CS 555: Distributed Systems [RMI]

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Frequently asked questions from the previous class survey

Topics covered in this lecture

- RMI
- Distributed garbage collection
- Activatable objects
- Serialization and pitfalls

Dynamic Invocations

Dynamic Invocation: Alternative to proxies

- Proxy is generated from an interface definition
  - Then compiled **static**ally
    - Sometimes this is not enough
- What if a client program receives a remote reference to an object *that was not available at compile time*?
- We need another way to invoke the object
  - **Dynamic Invocation**

Dynamic invocation

- The remote object reference includes information about the interface of the remote object
- The names of methods and types of arguments are needed to make the invocation

Server program

- Contains classes for the dispatchers and skeletons
  - Implementations of classes of all server remote objects
- Server remote objects also created in response to requests from clients

Factory methods

- Remote object interfaces **cannot include constructors**
  - Remote server objects cannot be created by remote invocation on constructors
- Remote server objects are created either in:
  - The initialization section
  - Methods in a remote interface designed for that purpose
    - Also called **factory** methods

The binder

- Client programs need a way to obtain a remote object reference
  - For *at least one* of the remote objects held by server
- A **binder** is separate service that maintains a *table* with a *mapping* of textual names to remote object references
- Used by:
  - Servers: Register their remote objects by name
  - Clients: Lookup remote objects

Server threads

- When an object executes a remote method invocation?
  - Execution may lead to **further invocations** of methods in *other* remote objects
- Avoid situations where execution of a remote invocation *delays* execution of another
- Servers allocate a ***separate thread*** for the execution of each remote invocation
  - There is also support for the thread per-object model

Activation of remote objects

- Often it is not practical for objects to be kept in running processes for unlimited periods
  - Especially if they are being used sporadically
- Servers can be started whenever they are needed by the clients
  - Similar strategy is used in standard TCP services such as FTP
    - Started on demand by a service called `Inetd`

Active and passive remote objects

- Active
  - Available for invocation within a running process
- Passive
  - Not currently active, but can be made so
  - Consists of two components
    - Implementation of its methods
    - **State in marshaled form**

Activation is the creation of active objects from passive ones

- **Register** passive objects that are available for activation
- **Start** named server processes and *activate* remote objects in them
- Keep **track** of locations of servers for remote objects

Java RMI includes ability to make some remote objects activatable

- When an activatable object is invoked?
  - If it is not active, it is made so from its marshaled state
- Uses one activator on each server machine

Distributed Garbage Collection

Distributed garbage collection

- Based on **reference counting**
- Whenever a remote object reference enters a process:
  - A *proxy is created* and stays there for as long as it is needed
  - The process where the remote object lives (its server) should be *informed* of the new proxy
  - When there is no proxy at client; server should be informed

The distributed garbage collector works with the local garbage collector [1/2]

- Each server process maintains a set of names of processes that *hold remote object references*
  - For each of its remote objects
  - `B.holders` is the set of client processes with proxies for remote object **B**
- When client **C** *receives* a remote reference to a particular remote object?
  - Makes `addRef(B)` invocation to server of that remote object and *then* creates a proxy
  - Server adds **C** to `B.holders`

The distributed garbage collector works with the local garbage collector [2/2]

- When **C**'s garbage collector notices that the proxy for remote object **B** is no longer reachable
  - Makes a `removeRef(B)` to the corresponding server
  - Then *deletes* the proxy
  - Server *removes* **C** from `B.holders`
- When `B.holders` is empty
  - Server's local garbage collector will reclaim space occupied by **B**
    - Unless there are local holders

The distributed garbage collection can tolerate failure of client processes

- Servers **lease** their objects to clients for a limited period of time
  - Starts when client makes an `addRef` invocation
  - Ends when time *expires* or a `removeRef` invocation is made
- Clients are responsible for requesting server to **renew leases** before they expire

Java RMI Interfaces

Java RMI remote objects

- Object making remote invocation is aware that target is remote
  - Must handle `RemoteExceptions`
- Implementer is aware that it is remote
  - Must implement the `Remote` interface

Programming distributed applications with RMI is easy

- Single-language system
- In CORBA, programmer should learn IDL
  - Understand how it **maps** to the implementation language

Remote interfaces in Java RMI

- Defined by extending `java.rmi.Remote`
- Methods **must throw** `java.rmi.RemoteException`
  - Application specific exceptions may also be thrown

Example

```
import java.rmi.*;

public interface Shape extends Remote {
    int getVersion() throws RemoteException;
    GraphicalObject getAllState() throws RemoteException;
}
```

```
import java.rmi.*;
import java.util.Vector;

public interface ShapeList extends Remote {
   Shape newShape(GraphicalObject graphObj)
                                  throws RemoteException;
   Vector allShapes() throws RemoteException;
   int getVersion() throws RemoteException;
}
```

Parameters and result passing

- Parameters of a method are assumed to be **input** parameters
- Result of a method is the **single output** parameter
- Any object that is *serializable* can be passed as an argument or result
  - i.e. Object implements the `Serializable` interface

Passing objects

- When the parameter or result value is defined as a *remote interface*?
  - Corresponding argument or result passed as a **remote object reference**
- All serializable non-remote objects:
  - Copied and **passed by value**
  - When object is passed by value, **new object** is created in the *receiver's process*
    - Methods on this object are invoked locally; so *state can differ* from the original object

Arguments and return values are serialized to a stream

- When an object that implements the `Remote` interface is serialized?
  - It is replaced by its remote object reference
    - Contains name of remote object's class
- When any object is serialized
  - Class information is **annotated** with the location of class (URL)
    - Allows class to be downloaded by the server

Downloading classes

- Java is designed to allow classes to be **downloaded** from one VM to another
- Relevant for distributed objects that interact via remote invocations
- Code is downloaded automatically when:
  - Recipient <u>does not possess</u> class of *object that is passed by value*
  - If recipient of remote object reference <u>does not possess</u> *class for a proxy*

Advantages of this model

- No need for users to keep same set of classes in their working environment
- Client and server programs make transparent use of instances of new classes when they are added

RMI Registry

- This is the **binder** for RMI
- An instance of `RMIRegistry` should run on every server computer that hosts remote objects
- Maintains a table that **maps**
  - Textual, URL-style names to references to remote objects
- Accessed by methods of the Naming class
  - Argument includes a URL formatted string
  - `rmi://computerName:port/objectName`

BUILDING CLIENT & SERVER PROGRAMS

Looking at our remote `ShapeList` interface

```
import java.rmi.*;
import java.util.Vector;

public interface ShapeList extends Remote {
   Shape newShape(GraphicalObject graphObj)
                                    throws RemoteException;
   Vector allShapes() throws RemoteException;
   int getVersion() throws RemoteException;
}
```


Implementation of the Remote `ShapeList` interface

```
import java.rmi.*;
import java.util.Vector;

public class ShapeLister implements ShapeList {
   private Vector theList;   //contains list of shapes
   private int version;

   public ShapeLister() {}

   public Shape newShape(GraphicalObject graphObj) throws RemoteException {
       version++;
      Shape shape = new ShapeRemote(graphObj, version);
      theList.addElements(shape);
      return shape;
   }

   public Vector allShapes() throws RemoteException {...} ;
   public int getVersion() throws RemoteException;
}
```


Implementation of the Remote interface

- Straightforward
- **No details relating to communications**
  - This is handled transparently

The Server for the `ShapeList` remote object

```
import java.rmi.*;
import java.rmi.server.UnicastRemoteObject;

public class ShapeListServer {
 public static void main(String[] args) {
   System.setSecurityManager(new RMISecurityManager());

   try {
     ShapeList shapeList = new ShapeLister();
     ShapeList exported =
        (ShapeList) UnicastRemoteObject.
                                exportObject(shapeList, port);
     Naming.rebind("rmi://carrot.cs.colostate.edu/ShapeList",
                   exported);
   } catch (...) {

   }
 }
```


A closer look at `exportObject`

- Defined on `UnicastRemoteObject`
- Makes object available to the RMI runtime
  - Makes it available to *receive incoming invocations*
- Using `UnicastRemoteObject` ensures …
  - Object *lives only as long* as the <u>process</u> in which it was created

Installing a Security Manager

- Needs to create a security manager
  - Let Java security apply protection appropriate for RMI server
- `RMISecurityManager` is default security manager that's provided
  - Protects local resources to ensure that classes loaded from remote sites cannot have any effect on local resources
    - Such as files
  - Differs from standard Java security manager in allowing program to use its **own** *class loader* and to *use reflection*

If an RMI server sets no security manager?

- Proxies and classes can only be loaded from the local classpath
  - To protect program from code that is downloaded as a result of remote method invocations

Client Program

```
import java.rmi.*;
import java.rmi.server.*;
import java.util.Vector;

public class ShapeListClient {

  public static void main(String[] args) {
     System.setSecurityManager(new RMISecurityManager());
     ShapeList shapeList = null;
     try {
       shapeList =
           (ShapeList)Naming.lookup("rmi://carrot/ShapeList");
       Vector shapes = shapeList.allShapes();

      } catch (RemoteException ..) {...
      } catch (Exception ..) {...  }
   }
}
```


Callbacks

Callbacks

- Instead of clients **polling** the server to see if some event occurred
- Server **informs** client when the event occurs
- **Callback** refers to a server's action of *notifying* clients about an event

Implementing callbacks in RMI

- Clients create a *remote* object
  - Remote interface contains a method for the server to call
  - This is the **callback object**
- Server provides operation allowing interested clients to **register** their callback objects
- When an event occurs?
  - Server calls the interested clients

Snippets outlining the callback

```
public interface WhiteboardCallback implements Remote {
   void callback(int version);
};
```

This is implemented as a remote object by client

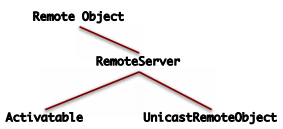
On the server-side the `ShapeList` **interface must have** ...

```
int register(WhiteboardCallback callback)
                              throws RemoteException;
void deregister(int callbackId) throws RemoteException;
```


The design of RMI

- The original implementation implemented all the components
- In Java 1.2, **reflection** facilities were used to make a generic dispatcher and avoid need for skeletons
- Prior to J2SE 5.0, client proxies were generated by a compiler `rmic`
  - No longer necessary with recent versions of J2SE
  - Support for dynamic generation of stub classes at runtime

Inheritance structure of classes supporting RMI Server



Marshalling and Unmarshalling

External data representation and marshalling

- Information in running programs represented as **data structures**
  - E.g., a set of interconnected objects
- Information in transmitted data?
  - **Sequence of bytes**
- Irrespective of the form of communications, data structures must be:
  - ***Flattened*** *before transmission* and ***rebuilt*** *on arrival*

Methods to enable computers to exchange binary data values

- Values are converted to an agreed **external format** before transmission
  - And, converted to local form upon receipt
- Values are transmitted in **sender's format**
  - With an indication of the format
  - Recipient converts values if necessary

Marshalling/Unmarshalling

- Marshalling
  - Translation of structured data items and primitive values into an external data representation
- Unmarshalling
  - Generation of primitive values from their external data representation
  - Rebuilding of data structure

An issue with design of marshalling methods

- Should we include type information?
- CORBA
  - Common Data Representation (CDR) includes values of transmitted objects and not the types
    - These can be inferred
- Java Serialization
  - Does include type information

CORBA's CDR

Type	Representation
sequence	length (unsigned long) followed by elements in order
string	length (unsigned long) followed by characters in order
array	Array elements in order (no length specified because it is fixed)
struct	In the order of declaration of components

Also includes primitive types: short (16-bit), long (32-bit), unsigned short, unsigned long, float (32-bit), double (64-bit), char, boolean (TRUE or FALSE), octet (8-bit) and *any*

Java Object Serialization

- Serialization
  - Flattening an object or a connected set of objects into serial form
    - For storing on disk or transmissions
- Deserialization
  - Restoring the state of the object from the serial form
  - Has no prior knowledge of the type of objects in the serialized form
    - Some information about the class of each object must be included in the serial form

The `Serializable` interface

- The `Serializable` interface **has no methods**
- Stating that a class implements the `Serializable` interface ?
  - Has the effect of allowing instances to be serialized

Let's look at a simple Class

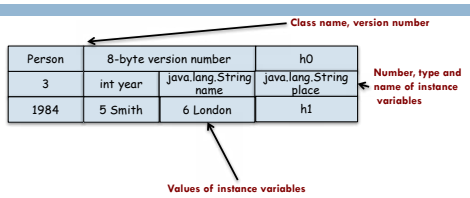
```
public class Person implements Serializable {
   private String name;
   private String place;
   private int year;

   public Person(String aName, String aPlace, int aYear) {
      name = aName;
      place = aPlace;
      year = aYear;
   }

   …. Methods for accessing instance variables follow ..

}
```

The Java Serialized form



Encoding class information

- The information about a class consists of the
  - Class name
  - Version
    - Should change with major changes to the class
- **Version** assignment
  - Set by programmer
  - Calculated as a *hash* of the name of the class and its instance variables, methods and interfaces
- Deserialization checks to see if it has correct version of the class

Java objects contain references to other objects

- When an object is serialized, all the objects that it references are serialized
  - Ensures when an object is reconstructed all its references call be fulfilled at the destination
- References are serialized as **handles**
  - Handle is a reference to an object *within* the serialized form
  - 1-1 correspondence between object references and handles
  - Each object is written exactly once
    - Subsequent occurrences of an object? The handle is written instead of the object

Serializing an object

- Class information is written out
  - Each class is given a **handle** and no class is written more than once
    - Handles are written where necessary
- This is followed by (types and names of) instance variables
- **Recursive** procedure continues until
  - Class information, types and names of instance variables of *all* classes are written out

How are things written out?

- Contents of instance variables that are of *primitive* types (e.g., `int`, `char`, `boolean`, etc) ?
  - Written in portable binary format using methods of the **`ObjectOutputStream`** class
- Strings and characters are written using the `writeUTF` method
  - Universal Transfer Format (UTF)
  - ASCII characters are represented unchanged (1 byte), Unicode characters with multiple bytes

Controlling serialization

- Programmers can **modify** the effects of serialization
- Declare variables that should not be serialized as **`transient`**
  - E.g. references to local resources such as files and sockets

Reflection makes it possible to do (de)serialization in a generic manner

- Java object serialization uses reflection to find out
  - Class name
  - The names, types, and values of instance variables
- For deserialization
  - Class name in serialized form is used to **create class**
  - This class is then used to **create a new constructor** *with argument types* corresponding to those in serialized form
  - New constructor is used to **create a new object** with instance variables who values are read from the serialized form

The contents of this slide-set are based on the following references

- *Distributed Systems: Concepts and Design*. George Coulouris, Jean Dollimore, Tim Kindberg, Gordon Blair. 5th Edition. Addison Wesley. ISBN: 978-0132143011 [Chapter 4 and 5]