CS18000: Problem Solving and Object-Oriented Programming

Network I/O

(revised 3/18/24)
Communication Among Computers

• In the early days, computers had no way to communicate directly with each other
• If you had information on computer A that you needed on computer B, you had to write a file onto a device that could be transported from computer A to be read on computer B
• In the late 1960s some researchers in universities, industry, and the military started working on a way to have computers directly communicate with each other
• The idea was a wire that would allow packets of bits to be transmitted from computer A to computer B
• This would be replaced with wireless means of sending information
Computer Networks

• Computers in one building could all have a pathway to send information to any other computer in that building -- a network

• The networks in two different buildings could be connected so that computers in one building could send information to computers in other buildings -- a network of networks

• Eventually resulted in worldwide Interconnected Computer Networks -- the Internet

• One of the pioneers whose research work helped in the development of the Internet is Purdue Computer Science Professor Douglas Comer
Some (Simplified) Definitions

• **Internet Protocol (IP):**
  Identifies hosts (servers, workstations, laptops, etc.) with a unique address (e.g., 128.10.2.21)

• **Domain Name System (DNS):**
  Maps domain names (e.g., galahad.cs.purdue.edu) to IP addresses (e.g., 128.10.9.143)

• **Transmission Control Protocol (TCP):**
  Identifies ports on hosts for a network connection

• **Socket:** IP address plus TCP port

• Two sockets makes a network connection
Client-Server

- A **Server** is a process that waits for a connection
- A **Client** is a process that connects to a server
- At different times, a process may be both a client and a server
- Need not be associated with a specific computer: Any computer can have both client and server processes running on it
- Once connected, the client and server can both read and write data to one another asynchronously ("a bi-directional byte pipe")
Use of Sockets

• Clients and Servers communicate via Sockets
• Socket: IP address plus TCP port
• Think: street name plus house number
• IP addresses
  – Identifies a computer on the Internet
  – Public addresses are globally unique
  – Represented using dotted-decimal (byte) notation: 128.10.9.143
  – Some firewalls translate addresses to internal ones (e.g., PAL)
• Port number
  – 0-65535 (16 bits)
  – Low-valued port numbers are reserved for privileged processes
Objects and Networking in Java

• You know that Java objects can be written to and read from files
• Java objects can also be exchanged over network connections
• Uses ObjectOutputStream and ObjectInputStream
• Tricky bits...
  – ObjectOutputStream generates a “header” of information that must be read
  – Requires “flush” to ensure ObjectInputStream reader is not blocked
• Blocking (or being blocked) means that code is prevented from running or data is prevented from moving from one computer to another.
ObjectStream Client-Server Timeline

Server Process

Server starts: opens ServerSocket and blocks (waiting for client)

Server receives connection

Server opens ObjectOutputStream, sends header with flush

Server receives object stream header

Client Process

Client starts: opens Socket to Server

Client opens ObjectOutputStream, sends header with flush

Client receives object stream header

Client and Server exchange objects in agreed upon order
Java Networking Class: Socket

- Models a TCP/IP socket
- Used by Client to identify Server
  - IP address (or DNS name)
  - Port number
  - `new Socket("pc.cs.purdue.edu", 12190)`
- Used by Server to identify connected Client
- Provides streams for communications:
  - `getOutputStream()`
  - `getInputStream()`
Java Networking Class: ServerSocket

- Used by Server to wait for a Client to connect
- Constructor specifies TCP port number to use:

  ServerSocket ss = new ServerSocket(4242);

- Method accept() blocks waiting for connection

  Socket socket = ss.accept();
Video 2
Clients and Servers
import java.io.*;
import java.net.*;

public class Server {
    public static void main(String[] args) throws IOException, ClassNotFoundException {
        // create socket on agreed-upon port...
        ServerSocket serverSocket = new ServerSocket(4242);

        // wait for client to connect, get socket connection...
        Socket socket = serverSocket.accept();

        // open output stream to client, flush send header, then input stream...
        ObjectOutputStream oos = new ObjectOutputStream(socket.getOutputStream());
        oos.flush();  // ensure data is sent to the client
        ObjectInputStream ois = new ObjectInputStream(socket.getInputStream());

        // send object(s) to client...
        String s1 = "hello there";
        oos.writeObject(s1);
        oos.flush();  // ensure data is sent to the client
        System.out.printf("sent to client: %s\n", s1);

        // read object(s) from client...
        String s2 = (String) ois.readObject();
        System.out.printf("received from client: %s\n", s2);

        // close streams...
        oos.close();
        ois.close();
    }
}
import java.io.*;
import java.net.*;

public class Client {
    public static void main(String[] args) throws UnknownHostException, IOException, ClassNotFoundException {

        // create socket on agreed upon port (and local host for this example)...
        Socket socket = new Socket("data.cs.purdue.edu", 4242);

        // open input stream first, gets header from server...
        ObjectInputStream ois = new ObjectInputStream(socket.getInputStream());
        // open output stream second, send header to server...
        ObjectOutputStream oos = new ObjectOutputStream(socket.getOutputStream());
        oos.flush(); // ensure data is sent to the server

        // read object(s) from server...
        String s1 = (String) ois.readObject();
        System.out.printf("received from server: %s\n", s1);

        // write object(s) to server...
        String s2 = s1.toUpperCase();
        oos.writeObject(s2);
        oos.flush(); // ensure data is sent to the server
        System.out.printf("sent to server: %s\n", s2);

        // close streams...
        oos.close();
        ois.close();
    }
}
Client-Server with Threads

• In many (most?) cases, a single server is connected to by multiple clients
• Server must be able to communicate with all clients simultaneously—no blocking
• Technique: server creates a separate thread to handle each client as it connects
• Client and server may also each create separate thread for reading and writing
Example: Echo Server

• Simple server that accepts connections from multiple clients
• Spawns a thread for each client
• Reads lines from the connection, logs information, echoes lines back
• Useful for debugging network and code
Echo Server Timeline

Server Process
- Server starts: opens ServerSocket and blocks (waiting for client)
- Server receives connection
- Server creates thread
- Server thread 1 reads/echoes line

Client Process
- Client 1 starts: opens Socket to Server
- Client 1 sends line
- Client 1 reads line
- Client 2 starts: opens Socket to Server
- Client 3 starts: opens Socket to Server
import java.io.IOException;
import java.io.PrintWriter;
import java.net.ServerSocket;
import java.net.Socket;
import java.util.Scanner;

public class EchoServer implements Runnable {
    Socket socket;

    public EchoServer(Socket socket) {
        this.socket = socket;
    }

    // continued…
Example: Echo Server (2)

// run method for thread...

```java
public void run() {
    System.out.printf("connection received from %s
", socket);
    try {
        // socket open: make PrintWriter and Scanner from it...
        PrintWriter pw = new PrintWriter(socket.getOutputStream());
        Scanner in = new Scanner(socket.getInputStream());

        // read from input, “log” client request, echo client input...
        while (in.hasNextLine()) {
            String line = in.nextLine();
            System.out.printf("%s says: %s
", socket, line);
            pw.printf("echo: %s
", line);
            pw.flush();
        }

        // input done, close connections...
        pw.close();
        in.close();
    } catch (IOException e) {
        e.printStackTrace();
    }
}
```
// main method...

public static void main(String[] args) throws IOException {
    // allocate server socket at given port...
    ServerSocket serverSocket = new ServerSocket(4343);
    System.out.printf("socket open, waiting for connections on %s\n", serverSocket);

    // infinite server loop: accept connection,
    // spawn thread to handle...
    while (true) {
        Socket socket = serverSocket.accept();
        EchoServer server = new EchoServer(socket);
        new Thread(server).start();
    }
}

}
Network Communication in Java

- Uses standard file I/O classes: low-level, high-level, object, and text
- Adds abstractions to deal with network connections
  - ServerSocket to wait for connections
  - Socket abstracts a TCP socket (IP address + port)
- Uses threads to improve responsiveness and avoid blocking