forever in a single thead
public class SimpleServerLoop {
  public static void main(String args[]) throws IOException {
    // Register service on port 1234
    ServerSocket s = new ServerSocket(1234);
    while(true)
    {
            Socket s1=s.accept(); // Wait and accept a connection
        // Get a communication stream associated with the socket
        OutputStream s1out = s1.getOutputStream();
        DataOutputStream dos = new DataOutputStream (s1out);
        // Send a string!
        dos.writeUTF("Hi there");
        // Close the connection, but not the server socket
        dos.close();
```

Java API for UDP Programming

- Java API provides datagram communication by means of two classes
  - DatagramPacket
    - | Msg | length | Host | serverPort |
  - DatagramSocket

Java API for UDP Programming

- Datagram packets are used to implement a connectionless packet delivery service supported by the UDP protocol.
- Each message is transferred from source machine to destination based on information contained within that packet.
- Hence, each packet needs to have destination address and each packet might be routed differently, and might arrive in any order (Side effect?)

UDP Client: Sends a Message and Gets reply

```
import java.net.*;
import java.io.*;
public class UDPClient
{
    public static void main(String args[]){
// args give message contents and server hostname
// "Usage: java UDPClient <message> <Host name> <Port number>"
        DatagramSocket aSocket = null;
          try {
                aSocket = new DatagramSocket();
                byte [] m = args[0].getBytes();
                InetAddress aHost = InetAddress.getByName(args[1]);
                int serverPort = 6789;  // Or
    Integer.valueOf(args[2]).intValue() if use <Port number> args[2]
                DatagramPacket request = new DatagramPacket(m,
    args[0].length(), aHost, serverPort);
                aSocket.send(request);
```

UDP Client: Sends a Message and Gets reply

```
    byte[] buffer = new byte[1000];
    DatagramPacket reply = new DatagramPacket(buffer,
    buffer.length);
    aSocket.receive(reply);
     System.out.println("Reply: " + new String(reply.getData()));
  }

    catch (SocketException e){System.out.println("Socket: " +
    e.getMessage());}
   catch (IOException e){System.out.println("IO: " + e.getMessage());}
          finally {
             if(aSocket != null) aSocket.close();
        }
     }
}
```

UDP Sever: repeatedly received a request and sends it back to the client

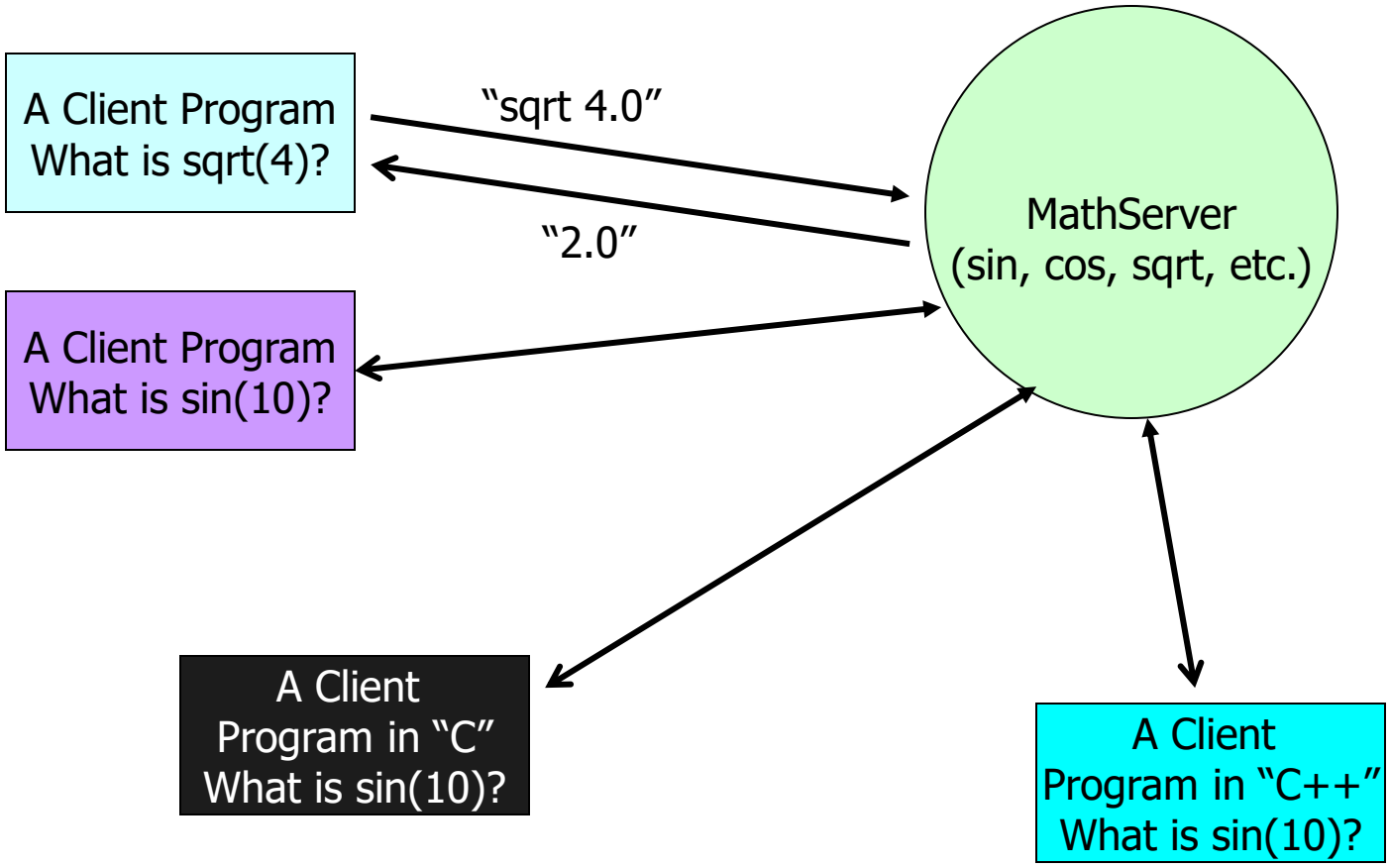
```
import java.net.*;
import java.io.*;
public class UDPServer{
        public static void main(String args[]){
        DatagramSocket aSocket = null;
            try{
                aSocket = new DatagramSocket(6789); // fixed port
    number
                byte[] buffer = new byte[1000];
                while(true){
                    DatagramPacket request = new
          DatagramPacket(buffer, buffer.length);
                   aSocket.receive(request);
```

UDP Sever: repeatedly received a request and sends it back to the client

```
    DatagramPacket reply = new
    DatagramPacket(request.getData(),
                        request.getLength(), request.getAddress(),
    request.getPort());
                    aSocket.send(reply);
                }
            }catch (SocketException e){System.out.println("Socket:
    " + e.getMessage());}
             catch (IOException e) {System.out.println("IO: " +
    e.getMessage());}
        finally {if(aSocket != null) aSocket.close();}
    }
}
```

Any comments?

Example 1: MathServer – Demonstrates the use of Sockets



Example 1: MathServer

- What could be the basic interface for usage?

Program 13.5

```
// MathService.java: A basic math interface.
public interface MathService {
   public double add(double firstValue, double secondValue);
   public double sub(double firstValue, double secondValue);
   public double div(double firstValue, double secondValue);
   public double mul(double firstValue, double secondValue);
}
```

Example 1: MathServer

- What could be the basic implementation for that interface?

Program 13.6

```
// PlainMathService.java: An implementation of the MathService interface.
public class PlainMathService implements MathService {

   public double add(double firstValue, double secondValue) {
      return firstValue+secondValue;
   }
   public double sub(double firstValue, double secondValue) {
      return firstValue-secondValue;
   }
   public double mul(double firstValue, double secondValue) {
     return firstValue * secondValue;
   }
   public double div(double firstValue, double secondValue) {
      if (secondValue != 0)
       return firstValue / secondValue;
      return Double.MAX_VALUE;
   }
}
```

Example 1: MathServer

- What could be the implementation MathServer?

```
// MathServer.java : An implementation of the MathServer.
import java.io.*;
import java.net.*;

public class MathServer{
   protected MathService mathService;
   protected Socket socket;
```

Example 1: MathServer

- What could be the implementation MathServer?

```
public void setMathService(MathService mathService) {
    this.mathService = mathService;
}
public void setSocket(Socket socket) {
    this.socket = socket;
}
```

Example 1: MathServer

- What could be the implementation MathServer?

```
public void execute() {
    try {
      BufferedReader reader = new BufferedReader(
           new InputStreamReader(socket.getInputStream()));
      // read the message from client and parse the execution
      String line = reader.readLine();
      double result = parseExecution(line);
      // write the result back to the client
      BufferedWriter writer = new BufferedWriter(
           new OutputStreamWriter(socket.getOutputStream()));
      writer.write(""+result);
      writer.newLine();
      writer.flush();
      // close the stream
      reader.close();
      writer.close();
    }
        catch (Exception e) {
      e.printStackTrace();
    }
}
```

Example 1: MathServer

- What could be the implementation MathServer?

```
// the predefined protocol for the math operation is
// operator:first value:second value
protected double parseExecution(String line)
                  throws IllegalArgumentException {
   double result = Double.MAX_VALUE;
   String [] elements = line.split(":");
   if (elements.length != 3)
     throw new IllegalArgumentException("parsing error!");
   double firstValue = 0;
   double secondValue = 0;
   try {
     firstValue = Double.parseDouble(elements[1]);
     secondValue = Double.parseDouble(elements[2]);
   }
        catch(Exception e) {
     throw new IllegalArgumentException("Invalid arguments!");
   }
   switch (elements[0].charAt(0)) {
     case '+':
       result = mathService.add(firstValue, secondValue);
     break;
     case '-':
```

Example 1: MathServer

- What could be the contents of the main methods?

```
public static void main(String [] args)throws Exception{
    int port = 10000;
    if (args.length == 1) {
      try {
        port = Integer.parseInt(args[0]);
      }
     catch(Exception e){
     }
    }
    System.out.println("Math Server is running...");
    // create a server socket and wait for client's connection
    ServerSocket serverSocket = new ServerSocket(port);
    Socket socket = serverSocket.accept();
    // run a math server that talks to the client
    MathServer mathServer = new MathServer();
    mathServer.setMathService(new PlainMathService());
    mathServer.setSocket(socket);
    mathServer.execute();
    System.out.println("Math Server is closed...");
}
```

Example 1: main() for MathServer?

```
public static void main(String [] args)throws Exception{
    int port = 10000;
    if (args.length == 1) {
      try {
        port = Integer.parseInt(args[0]);
      }
     catch(Exception e){
     }
    }
    System.out.println("Math Server is running...");
    // create a server socket and wait for client's connection
    ServerSocket serverSocket = new ServerSocket(port);
    Socket socket = serverSocket.accept();
    // run a math server that talks to the client
    MathServer mathServer = new MathServer();
    mathServer.setMathService(new PlainMathService());
    mathServer.setSocket(socket);
    mathServer.execute();
    System.out.println("Math Server is closed...");
}
```

Example 1: Client for MathServer?

```
// MathClient.java: A test client program to access MathServer.
import java.io.*;
import java.net.Socket;
public class MathClient {
   public static void main(String [] args){
      String hostname = "localhost";
      int port = 10000;
      if (args.length != 2) {
        System.out.println("Use the default setting...");
      }
           else {
```

Example 1: Client for MathServer?

```
        hostname = args[0];
        port = Integer.parseInt(args[1]);
      }
      try {
        // create a socket
        Socket socket = new Socket(hostname, port);
        // perform a simple math operation "12+21"
        BufferedWriter writer = new BufferedWriter(
                new OutputStreamWriter(socket.getOutputStream()));
        writer.write("+:12:21");
        writer.newLine();
        writer.flush();
        // get the result from the server
        BufferedReader reader = new BufferedReader(
                new InputStreamReader(socket.getInputStream()));
        System.out.println(reader.readLine());
        reader.close();
        writer.close();
      }
          catch (Exception e) {
        e.printStackTrace();
      }
    }
}
```

Required Reading

- Chapter 13: Socket Programming
  - R. Buyya, S. Selvi, X. Chu, **"Object Oriented Programming with Java: Essentials and Applications",** McGraw Hill, New Delhi, India, 2009.
  - Sample chapters at book website: http://www.buyya.com/java/