95-702 Distributed Systems
Project 3
Assigned: Friday, September 24, 2010

NEW DEADLINE!  Due: Friday, October 15, 11:59:59 PM

Principles

This project naturally leads to discussions concerning non-functional characteristics of distributed systems such as protocol reliability via positive acknowledgement with retransmission, unreliable networks, interoperability, marshaling and external data representation, naming, separation of concerns and design patterns.

Review

In Project 1 we worked with J2EE servlets and Java Server Pages using the Glassfish web container.

In Project 2 we worked with J2EE servlets and web services using Glassfish and the web service support provided by JAX-WS 2.0.

In this project we will be working at a lower level. That is, we will not have the Glassfish or the JAX-WS runtime environments to rely on. You may, however, continue to use Netbeans for most of this work. For the Android piece, you will use Eclipse.

This project has two parts:

1. The first part exposes the student to both TCP and UDP sockets. In this part we are interested in exploring issues associated with protocol reliability over unreliable networks. External representation and marshaling is also explored. And finally, we illustrate the ubiquity and interoperability of UDP by having the student build an Android application that interacts with a UDP server.

2. The second part exposes the student to issues associated with remote method invocation. Code is provided that is scaffolding upon which the student builds a more significant application. The scaffolding includes a client side proxy and server side skeleton. Using that code as a model to work from, the student writes a

*  
Due to mid-semester break, the project is due October 14, but we will give you one free grace day if you prefer to turn it in on mid-semester break, October 15.
simple registry and an object server and client. The program uses sockets but is
careful to illustrate separation of concerns and the use of the proxy design pattern.
Ideas from the Colouris text, such as remote object references and request reply
messages, must be implemented by the student.

Discussion of UDP and TCP

In the first part of this project you will work with both UDP and TCP over IP. UDP is a
simpler protocol than TCP and therefore usually requires more work from the
application programmer. TCP presents the application programmer with a stream
abstraction and is busier behind the scenes. TCP, unlike UDP, tries its best to make
sure packets are delivered to the recipient. The underlying network we are using may,
on occasion, drop packets. So, how can TCP provide for reliable delivery of packets?
TCP uses the fundamental principal of "positive acknowledgement with
retransmission".

A simplified example of "positive acknowledgement with retransmission" looks like the
following. In this scenario, no packets are lost. These notes are adapted from
"Internetworking with TCP/IP, Volume I: Principles, Protocols and Architecture" by
Douglas E. Comer

<table>
<thead>
<tr>
<th>Sender</th>
<th>Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Send packet 1</td>
<td>Service</td>
</tr>
<tr>
<td>Start timer</td>
<td>Receive packet 1</td>
</tr>
<tr>
<td>Receive ACK 1</td>
<td>Send ACK for packet 1</td>
</tr>
<tr>
<td>Cancel timer</td>
<td></td>
</tr>
<tr>
<td>Send packet 2</td>
<td></td>
</tr>
<tr>
<td>Start timer</td>
<td>Receive packet 2</td>
</tr>
<tr>
<td>Receive ACK 2</td>
<td>Send ACK for packet 2</td>
</tr>
<tr>
<td>Cancel timer</td>
<td></td>
</tr>
</tbody>
</table>
Here is an example where the first packet is lost.

<table>
<thead>
<tr>
<th>Sender</th>
<th>Service</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Send packet 1  
Start timer  
Packet lost

Time expires  
Send packet 1  
Start timer  
Receive packet 1  
Send ACK for packet 1

Receive ACK 1  
Cancel timer

Send packet 2  
Start timer  
Receive packet 2  
Send ACK for packet 2

Receive ACK 2  
Cancel timer
Here is an example where the first ACK is lost.

<table>
<thead>
<tr>
<th>Sender</th>
<th>Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Send packet 1</td>
<td></td>
</tr>
<tr>
<td>Start timer</td>
<td>Receive packet 1</td>
</tr>
<tr>
<td></td>
<td>Send ACK 1</td>
</tr>
<tr>
<td>ACK 1 lost</td>
<td></td>
</tr>
<tr>
<td>Time expires</td>
<td>Receive packet 1 a second time</td>
</tr>
<tr>
<td>Send packet 1</td>
<td>Send ACK for packet 1</td>
</tr>
<tr>
<td>Start timer</td>
<td></td>
</tr>
<tr>
<td>Receive ACK 1</td>
<td></td>
</tr>
<tr>
<td>Cancel timer</td>
<td></td>
</tr>
<tr>
<td>Send packet 2</td>
<td></td>
</tr>
<tr>
<td>Start timer</td>
<td>Receive packet 2</td>
</tr>
<tr>
<td></td>
<td>Send ACK for packet 2</td>
</tr>
<tr>
<td>Receive ACK 2</td>
<td></td>
</tr>
<tr>
<td>Cancel timer</td>
<td></td>
</tr>
</tbody>
</table>
The acknowledgement may be replaced with the result of the service. Here is another example.

<table>
<thead>
<tr>
<th>Sender</th>
<th>Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Send packet 1</td>
<td></td>
</tr>
<tr>
<td>Start timer</td>
<td>Receive packet 1</td>
</tr>
<tr>
<td></td>
<td>Send response</td>
</tr>
<tr>
<td>Response</td>
<td>Lost</td>
</tr>
<tr>
<td>Time expires</td>
<td></td>
</tr>
<tr>
<td>Send packet 1</td>
<td>Receive packet 1 a second time</td>
</tr>
<tr>
<td>Start timer</td>
<td>Send response again</td>
</tr>
<tr>
<td>Receive response</td>
<td></td>
</tr>
<tr>
<td>Cancel timer</td>
<td></td>
</tr>
<tr>
<td>Send packet 2</td>
<td></td>
</tr>
<tr>
<td>Start timer</td>
<td>Receive packet 2</td>
</tr>
<tr>
<td></td>
<td>Send response for packet 2</td>
</tr>
<tr>
<td>Receive response</td>
<td></td>
</tr>
<tr>
<td>Cancel timer</td>
<td></td>
</tr>
</tbody>
</table>

**Task 1a**

On pages 138 and 139 of the Coulouris text, two short UDPClient and UDPServer programs are presented. The code for these can also be found at:

http://www.cdk4.net/additional/index.html

Make modifications to the UDPClient and UDPServer programs so that the client may ask the server to perform simple integer arithmetic. You need to implement addition, subtraction, multiplication and division of integers. You may assume that you have a well behaved user and all input is correct. You may also assume that the user uses spaces to separate the command line arguments. As mathematical operators use +, -, /, and X for multiplication (trying to use * presents many problems when used on a command line).
The execution of the client program will look like the following:

```
java UDPClient 100 + 234
Reply: 334
```

In Netbeans, command line arguments can be set by choosing Run/Set Project Configuration/Customize.

UDPCClient.java and UDPServer.java will be placed in a project called Project3Task1 and submitted to Blackboard.

**Task 1b**

Using the same UDP server that you wrote for Task 1a, write a new UDP client named UDPCClientWithProxy.java that has a main routine that computes and displays the sum of the integers 1+2+3+...+100. The main routine of the client must be very clean and contain no socket level programming. All of the socket work will be done within a single method with the following signature:

```
public static int add(int x,int y);
```

The main routine will make 100 calls on the add method. The add method, however, will not perform any addition. Instead, it will send a UDP message to the server and receive the server’s response. It will return that response as a simple int. This is a proxy design.

UDPCClientWithProxy.java will be placed in the same project (Project3Task1) as Task 1a.
Task 2

Build a new project called Project3Task2. Modify the UDPServer and create a new Java class called UDPServerThatIgnoresYou.java. Write the new server so that it randomly ignores 70% of requests. In other words, the new UDPServerThatIgnoresYou will contain code close to this:

```java
// rnd is an object of the Random class

aSocket.receive(request);

if(rnd.nextInt(10) < 7) {
    System.out.println("Got request " +
    new String(request.getData()) +
    " but ignoring it.");
    continue;
} else {
    System.out.println("Got request" +
    new String(request.getData()));
    System.out.println("And making a reply");
}
```

Create a new client called UDPClientWithReliability.java. This new client is a modification of UDPClientWithProxy. After a request, it waits only 2 seconds for a reply. If the reply does not arrive after two seconds, the client tries again. It never gives up. The UDP receive will look something like this.

```java
aSocket.setSoTimeout(2000); 
aSocket.receive(reply);
```

See the above discussion on "positive acknowledgement with retransmission".

UDPClientWithReliability.java will have a main routine that computes and displays the sum of the integers 1+2+3+...+100. The main routine of the client must be very clean and contain no socket level programming. All of the socket work (and retry code) will be done within a single method with the following signature:

```java
public static int add(int x, int y);
```

All files for this Task should be in a project named Project3Task2.
Task 3

On pages 142 and 143 of the Coulouris text, two additional short programs are presented: TCPClient and TCPServer. You can also find these programs at:

http://www.cdk4.net/additional/index.html

The TCPClient program takes two string arguments: the first is a message to pass and the second is an IP address of the server (e.g. localhost). The server will echo back the message to the client.

Make modifications to the TCPClient and TCPServer programs to exchange ultra-secret messages between spies in the field and their boss in Intelligence Headquarters.

For example, when the client is run with the following arguments:

“spy on Sean Beggs” localhost

The “spy on Sean Beggs” message would be sent by TCPClient to TCPServer.

The TCPServer should return to TCPClient:

The plan to spy on Sean Beggs has been approved.

And finally TCPClient should print:

The reply from headquarters is: The plan to spy on Sean Beggs has been approved.

Intelligence Headquarters is pretty incompetent, and they decide whether to approve or deny a plan based on a coin flip. (i.e. based on a random number generator which has equally likely chance of approval or rejection.) Therefore the response from the sever should always be of one of two forms:

“The plan to " +original-message+ " has been approved."

or

“The plan to " +original-message+ " has been rejected."

These are top secret plans, however, so Eve should not be able to intercept them. Therefore part of your marshaling and un-marshaling of the messages should be to encrypt and decrypt the messages using a Caesar Cipher. (See Wikipedia. You can choose the number to shift.)

It is required that a proxy design be used. All of the socket level programming needs to be isolated.

Name this project Project3Task3. It will contain the files TCPServer.java, TCPClient.java, and caesarCipher.java.
Task 4

Write an Android application that uses UDP to interact with the server in Task 1a. Call this application AndroidUsingUDPProject. This will be an interactive application with a button labelled "UDP Send" and a text box that is able to collect a simple arithmetic expression. The result of the computation will be displayed on the phone.

Name the Eclipse Project Project3Task4.

Task 5

Review the programs at the end of this document. These programs illustrate low level remote method invocation (RMI). That is, we are not yet working with Java RMI. We are implementing a simple RMI system using TCP sockets.

Get these programs running and study them closely. The terms "skeleton" and "stub" are used and you should understand exactly what kind of objects these terms refer to. Get the programs working in two separate Netbeans projects. Two separate projects works best (Project3Task5Client and Project3Task5Server) because it clearly separates the client code from the server code. The interface file (Person.java) must be placed on the server side as well as the client side. When the server and client are run, Netbeans will present two different console windows - one for the client and one for the server. There is a box on the console window that may be used to stop the server process.

Name these projects Project3Task5Client and Project3Task5Server. Submit these to Blackboard.

Task 6

This task asks you to build a distributed object server, a registry and a client.

```
The registry is located at port 9090.
/                        \
lookup /                  bind
/                        \

The client makes a lookup call on the registry and then calls methods on the remote object.
The object server at port 9000 makes a bind call on the registry and then services calls on an object.
```

Create three new Netbeans projects named Project3Task6Client, Project3Task6ObjectServer, and Project3Task6Registry.
a. Write a new Java class called RemoteObjectReference that implements Serializable. This class will encapsulate the private fields found in Figure 4.13, on page 154, of the Coulouris text. This class will have getter and setter methods for each field and a small main routine used as a test driver. The "interface of remote object" field will be defined as a String object. The IPAddress field is an array of 4 bytes. The other two fields are simple integers. This class will be present in Project3Task6Client, Project3Task6ObjectServer, and Project3Task6Registry projects.

b. Write a new Java class called RequestReplyMessage that implements Serializable. This class will encapsulate the private fields found in Figure 4.16, on page 157, of the Coulouris text. Note that a RequestReplyMessage object has a RemoteObjectRef member. This must be the same class as defined in the previous step. Setter and getter methods need to be defined.

Note that a RemoteObjectReference object contains enough information to specify a remote object. The RequestReplyMessage contains, in addition, information on the method that will be invoked (or was invoked) on that object as well as an array of bytes specifying the arguments to or return values from the method.

The RequestReplyMessage class will be present on the client, object server and registry server.

c. Write the following Java classes for the client project:

**PersonClient.java**
PersonClient creates a Binder_Stub object so that it may make lookup calls on the registry. It will call lookup("Mike") and receive a RemoteObjectReference object from the registry. PersonClient will then create a Person_Stub object with the RemoteObjectReference as a parameter to the Person_Stub constructor. It will then make calls on the stub to retrieve the name and ID in the remote object.

**Binder_Stub.java**
The client needs to speak to the registry.
This class implements the Binder interface and contains bind and lookup methods.
The client only makes use of the lookup method.

**Binder.java**
This interface defines the lookup method as taking a string argument and returning a RemoteObjectReference value. It also defines the bind method that takes a string and a RemoteObjectReference as input. Its return type is void.
**Person_Stub.java**
The client needs to speak with the server. This class implements the Person interface and contains getId and getName methods. When making a call on the server, it creates a RequestReplyMessage from the information found in the RemoteObjectReference and sends this message to a TCP socket.

When receiving a reply, it reads a RequestReplyMessage from the socket, extracts bytes, and returns to the caller either the name or ID.

**Person.java**
This is the same interface as shown below.

**RemoteObjectReference.java and RequestReplyMessage.java.**
See above for a description of these classes.

d. Write the following Java classes for the registry project.

**Binder_Servant.java**
This servant object holds a mapping of names to RemoteObjectReference objects. This class implements the Binder interface. A Java TreeMap will be used to hold the mappings.

**Binder.java**
See above for a description.

**Binder_Skeleton.java**
This skeleton is used to communicate with the server and the client. The serve method of this class is written like the serve method in Person_Skeleton shown below. On bind calls, it reads String objects and remote object reference objects from sockets and makes calls on its Binder_Servant. On calls to lookup, it writes a RemoteObjectReference object to the socket. Nothing is written to the socket on a call to bind.

**BinderServer.java**
This class starts up the registry. It creates a Binder_Servant and passes that servant to its new Binder_Skeleton and calls serve.

**RemoteObjectReference.java**
This class is described above.
e. Write the following Java classes for the object server:

**Binder_Stub.java**
See above.

**Binder.java**
See above.

**Person_Servant.java**
This class implements Person and is shown below.

**Person_Skeleton.java**
This class has a server method that reads RequestReplyMessages and writes RequestReplyMessages. In between the reading and writing it makes a call on the Person_Servant object.

**Person.java**
See below.

**PersonServer.java**
This class creates a Person_Servant object and a RemoteObjectReference. It uses the Binder_Stub to make a bind call on the registry. It creates a Person_Skeleton object and asks it to serve.

**RemoteObjectReference.java**
See above.

**RequestReplyMessage.java**
See above.

You need not communicate with the registry using a request reply message. On a call to bind, simply call with two objects (a string and a remote object reference.)
### Summary

<table>
<thead>
<tr>
<th>Task Number</th>
<th>Project Names</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a &amp; 1b</td>
<td>Project3Task1</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>Project3Task2</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>Project3Task3</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>Project3Task4 (Eclipse)</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>Project3Task5Client</td>
<td>10</td>
</tr>
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<td>Project3Task5Server</td>
<td></td>
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<tr>
<td>6</td>
<td>Project3Task6Client</td>
<td>25</td>
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<tr>
<td></td>
<td>Project3Task6ObjectServer</td>
<td></td>
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<tr>
<td></td>
<td>Project3Task6Registry</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reflection Questions on Blackboard</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

### Code

// file: Person.java on both the client and server side
```java
public interface Person {
    public int getID() throws Exception;
    public String getName() throws Exception;
}
```

// file: Person_Stub.java found only on the client side
```java
import java.io.ObjectOutputStream;
import java.io.ObjectInputStream;
import java.net.Socket;

public class Person_Stub implements Person {
    Socket socket;
    ObjectOutputStream o;
    ObjectInputStream i;
    public Person_Stub() throws Exception {
    }

    public int getID() throws Exception {
        socket = new Socket("localhost",9000);
        o = new ObjectOutputStream(socket.getOutputStream());
        o.writeObject("ID");
        o.flush();
        i = new ObjectInputStream(socket.getInputStream());
        int ret = i.readInt();
        socket.close();
        return ret;
    }
}
```
public String getName() throws Exception {
    socket = new Socket("localhost", 9000);
    o = new ObjectOutputStream(socket.getOutputStream());
    o.writeObject("name");
    o.flush();
    i = new ObjectInputStream(socket.getInputStream());
    String ret = (String)(i.readObject());
    socket.close();
    return (String)ret;
}
}

// file: PersonClient.java exists only on the client side
public class PersonClient {
    public static void main(String args[]) {
        try {
            Person p = new Person_Stub();
            int id = p.getID();
            System.out.println("ID = " + id);
            String name = p.getName();
            System.out.println(name + " has ID number" + id);
        }
        catch(Exception t) {
            t.printStackTrace();
            System.exit(0);
        }
    }
}

// file: Person_Skeleton.java exists only on the server side
import java.io.ObjectOutputStream;
import java.io.ObjectInputStream;
import java.net.Socket;
import java.net.ServerSocket;

public class Person_Skeleton {
    Person myServer;

    public Person_Skeleton(Person s) {
        myServer = s;
    }
}
public void serve()  {
    try {
        ServerSocket s = new ServerSocket(9000);
        while(true) {
            Socket socket = s.accept();
            ObjectInputStream i = new ObjectInputStream(socket.getInputStream());
            String method = (String)i.readObject();
            if(method.equals("ID")) {
                int a = myServer.getID();
                ObjectOutputStream o = new ObjectOutputStream(socket.getOutputStream());
                o.writeInt(a);
                o.flush();
            } else if(method.equals("name")) {
                String n = myServer.getName();
                ObjectOutputStream o = new ObjectOutputStream(socket.getOutputStream());
                o.writeObject(n);
                o.flush();
            }
        }
    } catch(Exception t) {
        System.out.println("Error " + t);
        System.exit(0);
    }
}

// file: Person_Servant.java exists only on the server side
public class Person_Servant implements Person {

    int id;
    String name;
    public Person_Servant(String n, int i) {
        name = n;
        id = i;
    }

    public intgetID() {
        return id;
    }
    public String getName() {
        return name;
    }
}
// file: PersonServer.java exists only on the server side
public class PersonServer {
    public static void main(String args[]) {
        Person p = new Person_Servant("Mike",23);
        Person_Skeleton ps = new Person_Skeleton(p);
        ps.serve();
    }
}