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")

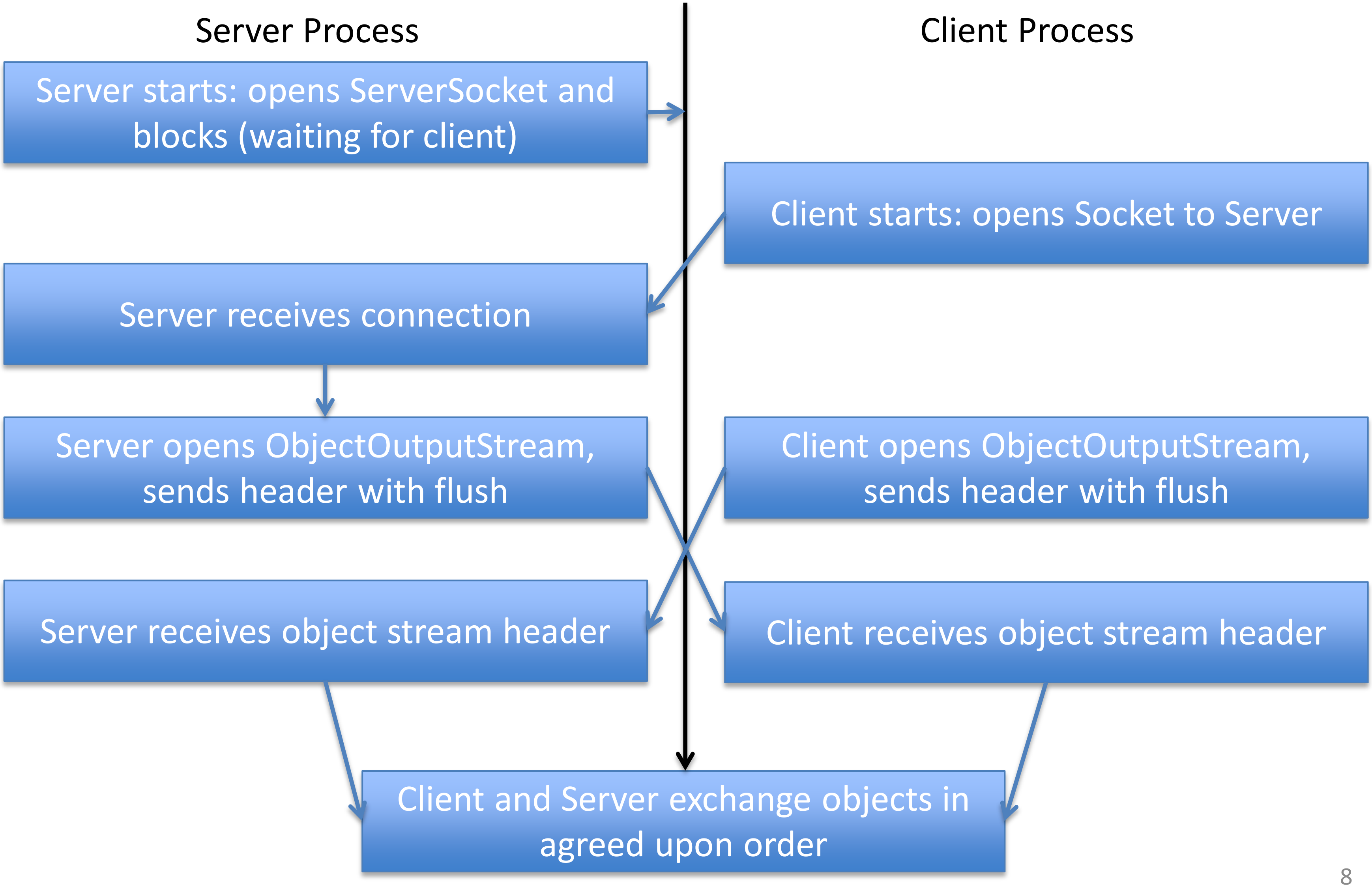
Use of Sockets

- 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

Client Process

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

Client starts: opens Socket to Server

Server receives connection

Server opens ObjectOutputStream, sends header with flush

Client opens ObjectOutputStream, sends header with flush

Server receives object stream header

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

Example: Object Server

```java
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();
    }
}
```

Example: Object Client

```java
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();
    }
}
```

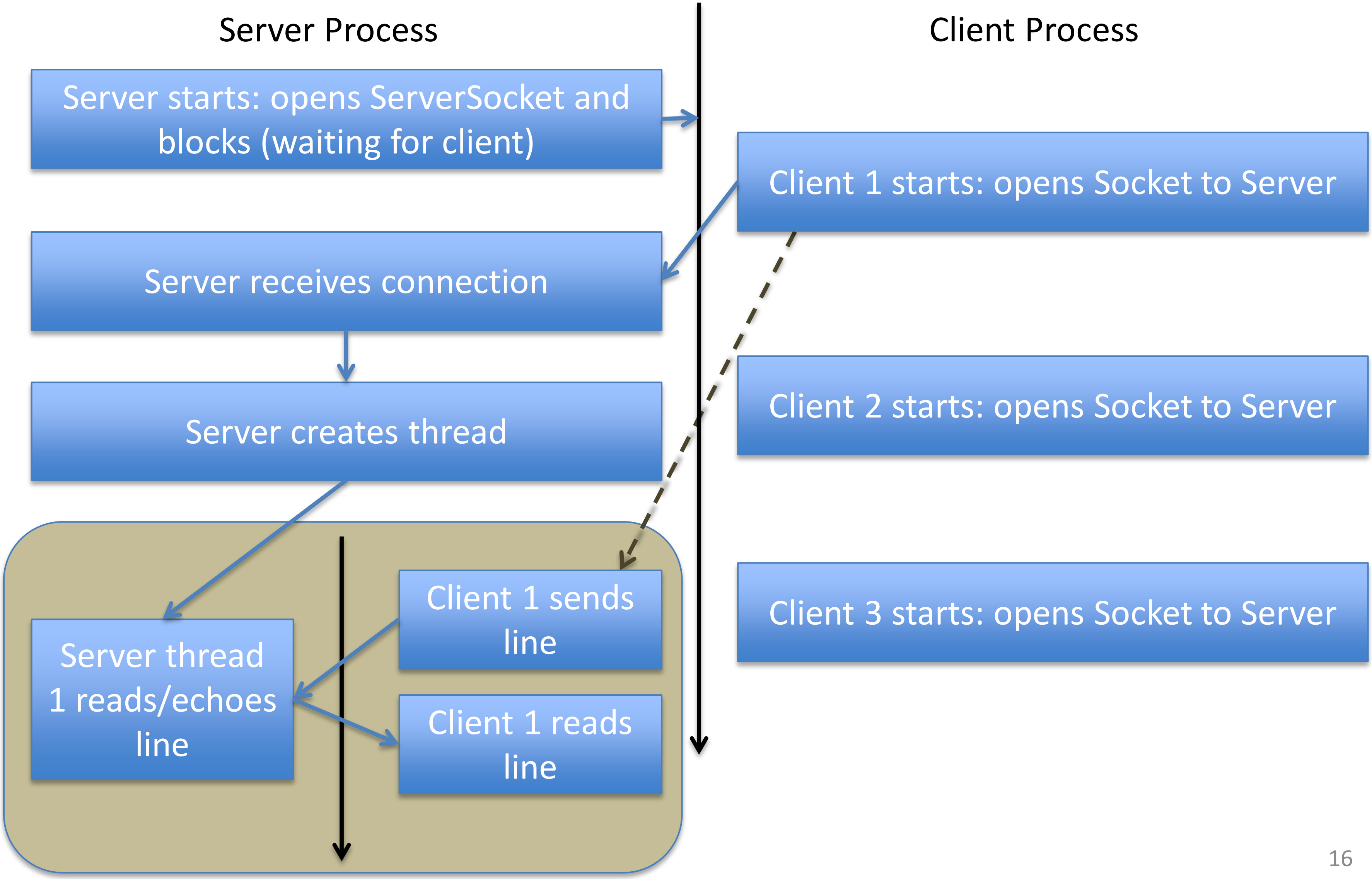
Client-Server with Threads

- 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

Client Process

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

Client 1 starts: opens Socket to Server

Server receives connection

Server creates thread

Client 2 starts: opens Socket to Server

Client 1 sends line

Server thread 1 reads/echoes line

Client 1 reads line

Client 3 starts: opens Socket to Server

Example: Echo Server (1)

```
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...
    public void run() {
        System.out.printf("connection received from %s\n", socket);
        try {
            // socket open: make PrinterWriter 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\n", socket, line);
                pw.printf("echo: %s\n", line);
                pw.flush();
            }

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

Example: Echo Server (3)

```
// 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