Distributed Computing

- Programs that cooperate and communicate over a network
  - e-mail
  - web server and web client
  - SETI @Home

Key Features of Distrib. Comp.

- Machines are not all the same
  - But all adhere to same communication protocol
- Network is “slow”
  - Sending a message takes a lot of time
- Network is unreliable
  - Machines may join and leave with no warning
  - Part of the network may fail

Different Approaches to Distributed Computation

- Connecting via sockets
  - E.g., project 1
  - custom protocols for each application
- RPC/DCOM/CORBA/RMI
  - make what looks like a normal function call
  - function actually invoked on another machine
  - Arguments are *marshalled* for transport
  - Value is *unmarshalled* on return

Remote Method Invocation

- Easy way to get distributed computation
- Have stub for remote object
  - calls to stub get translated into network call
- Arguments and return values are passed over network
  - Java takes care of the details

A Simple Example

```java
class ChatServerImpl ... { // runs on one mach.
    public void receive(String s) {
        System.out.println(s);
    }
    ...
}

class Chatter { // runs on another mach.
    public static void main(String args[]) {
        ChatServer c = // get remote object;
        BufferedReader br = new BufferedReader(new InputStreamReader(System.in));
        while (true) {
            System.out.print(">");
            c.receive(br.readLine());
        }
    }
}
```
Remote Objects

- Object should
  - extend java.rmi.server.UnicastRemoteObject
    - Constructor declared to throw RemoteException
  - implement a remote interface
    - A remote interface extends java.rmi.Remote
    - All methods in a remote interface throw RemoteException
      - "Something bad happened on the network"
  - Side note: actually, don’t need to extend UnicastRemoteObject, but it’s much easier

Remote Interfaces

- A remote interface extends java.rmi.Remote
- All methods in a remote interface throw RemoteException
  - “Something bad happened on the network”
- Side note: actually, don’t need to extend UnicastRemoteObject, but it’s much easier

Stubs

- Client only sees the RemoteInterface
  - ConcreteObject can have other methods
- Remote objects represented using stub
  - Stub sends arguments over network
  - Stub receives result back from network

Compiling Stubs with rmic

- Generates stub code for a class
  - For 1.1, also generates skeleton class
    - Stub on client side communicates with skeleton on remote side
  - skeleton not needed for 1.2+
    - And 1.2+ generates position-independent code
      - Use -v1.2 if you can (e.g., for project 5)
  - Generates stubs for all methods declared in the class’s Remote interface
    - other methods don’t get a stub

Passing Arguments

- To pass an argument to a remote method
  - (or return a result from a remote method)
  - it must be either
    - a primitive type (int, double, etc.),
    - Serializable (e.g., String), or
    - Remote (i.e., implement a sub-interface of Remote)
  - Primitives passed as you’d expect

Passing Serializable vs. Remote

- Serializable objects passed by value
  - Same Serializable in different calls materializes different objects at receiver
- Remote objects passed by reference
  - Same Remote object in different calls yields same stub object, which passes arguments back to same remote object
Stub Code

- Objects contain both data and code
  - When you receive a remote object, you need the stub for that remote object

- Solution #1: All clients have stub code on their classpath
  - Or stub code for another class with same remote interface

Downloading Code

- Solution #2: Provide a code base where stub code for objects can be downloaded
  
  ```java
  java -Djava.rmi.server.codebase=<url> ...
  ```
  - Specifies location of classes originating from this server
  - url can be, e.g., http:// or file:/

Security Manager

- Downloading code (even stub code) from the internet is potentially risky
  - Need to limit what downloaded code could do
  - Must install a Security Manager before you download any code from RMI code bases

- Can use
  ```java
  System.setSecurityManager(new RMISecurityManager());
  ```

Policy Files

- In addition to security manager, need to specify a security policy
  ```java
  grant {
  permission java.net.SocketPermission 
  "*:1024-65535", "connect,accept";
  permission java.net.SocketPermission "*:80", "connect";
  }
  ```
  - Set security policy when JVM started
    - `java -Djava.security.policy=<file name>`

Getting the First Remote Object

- Can make objects available in RMI registry
  - Each object has a name (that you specify)
  - Registry listens on a port (1099 default)

- Naming.lookup(url) gets object from reg.
  - E.g., `Naming.lookup("rmi://localhost/Chat")`
  - Use to get first reference to remote object
  - Don’t need to lookup for objects returned by remote methods

Starting an RMI Registry

- Method 1: Separate RMI registry process
  - Command `rmiregistry`
    - Run with stubs in classpath, or specify codebase
    - Listens on port 1099 by default

- Method 2: Start in same JVM
  - `LocateRegistry.createRegistry(int port)`
  - Advantage: dies when your program dies
    - No registries lying around on machine
Advertising Remote Objects

- Call Naming {bind/unbind/rebind} to place objects in registry
  - E.g., Naming.bind("rmi://localhost/Chat");
- Can bind/unbind/rebind name on localhost
- Can lookup name on any host

Example: RMI Chat Server

- Server
  - runs the chat room
- Client
  - participant in chat room
  - receives messages from others in room
- Connection
  - uniquely identifies a client
  - used to speak in chat room

Server

```java
interface Server extends Remote {
    Connection logon(String name, Client c)
        throws RemoteException;
}
```

Connection

```java
interface Connection extends Remote {
    /** Say to everyone */
    void say(String msg)
        throws RemoteException;
    /** Say to one person */
    void say(String who, String msg)
        throws RemoteException;
    String [] who()
        throws RemoteException;
    void logoff()
        throws RemoteException;
}
```

Client

```java
interface Client extends Remote {
    void said(String who, String msg)
        throws RemoteException;
    void whoChanged(String [] who)
        throws RemoteException;
}
```

Server’s Remote Object creation

```java
Server s = new ServerImpl();
```

Diagram:

- Server
- Hosted Remote Objects
- ServerImpl
- Object added to table because it implements extension of Remote Interface
Remote Object registry

```
Naming.rebind("ChatServer", s);
```

```
ChatServer
```

```
ServerImpl
```

```
Hosted Remote Objects
```

```
RMI Registry
```

Client’s Remote Object creation

```
Client c = new ClientImpl();
```

```
ClientImpl
```

```
Hosted Remote Objects
```

```
Client
```

Hosted Remote Objects

Client looks up Server

```
Server s = (Server)
Naming.lookup("/host/ChatServer");
```

```
ServerImpl
```

```
Stub
```

```
Hosted Remote Objects
```

```
RMI Registry
```

```
Client
```

```
Stub
```

```
ServerImpl
```

```
Stub
```

```
ClientImpl
```

```
Hosted Remote Objects
```

```
Server
```

After lookup finished

```
Connection conn = s.logon("Bill", c);
```

```
ClientImpl
```

```
Stub code for remote logon call
```

```
ServerImpl
```

```
Stub for c
```

```
Method: logon
```

```
String "Bill"
```

```
Stub code for remote logon call
```

```
(Skeleton) code for remote logon call
```

```
Hosted Remote Objects
```

```
Server
```

Invokes remote Server method

```
Invokes remote Server method
```

```
Receives remote call
```

```
Remote method unmarshalled arguments
```

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```

```
ServerImpl
```

```
Stub`
Executes the call

- Server

- ServerImpl

- Hosted Remote Objects

- ClientImplStub

- call logon "Bill"

Returns the result

- Server

- ServerImpl

- Hosted Remote Objects

- (Skeleton) code for remote logon call

Receives the result

- Client

- ServerImplStub

- Conn Stub

- Return value: Stub for conn

- conn = unmarshalled return value

- logon

... create new Connection object

... return this as the result

... to client process