RMI
(Remote Method Invocation)

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Topics

- What is RMI? Why RMI?
- Architectural components
- Serialization & Marshaled Objects
- Dynamic class loading
- Code movement
- Codebase
- ClassLoader delegation
- RMI Security
- Writing RMI Server and Client
- Activation
- HTTP Tunneling

What is RMI?

What is RMI?

- RPC (Remote Procedure Call) between Java Objects
- General RPC behavior
  - Invoke remote methods
  - Pass arguments into methods
  - Receive results from methods
- RPC Evolution
  - Non-object-oriented RPC
  - CORBA (Object-oriented)
  - RMI (Object-based)

What is RMI?

- Differences from other RPC’s
  - Java-based
  - Code movement semantics
  - Built-in security mechanism
  - Exposure of network failures to application programmers through RemoteException

Why RMI?

- Capitalizes on the Java object model
- Minimizes complexity of distributed programming
- Uses pure Java interfaces
  - no new interface definition language (IDL)
- Preserves safety of Java runtime
- Recognizes differences of remote call from local call
  - partial failure
  - latency
  - no global knowledge on system state

RMI Architectural Components

RMI Architectural Components

- Remote interface
- Stub and Skeleton
- Remote object

Remote Interface

- Java interface
  - Specify remotely accessible methods
- Implemented by a class, an instance of which becomes a remote object
- Contract between caller of the remote method (RMI client) and remote object (RMI server)
- Extends *java.rmi.Remote* interface
  - Markup interface

Stub & Skeleton

Stub and Skeleton

- A tool (rmic) creates
  - RMI stub
  - (Optionally) RMI skeleton
- Gets created from RMI server implementation (not from RMI interface)

Stub and Skeleton

- RMI Stub
  - Resides in caller’s local address space
  - Represents remote object to caller (client)
    - Plays the role of proxy of remote object
    - Implementation of Remote interface
    - Caller invokes methods of RMI Stub locally
  - Connects to the remote object
  - Sends arguments to and receive results from remote object
    - Performs marshaling and unmarshaling

Stub and Skeleton

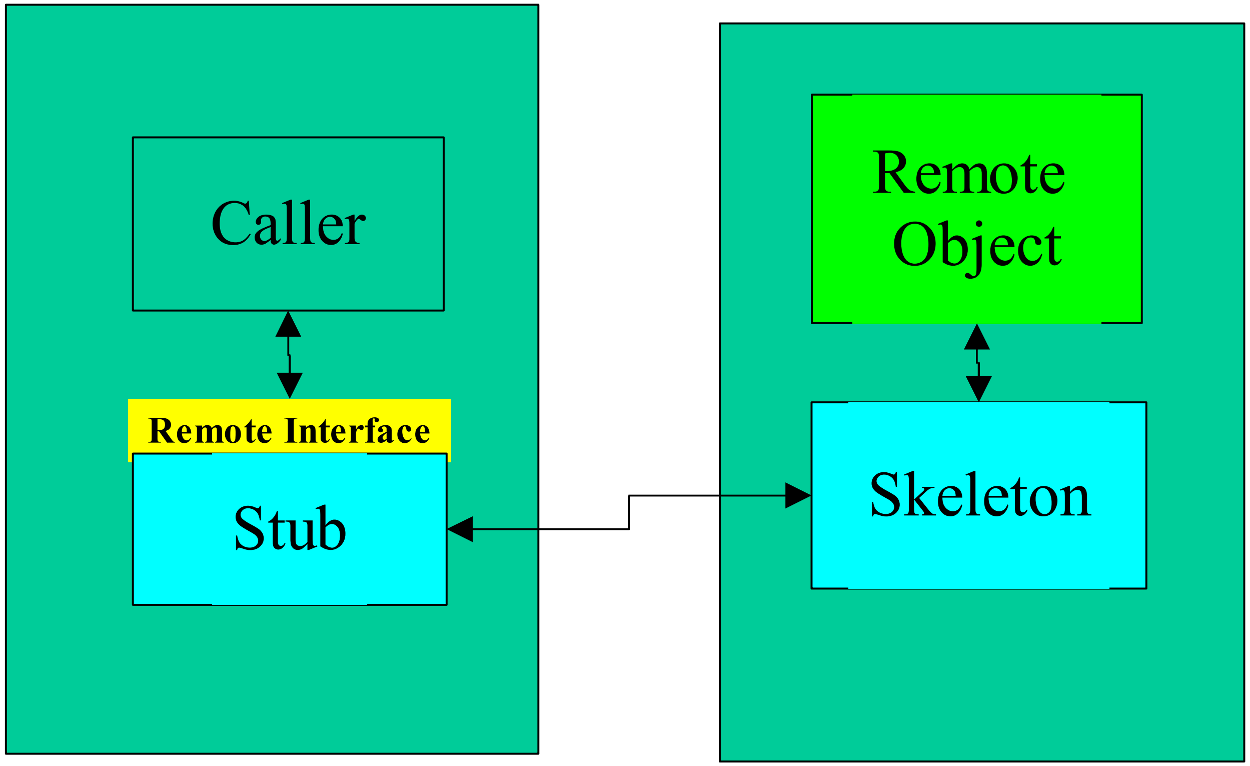
- RMI Skeleton
  - Resides in server’s address space
  - Receives arguments from caller (RMI Client's Stub) and send results back to caller
    - Performs marshaling and unmarshaling
  - Figures out which method of remote object to be called
  - In JDK 1.3, RMI Skeleton gets created automatically via reflection

Remote Object

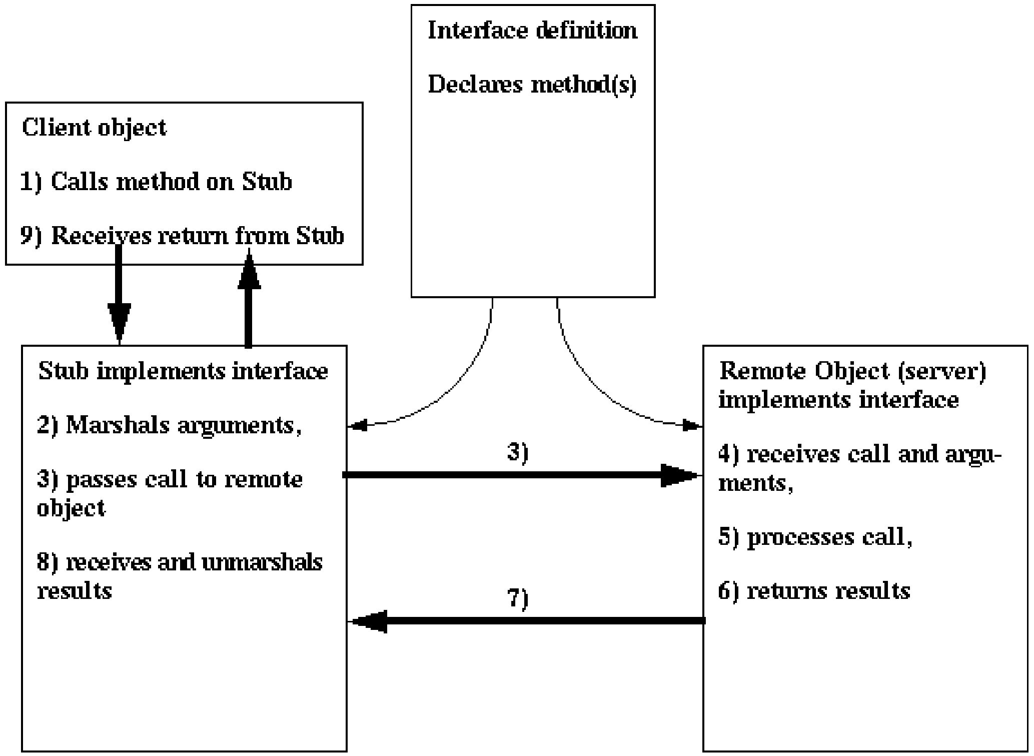
- Implementation of remote interface
- Needs to be exported
  - In order to be ready to receive calls from caller
- Can be exported in two types
  - Non-activatable (extends *java.rmi.server.UnicastRemoteObject*)
  - Activatable (extends *java.rmi.server.Activatable*)

RMI Communication Model

RMI Communication Model



RMI Control Flow


Interface definition
Declares method(s)
Client object
1) Calls method on Stub
9) Receives return from Stub
Stub implements interface
2) Marshals arguments,
3) passes call to remote object
8) receives and unmarshals results
3)
7)
Remote Object (server) implements interface
4) receives call and arguments,
5) processes call,
6) returns results

RMI Control Flow

- Caller (Client)
  1. invokes a method of a remote object
- Stub of the remote object
  1. intercepts the method call
  2. marshals the arguments
  3. makes calls to remote object

RMI Control Flow

- Remote object
    1. Receives the calls via Skeleton
    2. Unmarshals the arguments
    3. Performs the call locally
    4. Marshals the result
    5. Send the result to client
- Stub
    1. Receives result
    2. Unmarshal result
    3. Return result to client

Serialization in RMI

Marshaling and Unmarshaling

- Marshaling is a process of encoding objects to put them on the wire
- Unmarshaling is the process of decoding from the wire and placing object in the address space
- RMI uses Java programming lanaguage's serialization and deserialization to perform marshaling and unmarshaling
  - These terms are used interchangeably

Serialization in RMI

- Arguments/Results get serialized before being transported by sender
- Arguments/Results get deserialized after being transported by receiver
- Arguments/Results in RMI can be one of the following two
  - Remote object
  - Non-remote object

Serialization in RMI

- For remote object
  - Remote interface type
  - Stub gets serialized (instead of remote object itself)
  - "Pass by reference" semantics
    - Stub is kind of a reference to remote object
- For non-remote object
  - Normal serialized copy of the object
  - Should be type of *java.io.Serializable*
  - "Pass by Value" semantics

Example

```
// Arguments and Returns are non-remote objects
public interface SayHelloStringRemote extends Remote {
    public String SayHelloString (String message)
                                        throws  RemoteException;
}

// Arguments has both remote and non-remote objects
public interface SayHelloObjectRemote extends Remote {
    public String SayHelloObject (String messsage,
                                   SayHelloStringRemote  someName)
                                        throws  RemoteException;
}
```

Serialization

- Serialized copy of an object
  - Stream of bytes
  - Persistently maintains state of an object
    - State of non-static and non-transient variables of the object
  - Does NOT contain class bytecodes (*.class files)
    - Instead maintains information on "where to get the class bytecodes"
      - codebase annotation
      - Who performs the codebase annotation?
    - If the class is unknown to the recipient, it will be downloaded automatically

Serialization

- **Serialized copy defines state**
- **Class files define behavior**
- Both can be moved around over the network
    - Collectively this is called "Code movement"

Marshaled Objects

What and Why Marshaled Objects?

- Container object of serialized object
  - Constructed by passing object into constructor
  - get() method retrieves the deserialized object
- Used when you want to maintain the serialized object without deserializing it immediately
  - Storage service of objects
    - Lookup service

Dynamic Class Loading

Dynamic Class Loading

- Class bytecodes (Class file) get downloaded during runtime
  - When caller does not have the class bytecodes in local classpath
    - RMI Stub needs to be downloaded to RMI Caller's address space from somewhere
  - Serialized copy of an object contains "where to get class bytecodes" information
    - Codebase annotation

Who Does Provide Codebase Annotation Information?

- By the exporter of the class
- Via Export codebase (RMI codebase) property
  - *java.rmi.server.codebase*
  - Typically via HTTP URL

When Does the Codebase Annotation occurs?

- Whenever an object gets serialized
- For remote object
  - Codebase information of Stub class
- For non-remote object
  - Codebase information of normal class

RMI Server and Client Deployment Scenario

- Both client and server have RMI Remote interface class in their local classpaths
- Server has HelloWorld_Stub class in its local classpath
- Client does not have HelloWorld_Stub class in its localpath
  - He could, but is diminishes the whole purpose of class downloading
- Server exports HelloWorld_Stub class via HTTP server

RMI Server and Client Deployment Scenario

- Client gets HelloWorld_Stub serialized object from Registry
  - Client typically does not have HelloWorld_Stub class in its local classpath
  - So it will read the RMI codebase annotation (from the serialized stub object) and will try to download the HelloWorld_Stub class from the location specified in codebase annotation

Code (and Data) Movement

Code movement in Jini? (new slide)

- Service proxy object gets moved
  - Moved from service provider to Lookup service
    - In marshaled object form
  - Moved from Lookup service to client address space
    - Marshaled object gets unmarshaled into serialized object
    - Client has to recreate an instance of that service proxy object
      - From serialized service proxy object, client reads codebase annotation
      - Download class

Code (and Data) Movement (new slide)

- Performed in two phases
  1. Serialized object (Marshalled Object) gets moved
  2. Class files get downloaded
- Code
  - Represented by class files
- Data
  - Represented by state captured in serialized object

Serialized Object (new slide)

- Contains
  - Values of the fields of the object
  - Name of the class
  - Location of the class
    - Via codebase annotation performed by the exporter of the class
    - RMI codebase property

Codebase

What is Codebase?

- Location where class bytecodes (Class files) reside

Two types of Codebase

- Import codebase
  - codebase your local VM uses to load classes it needs
  - specified via *CLASSPATH* or *-cp* option
- Export codebase (RMI codebase)
  - codebase remote VMs use to obtain the class files "exported" from your local VM
  - specified via *java.rmi.server.codebase* property
    - Codebase annotation

Behind the Scene Activities

- Any objects marshaled by a server will be annotated with RMI codebase
  - For remote object, the stub object gets marshaled and annotated
- When a client instantiates the object, the bytecodes of the class will be downloaded by RMIClassloader from the location specified as RMI codebase

RMI codebase forms

- Could be in any URI form
  - HTTP (Recommended)
  - FTP
  - FILE (Not recommended)
- Classes can be accessible via
  - JAR
  - Directory path
    - Trailing slash required

RMI codebase

- For Jini service (as an RMI server)
  - Export classes that are needed by its client
    - Stub classes for remote objects
    - Interface classes of remote objects
      - If client has the classes in its local classpath, no downloading occurs
    - Any classes that are needed by the interface and stub classes
- For Jini client
  - Export classes that are needed by the server
    - Same as above

RMI codebase examples

- Directories need a trailing slash
  - -Djava.rmi.server.codebase="file:/export/home/btm/classes/”
  - -Djava.rmi.server.codebase= "http://daydreamer:8080/export/home/btm/root/dir/”
- Jar files do not need a trailing slash
  - -Djava.rmi.server.codebase= "file:/export/home/btm/jars/examples-dl.jar”
  - -Djava.rmi.server.codebase= "http://daydreamer:8080/export/home/btm/jars/examples-dl.jar”
- You can specify multiple locations
  - -Djava.rmi.server.codebase= "http://daydreamer:8080/export/home/btm/jars/examples-dl.jar http://daydreamer:8080/export/home/btm/root/dir/"

Jini RMI codebase examples

- Lookup service
  - java -jar C:\files\jini1_1\lib\reggie.jar http://daydreamer:8081/reggie-dl.jar C:\files\jini1_1\policy\policy.all C:\tmp\reggie_log public
- Lookup browser (Client)
  - java -cp C:\files\jini1_1\lib\jini-examples.jar

    -Djava.security.policy=C:\files\jini1_1\example\browser\policy

    -Djava.rmi.server.codebase=http://daydreamer:8081/jini-examples-dl.jar com.sun.jini.example.browser.Browser

jini-examples-dl.jar

- Lookup browser (as Lookup service client) exports classes needed by Lookup service

```
   0 .. META-INF/
  66 .. META-INF/MANIFEST.MF
2003 .. com/sun/jini/example/browser/
             Browser$Listener_Stub.class
2015 .. com/sun/jini/example/browser/
             ServiceEditor$NotifyReceiver_Stub.class
1045 .. net/jini/core/event/RemoteEvent.class
 376 .. net/jini/core/event/RemoteEventListener.class
 389 .. net/jini/core/event/UnknownEventException.class
```

Typical Causes of Problems

- The *java.rmi.server.codebase* (RMI codebase) property was not set at all
  - Do not use “localhost”
- RMI codebase was set, but HTTP server is not running
- RMI codebase was set, HTTP server is running, but the class is not present under the proper path in HTTP server
- The port number on which HTTP server is listening is not the same as the port number in the RMI codebase
- The name of the host on which HTTP server is running is not the same as the hostname in the RMI codebase
- If a non-jar URL is being used in the RMI codebase, there is no trailing slash (if class file location is in a jar file, no trailing slash is required)

Typical RMI codebase Symptom

java.rmi.UnmarshalException: error unmarshalling return; nested exception is:
java.lang.ClassNotFoundException: example.testService_Stub

- Client could not download the stub class from the server
- The error message could be misleading in JDK 1.2 (Fixed in JDK 1.3)
    - The problem could be that the stub class itself is downloadable but other classes that the stub needs are not downloadable
    - Use "javap -classpath <path1:path2> <classname>"

Typical RMI codebase Symptom

```
RemoteException occurred in server thread;  nested
    exception is: java.rmi.UnmarshalExceptionException:
    error unmarshalling arguments; nested exception is:

    java.lang.ClassNotFoundException:test.TestClient$S
    erviceListener_Stub
```

- Server could not download the remote event listener stub class from the client
  - See if stub was generated correctly (via RMIC)
  - See if listener object was exported (via .exportObject() method)
  - See if RMI codebase is set correctly by the client

Typical RMI codebase Symptom

- Things are working fine but when client and server are on different machines, I get ClassNotFoundException
  - Very likely due to the fact that the class files are not available anymore
    - Do not use CLASSPATH for downloadable files
      - Do **use** RMI codebase
    - Do not use “localhost”

RMI Codebase FAQ

- Should client applications include mahalo-dl.jar or reggie-dl.jar in their CLASSPATH?
  - They can. But it diminishes the whole purpose of dynamic class downloading during runtime. It is better they get exported by specific implementations of TxnManager and Lookup service (I.e. Mahalo and Reggie)
  - The client apps need the following in their CLASSPATH (or Class-Path of manifest file)
    - jini-core.jar, jini-ext.jar, sun-util.jar
- Should each service have its own embedded HTTP server?
  - It depends

RMI Codebase FAQ

- The Stub file is definitely being exported. And HTTP server is up and running OK. Yet, the client still complains ClassNotFoundException on Stub file under JDK 1.2
  - This is typically due to the fact that the class file that the stub file needs is not being exported
  - Use javap command to find out which class file is really missing
    - javap -classpath abc.jar:def.jar example.test

Implementation Guideline

- Client has remote interface class file in its local classpath (unless it uses reflection)
- The classes that are needed for implementation should be downloadable from the server
  - Stub classes
  - Interface classes
    - Needed when client does not have interface classes in its local path
  - Any other classes that the stub and interface refers to
- Make jar file in the form of xxx-dl.jar

Example

- eventg/buildEventGenerator & eventg/runEventGenerator

```
[daydreamer] java -Djava.security.policy=/home/sang/src/examples/lease/policyEventGenerator
-Djava.rmi.server.codebase=http://daydreamer:8081/EventGenerator-srvc-dl.jar
http://daydreamer:8081/EventGenerator-attr-dl.jar -jar
/home/sang/jars/EventGenerator.jar daydreamer

[daydreamer] jar -tvf EventGenerator-srvc-dl.jar
     0 Mon Mar 22 13:04:56 EST 1999 META-INF/
    66 Mon Mar 22 13:04:56 EST 1999 META-INF/MANIFEST.MF
   982 Mon Mar 22 13:04:04 EST 1999 examples/eventg/EventGenerator.class
  7933 Mon Mar 22 13:04:20 EST 1999
examples/eventg/EventGeneratorImpl_Stub.class
  1532 Mon Mar 22 13:03:52 EST 1999 examples/eventg/TestLease.class
   911 Mon Mar 22 13:03:52 EST 1999 examples/eventg/TestLeaseMap.class
  1554 Mon Mar 22 13:04:00 EST 1999 examples/eventg/TestEventLease.class
   967 Mon Mar 22 13:04:00 EST 1999 examples/eventg/TestEventLeaseMap.class
   410 Mon Mar 22 13:03:56 EST 1999 examples/eventg/TestEvent.class

[daydreamer] jar -tvf EventGenerator-attr-dl.jar
     0 Mon Mar 22 13:05:14 EST 1999 META-INF/
    66 Mon Mar 22 13:05:14 EST 1999 META-INF/MANIFEST.MF
   752 Mon Mar 22 13:05:10 EST 1999 net/jini/lookup/entry/ServiceInfo.class
  1764 Mon Mar 22 13:05:12 EST 1999
com/sun/jini/lookup/entry/BasicServiceType.class
```

Deployment Tips

- Run separate HTTP servers on different ports if possible
  - One for Jini infrastructure services
    - Lookup services
    - Transaction Manager
  - The other for your own service

Trouble-shooting methods

- Run HTTP server in verbose mode (Example next slide)
  - Will display all the jar or class files being downloaded
- Set "-Djava.rmi.loader.logLevel=VERBOSE" on RMI client (Example next slide)
  - Will tell which class file is being downloaded from which location
- Try "javap -classpath <pathlist or jar files> <classname>" on command line (Example next slide)
  - Will tell what is really missing
- See if you can access the jar file using a browser
  - "Save as" dialog box pops up if the file is accessible
- Try FTP URL notation (instead of HTTP)
  - If it works, HTTP has a problem

Running HTTP server in verbose mode

```
[daydreamer] java -cp /files/jini1_0/lib/tools.jar com.sun.jini.tool.ClassServer
    -port 8081   -dir /home/sang/jars -verbose
```

```
java -cp /home/sang/files/jini1_0/lib/tools.jar com.sun.jini.tool.ClassServe
ort 8081 -dir /home/sang/jars -verbose
RegRemoteAndProvideLease-srvc-dl.jar from daydreamer:65296
RegRemoteAndProvideLease-srvc-dl.jar from daydreamer:33431
RegRemoteAndProvideLease-srvc-dl.jar from daydreamer:33797
DiscoveryByGroup-srvc-dl.jar from daydreamer:37616
DiscoveryByGroup-srvc-dl.jar from daydreamer:37617
DiscoveryByGroup-attr-dl.jar from daydreamer:37620
DiscoveryByGroup-attr-dl.jar from daydreamer:37621
DiscoveryByLocator-srvc-dl.jar from daydreamer:37886
DiscoveryByLocator-srvc-dl.jar from daydreamer:37887
```

-Djava.rmi.loader.logLevel=VERBOSE

```
[daydreamer] java                                                    -Djava
        .security.policy=/home/sang/src/examples/client/policyLookupSrvcAndInvoke          -Dsun.rmi.loader.logLevel=VERBOSE
                                         -jar /home/sang/jars/LookupSrvcAndInvoke.jar daydreamer

groupsWanted[0] = daydreamer
Waiting For Discovery to Complete

Wed Mar 17 07:43:01 EST 1999:loader:unicast discovery:LoaderHandler.loadClass: loading class "com.sun.jini.reggie.RegistrarProxy"
        from [http://daydreamer:8080/reggie-dl.jar]
.Wed Mar 17 07:43:02 EST 1999:loader:unicast discovery:LoaderHandler.loadClass: loading class
        "com.sun.jini.reggie.RegistrarImpl_Stub" from [http://daydreamer:8080/reggie-dl.jar]
LookupDiscoveryListener:  discovered...
  Lookup on host jini://daydreamer/:
    regGroups[0] belongs to Group: myGroup
    regGroups[1] belongs to Group: daydreamer
...........
Discovery of Available Lookups Complete.
Query each Lookup for known Services, the Invoke ...
Lookup Service on Host: jini://daydreamer/
  Belongs to Group: daydreamer
Wed Mar 17 07:43:13 EST 1999:loader:main:LoaderHandler.loadClass: loading class "com.sun.jini.lookup.entry.BasicServiceType" from
        [http://daydreamer:8080/reggie-dl.jar]
Wed Mar 17 07:43:13 EST 1999:loader:main:LoaderHandler.loadClass: loading class "net.jini.lookup.entry.ServiceInfo" from
        [http://daydreamer:8080/reggie-dl.jar]
Wed Mar 17 07:43:13 EST 1999:loader:main:LoaderHandler.loadClass: loading class "com.sun.jini.lookup.entry.BasicServiceType" from
        [http://daydreamer:8080/sun-util.jar, http://daydreamer:8081/RegRemoteAndProvideLease-srvc-dl.jar,
        http://daydreamer:8081/RegRemoteAndProvideLease-attr-dl.jar]
Wed Mar 17 07:43:13 EST 1999:loader:main:LoaderHandler.loadClass: loading class "net.jini.lookup.entry.ServiceInfo" from
        [http://daydreamer:8080/sun-util.jar, http://daydreamer:8081/RegRemoteAndProvideLease-srvc-dl.jar,
        http://daydreamer:8081/RegRemoteAndProvideLease-attr-dl.jar]
```

javap

```
[daydreamer:291] javap -classpath LookupSrvcAndInvoke.jar examples/lease/TestLease
Class 'examples/lease/TestLease' not found

[daydreamer:289] javap -classpath RegRemoteAndProvideLease-srvc-dl.jar examples/lease/TestLease
Error: No binary file 'AbstractLease'

[daydreamer:326] javap -classpath RegRemoteAndProvideLease.jar:sun-util.jar examples/lease/TestLease
Error: No binary file 'Lease'

[daydreamer:332] javap -classpath RegRemoteAndProvideLease.jar:sun-util.jar:jini-core.jar
        examples/lease/TestLease
Compiled from TestLease.java
public class examples/lease/TestLease extends com.sun.jini.lease.AbstractLease {
   protected final examples.lease.RegRemoteAndProvideLease server;
   protected final java.lang.String leaseID;
   protected examples/lease/TestLease(examples.lease.RegRemoteAndProvideLease,java.lang.String,long);
   public boolean canBatch(net.jini.core.lease.Lease);
   public void cancel() throws net.jini.core.lease.UnknownLeaseException, java.rmi.RemoteException;
   public net.jini.core.lease.LeaseMap createLeaseMap(long);
   public long doRenew(long) throws net.jini.core.lease.UnknownLeaseException, java.rmi.RemoteException;
   java.lang.String getLeaseID();
   examples.lease.RegRemoteAndProvideLease getRegRemoteAndProvideLease();
   void setExpiration(long);
}
```

javap

- admin/AdminServer registers with a lookup service without including OurOwnAdmin class file in its downloadable jar
  - You will see unknown service on the Lookup browser

```
[daydreamer:230] cd ~sang/jars
[daydreamer:232] ls -lat Admin*
-rw-rw----   1 sang     jinieast    8035 Mar 22 21:19 AdminClient.jar
-rw-rw----   1 sang     jinieast    2083 Mar 21 23:44 AdminServer-attr-dl.jar
-rw-rw----   1 sang     jinieast    4953 Mar 21 23:44 AdminServer-srvc-dl.jar
-rw-rw----   1 sang     jinieast   13560 Mar 21 23:44 AdminServer.jar

[daydreamer:229] !226
javap -classpath AdminServer-srvc-dl.jar examples/admin/AdminServerImpl_Stub
Error: No binary file 'Administrable'

[daydreamer:229] javap -classpath AdminServer-srvc-dl.jar:jini-ext.jar examples/admin/AdminServerImpl_Stub
Error: No binary file 'DestroyAdmin'

[daydreamer:229] javap -classpath AdminServer-srvc-dl.jar:jini-ext.jar:sun-util.jar examples/admin/AdminServerImpl_Stub
Error: No binary file 'OurOwnAdmin'
```

Review Points

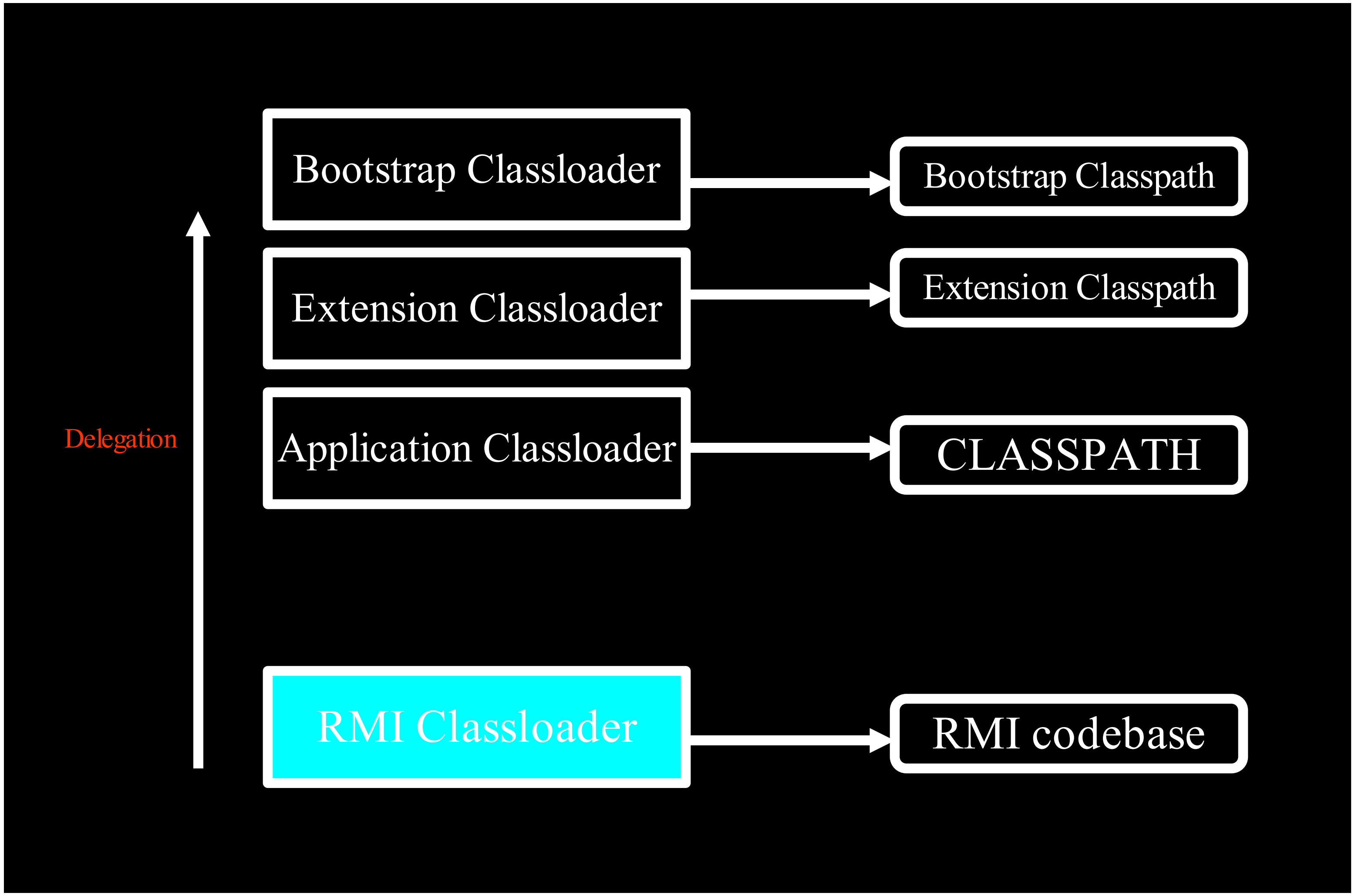
- RMI codebase
  - Used for exporting class files
    - Serialized object has codebase annotation
  - Set via *java.rmi.server.codebase* property
  - Cause of most of *ClassNotFoundException* problems

ClassLoader Delegation

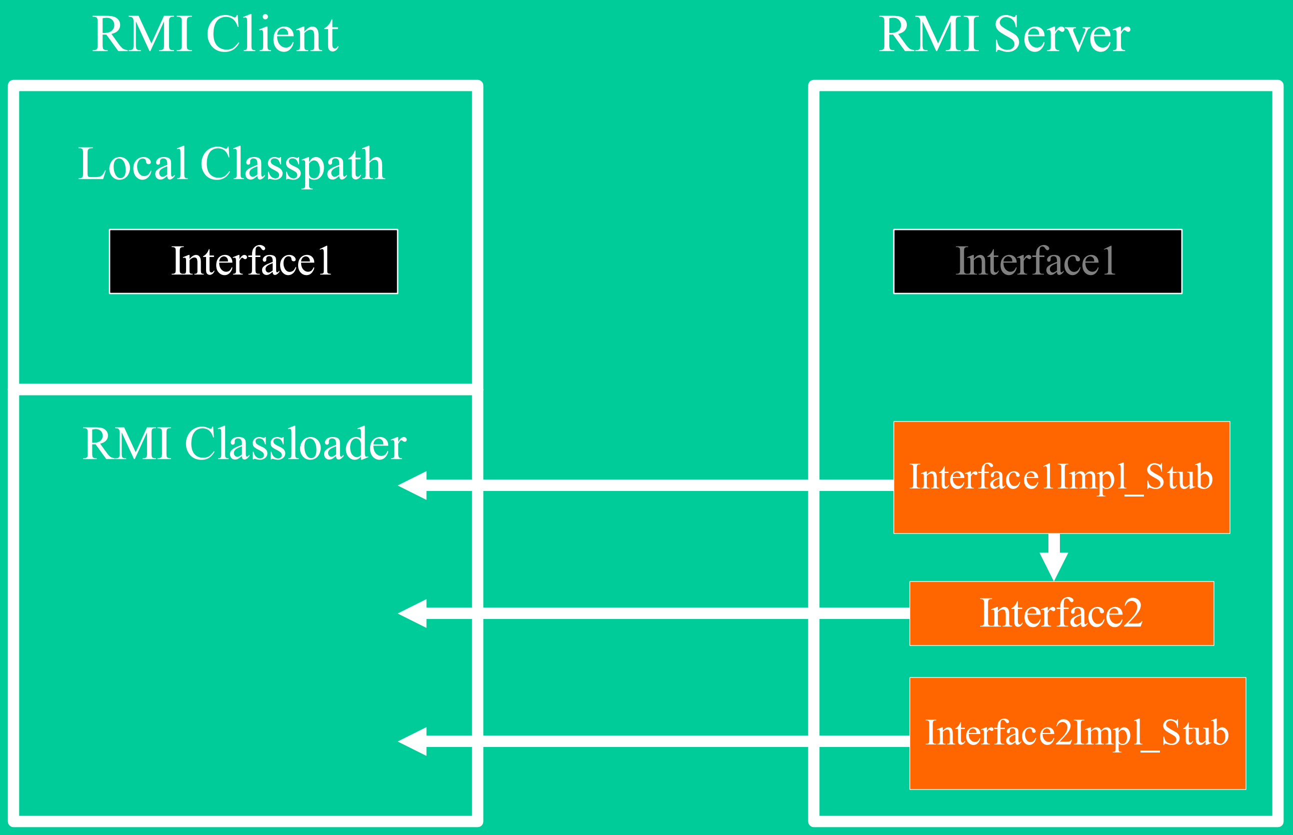
ClassLoader Delegation

- Introduced in JDK 1.2
  - Class files are searched based on classloader hierarchy
    - Bootstrap classloader
    - Extension classloader
    - Application classloader
    - RMI classloader
  - Ask parent classloader first
    - Reason why a class file in local CLASSPATH gets picked up first before the same class file gets downloaded from remote location

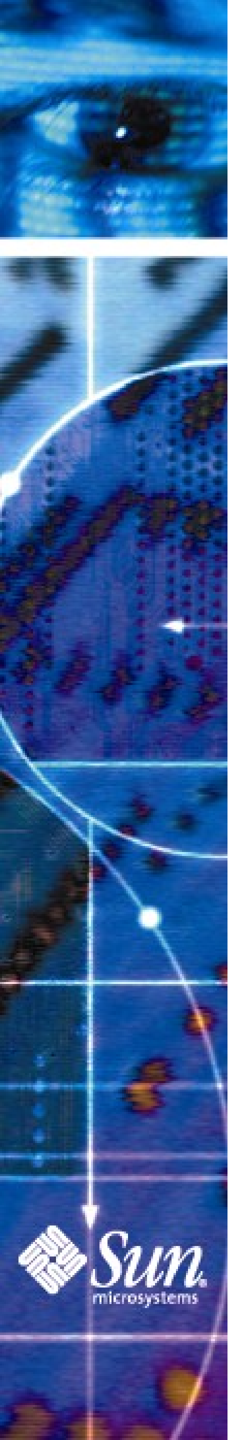
Classloader Hierarchy



Example


RMI Client
RMI Server
Local Classpath
Interface1
Interface1
RMI Classloader
Interface1Impl_Stub
Interface2
Interface2Impl_Stub

RMI Security



Java Security

- In Java, SecurityManager handles security control
  - Based on security policy file
  - Security policy define "permission control" based on
    - Where the code came from
    - Who signed the code
    - Examples
      - All code signed by Dave can write to a particular directory
      - Any code downloaded from a particular HTTP server site has no filesystem access

Security Policy Example

- Give all all permission to any code

```
grant {
    permission java.security.AllPermission "", "";
};
```

- Use only during testing
  - Never use it in production environment

Security Policy Example: for Reggie

```
grant codebase "file:${java.class.path}" {
    // file system dependent permissions for unix file system
    permission java.io.FilePermission "./*", "read,write,execute,delete";
    permission java.io.FilePermission "/tmp", "read,write,execute,delete";
    permission java.io.FilePermission "/tmp/-", "read,write,execute,delete";
    permission java.io.FilePermission "/var/tmp", "read,write,execute,delete";
    permission java.io.FilePermission "/var/tmp/-", "read,write,execute,delete";
    // uncomment this one if you need lookup to accept file: codebases
    // permission java.io.FilePermission "<<ALL FILES>>", "read";
    permission java.lang.RuntimePermission "modifyThreadGroup";
    permission java.lang.RuntimePermission "modifyThread";
    permission java.net.SocketPermission "*:1024-", "connect,accept";
    // for http: codebases
    permission java.net.SocketPermission "*:80", "connect";
    permission java.net.SocketPermission "224.0.1.84", "connect,accept";
    permission java.net.SocketPermission "224.0.1.85", "connect,accept";
    permission java.util.PropertyPermission "java.rmi.server.hostname", "read";
    permission java.util.PropertyPermission "com.sun.jini.reggie.*", "read";
    permission java.util.PropertyPermission "net.jini.discovery.*", "read";
    permission net.jini.discovery.DiscoveryPermission "*";
    // file system dependent permissions for windows file system
    permission java.io.FilePermission ".\\*", "read,write,execute,delete";
    permission java.io.FilePermission "c:\\temp", "read,write,execute,delete";
    permission java.io.FilePermission "c:\\temp\\-", "read,write,execute,delete";
    permission java.io.FilePermission "c:\\windows\\temp", "read,write,execute,delete";
    permission java.io.FilePermission "c:\\windows\\temp\\-", "read,write,execute,delete";
    // Deleted the rest
};
```

RMI/Jini Security

- Security is a serious concern since executable code is being downloaded from remote location
- In RMI/Jini, *SecurityManager* has to be installed in order to be able to download any code from remote location
  - Without its installation, RMI/Jini will search for class files only from local classpath
- The security policy file further specifies the “permission control”

RMI Security

- RMI client needs to install security manager because it needs to download Stub file of RMI object
- A simple RMI server might not need to install security manager if it does not need to download class files from remote location
  - It is still good practice to install it anyway

Writing RMI Server

Steps of Writing RMI Server

- S1: Define remote interface
- S2: Implement remote interface
- S3: Provide an implementation for each remote method
- S4: Write server class
  - Contains main() method
  - Create and export remote object
  - Create and install a security manager
  - Register remote object with RMI registry

S1: Define Remote Interface

- Defines methods that are called remotely
- Must be declared as *public*
- Extends the *java.rmi.Remote* interface
- Each method must declare *java.rmi.RemoteException*
- The data type of any remote object that is passed as an argument or return value (either directly or embedded within a local object) must be declared as the Remote interface type (for example, Hello) not the implementation class (HelloImpl).

S1: Remote Interface Example

```
// A remote interface for getting increasing numbers

package corejini.appendixa;

import java.rmi.Remote;
import java.rmi.RemoteException;

public interface NextNumber extends Remote {
    public int getNextNumber(int n)
                            throws RemoteException;
}
```

S2: Write the implementation

- Implement the remote interface
- Extend one of the two remote classes
  - *java.rmi.server.UnicastRemoteObject*
  - *java.rmi.activation.Activatable*
- Write constructor for the remote object
  - By extending one of the two remote classes above, they are automatically exported
    - You can manually export it as well
  - Throw RemoteException
  - Install Security Manager
  - Register remote objects with RMI registry

S2: Server Implementation Example

```
// A server object that implements the NextNumber
// remote interface

package corejini.appendixa;
import java.rmi.RemoteException;
import java.rmi.RMISecurityManager;
import java.rmi.Naming;
import java.rmi.server.UnicastRemoteObject;
import java.net.InetAddress;
import java.net.UnknownHostException;
import java.net.MalformedURLException;
```

S2: Example -Continued

```
public class NextNumberImpl extends UnicastRemoteObject
implements NextNumber {

    public NextNumberImpl() throws RemoteException {

       // Install SecurityManager
      if (System.getSecurityManager() == null) {
          System.setSecurityManager(
                      new RMISecurityManager());
       }
```

S2: Example -Continued

```
try {
            // Bind it with RMI Registry
            String host = InetAddress.getLocalHost().getHostName();
            String url = "rmi://" + host + "/nextNumber";
            Naming.rebind(url, this);
            System.out.println("Server bound to: " + url);
} catch (UnknownHostException ex) {
           System.err.println("Couldn't get local host name");
           System.exit(1);
} catch (RemoteException ex) {
           System.err.println("Couldn't contact rmiregistry.");
                    System.exit(1);
} catch (MalformedURLException ex) {
           System.exit(1);
}
```

S3: Implement Remote Methods

- Implement service logic within the methods
- Do not throw RemoteException
  - They are called locally (same address space) from RMI Skeleton

S3: Example

```
// Implement remote method
public int getNextNumber(int n) {
    return n+1;
}
```

S4: Write Server Class

- Setup (or Wrapper) class
  - Contains main() method
  - Create one or more instances of remote objects

S3: Example

```
// Write main method
public static void main(String[] args) {
  try {
            NextNumberImpl server = new NextNumberImpl();
  } catch (RemoteException ex) {
            ex.printStackTrace();
  }
}
```

Create one or more instances of a remote object

- Remote object gets exported during instantiation process
  - Remote object is ready to receive incoming RMI calls

Register the remote object with RMI Registry

- RMI Registry is a simple naming service
    - Bootstrap mechanism
    - Typically is used by caller to get the remote reference of the first remote object
- Client gets reference to remote object - actually reference to stub object of the remote object

Writing RMI Client

Steps of Writing RMI Client

- Install security manager
- Get a reference to the remote object implementation
  - The registry returns the Stub instance of the remote object bound to that name
- Invoke remote methods

Example

```
// A client to test the NextNumber server
package corejini.appendixa;
import java.rmi.Remote;
import java.rmi.RemoteException;
import java.rmi.RMISecurityManager;
import java.rmi.NotBoundException;
import java.rmi.Naming;
import java.net.MalformedURLException;

public class NextNumberClient {
    public static void main(String[] args) {
        if (args.length != 1) {
            System.err.println("Usage: NextNumberClient <url>");
            System.exit(1);
        }
```

Example - Continued

```
if (System.getSecurityManager() == null) {
    System.setSecurityManager(
       new RMISecurityManager());
}
```

Example - Continued

```
Remote r = null;
try {
    r = Naming.lookup(args[0]);
} catch (RemoteException ex) {
    System.err.println("Couldn't contact registry.");
    System.exit(1);
} catch (NotBoundException ex) {
    System.err.println("There is no object bound to " + args[0]);
    System.exit(1);
} catch (MalformedURLException ex) {
    System.err.println("The string " + args[0] +
       " is not a valid RMI URL");
    System.exit(1);
}
```

Example - Continued

```
try {
    if (r instanceof NextNumber) {
        NextNumber nn = (NextNumber) r;
        System.out.println("Next number after 1 is " +
        nn.getNextNumber(1));
        System.out.println("Next number after 2 is " +
        nn.getNextNumber(2));
    } else {
        System.err.println("Uh oh, the name " +
                 args[0] + "isn't a NextNumber");
    }
} catch (RemoteException ex) {
              ex.printStackTrace();
}
```

Building, Deploying RMI Server and Client

Build Process

- Compile
  - Compile client and server in separate directories
- Generate Stub and Skeleton
  - Use RMIC
  - Takes fully qualified Java class name of Implementation class
    - *rmic corejini.appendixa.NextNumberImpl*

Example: RMIC

```
C:\files\corejini\appendixa>rmic corejini.appendixa.NextNumberImpl
error: Class corejini.appendixa.NextNumberImpl not found.

C:\files\corejini\appendixa>cd \files
C:\files>rmic corejini.appendixa.NextNumberImpl
C:\files>cd corejini\appendixa
C:\files\corejini\appendixa>dir

HELLOW~1 JAV        5,260  01-04-01  1:36p HelloWorldServiceActivatable.java
NEXTNU~1 JAV          249  01-04-01  1:36p NextNumber.java
NEXTNU~2 JAV        1,802  01-04-01  1:36p NextNumberClient.java
NEXTNU~3 JAV        1,540  01-04-01  1:36p NextNumberImpl.java
NEXTNU~1 CLA          227  06-21-01 10:56p NextNumber.class
NEXTNU~2 CLA        1,719  06-21-01 10:56p NextNumberImpl.class
NEXTNU~3 CLA        2,023  06-21-01 10:56p NextNumberClient.class
NEXTNU~4 CLA        3,218  06-21-01 10:59p NextNumberImpl_Stub.class
NEXTNU~5 CLA        1,640  06-21-01 10:59p NextNumberImpl_Skel.class
```

Server Deployment Process

- Start RMI Registry
  - Has to run on the same machine that has RMI object
    - rmiregistry
- Start HTTP server
  - Root directory has to directory structure that is comparable to exportable class files
    - C:\files\corejini\appendixa\NextNumberImpl_Stub.class
    - c:>java -jar C:\files\jini1_2\lib\tools.jar -port 8081 -dir c:\files\ -verbose

Server Deployment Process

- Create Security policy file
- Run the RMI server
  - c:\files>java -Djava.security.policy=c:\files\jini1_2\policy\policy.all -Djava.rmi.server.codebase=http://hannah:8081/ corejini.appendixa.NextNumberImpl

Client Deployment Process

- Create Security policy file
- Start HTTP server if needed
  - c:>java -jar C:\files\jini1_2\lib\tools.jar -port 8082 -dir c:\files\ -verbose
  - In this example, no need for this since client is not exporting any classes
- Run the RMI Client
  - c:>cd \files
  - c:\files>java -Djava.security.policy=c:\files\jini1_2\policy\policy.all corejini.appendixa.NextNumberClient rmi://hannah/nextNumber

Activation

Activation

- Why activatable objects?
  - Service could be shut down inadvertently or intentionally
  - Activatable service gets restarted automatically when system boots up or on-demand basis
    - Activatable service needs to be started (registered with RMID) only once
- Activation system components
  - RMID (Activation system daemon)
  - RMID log file
    - Persistently stores all activatable objects
    - Default is <Directory where RMID gets started>/log directory
  - Activatable services
    - They are run as child processes of RMID

Control Flow of Activation

[A new activatable service with running RMID]

(1) RMID running

(2) A new service registers with RMID and gets a special RMI reference -RMID logs the information in persistent storage

(3) The service (actually the proxy object) registers with the lookup service - the proxy object contains the RMI reference

(4) The service goes inactive (intentionally or inadvertently)

(5) Client, via lookup operation, retrieves the proxy object, which contains the RMI reference

(6) Client Stub talks to the service directly and gets an exception since the service (as an RMI server) is inactive

(7) Client Stub then talks to RMID

(8) RMID restarts the service if necessary in a new VM

(9) Client now can talk directly with the service

Control Flow of Activation

[RMID crash and reboot]

(1) A service is registered with RMID

(2) RMID crashes and reboots

(3) RMID reads the log file and restarted the services (the ones which set the RESTART flag during the registration with RMID)

.

.

(5) Client, via lookup operation, retrieves the proxy object, which contains the RMI reference

(6) Client talks to the service directly .

RMID

- As long as RMID is running and RMID log file is persistent, a service can get started on “as needed” basis
- Methods of destroying a service
  - Kill RMID and remove RMID log file
    - Other services will be destroyed as well
    - Sledge hammer approach
  - Use com.sun.jini.admin.DestroyAdmin interface’s destroy() method if the service supports it
    - Recommended approach

Jini Activatable Services

- Reggie (Lookup service)
- Mahalo (Transaction Manager)
- Outrigger (JavaSpace)
- Fiddler (Lookup Discovery Service)
- Norm (Lease Renewal Service)
- Mercury (Event Mailbox Service)

Activation Trouble-shooting

- java.rmi.activation.ActivationException: ActivationSystem not running
  - Possibly DNS lookup problem
  - Try CTRL-\ (Solaris) and CTRL-BREAK (Win32) for stack trace
- Start RMID with
  - -J-Dsun.rmi.server.activation.debugExec=true
- For any RMI properties you want to set for activatable services (child processes of RMID), start RMID with “-C-Dproperty=value”
  - -C-Djava.rmi.server.logCalls=true

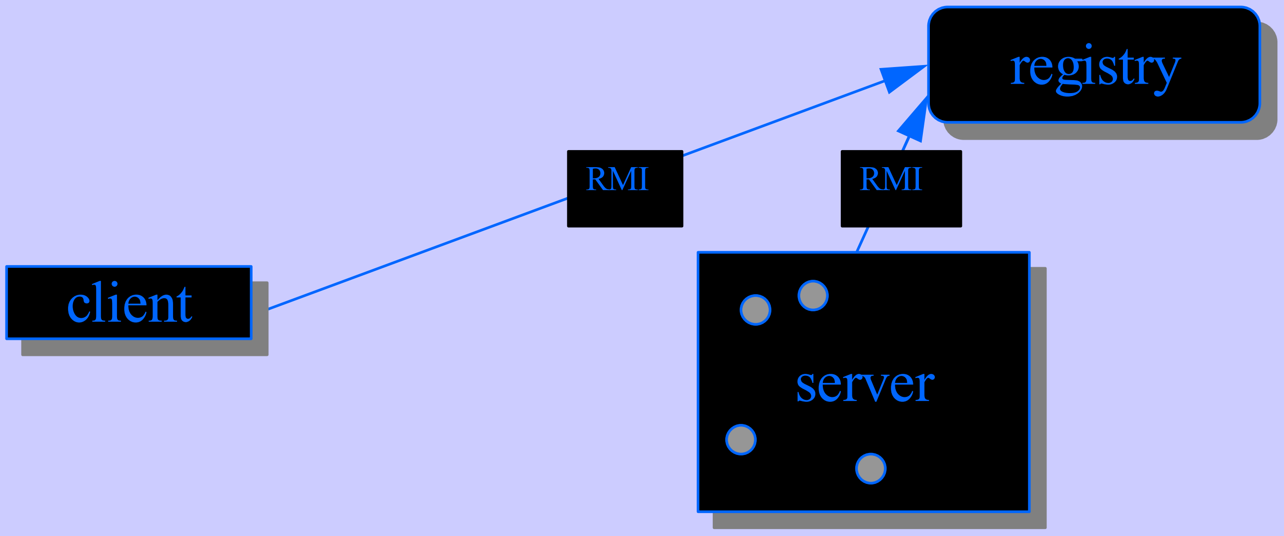
RMI Tunneling

RMI Tunneling

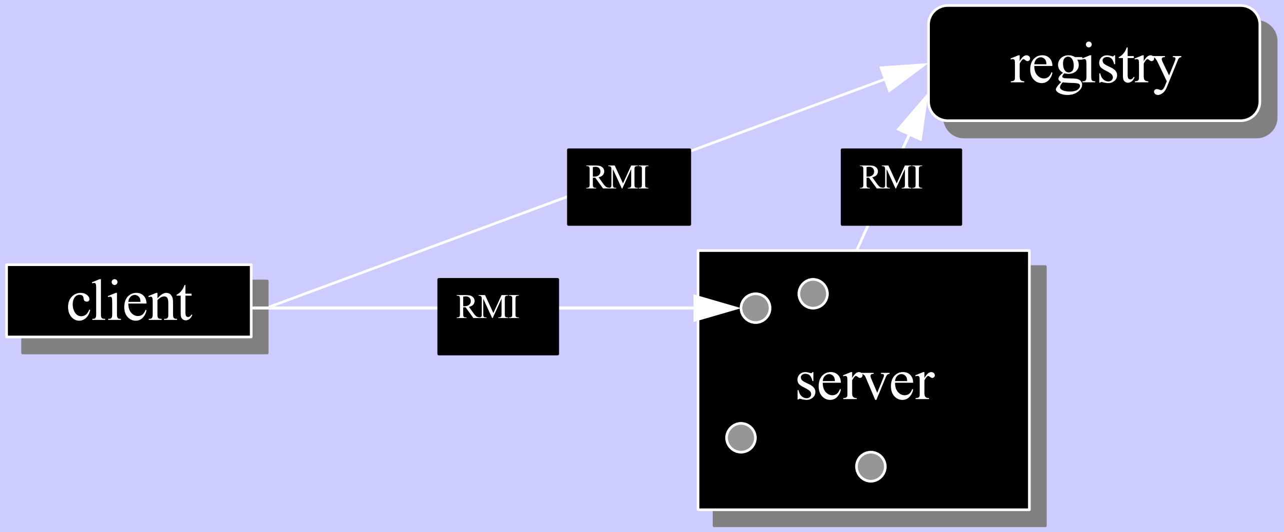
- Features
  - Protocol runs over HTTP protocol
  - Allows RMI client within a firewall to talk to an RMI server outside of the firewall
- Limitation
  - RMI server cannot talk back to the RMI client
- Implications to Jini
  - No multicast discovery
    - Have to use Unicast
  - No event notification from RMI server to RMI client

Review Points

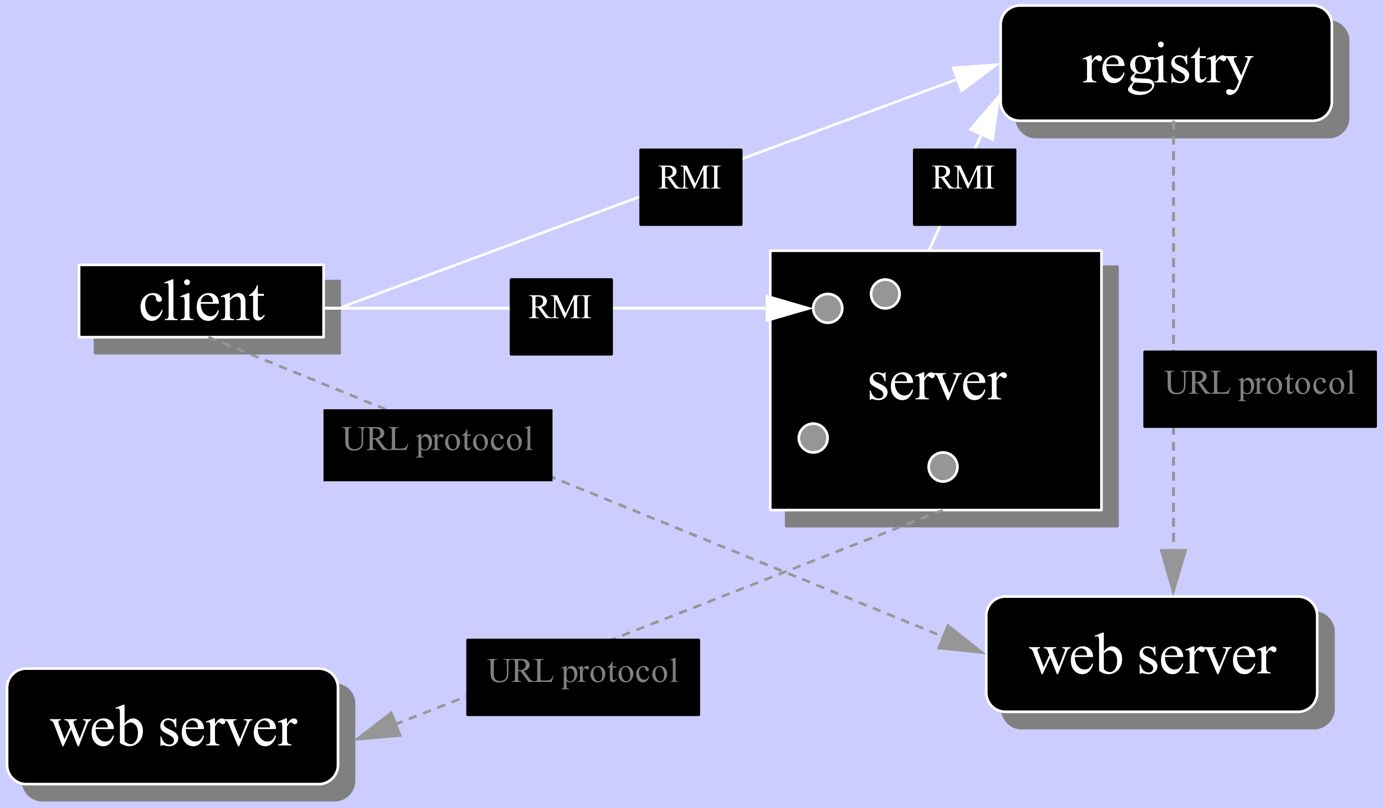
Locating Remote Objects



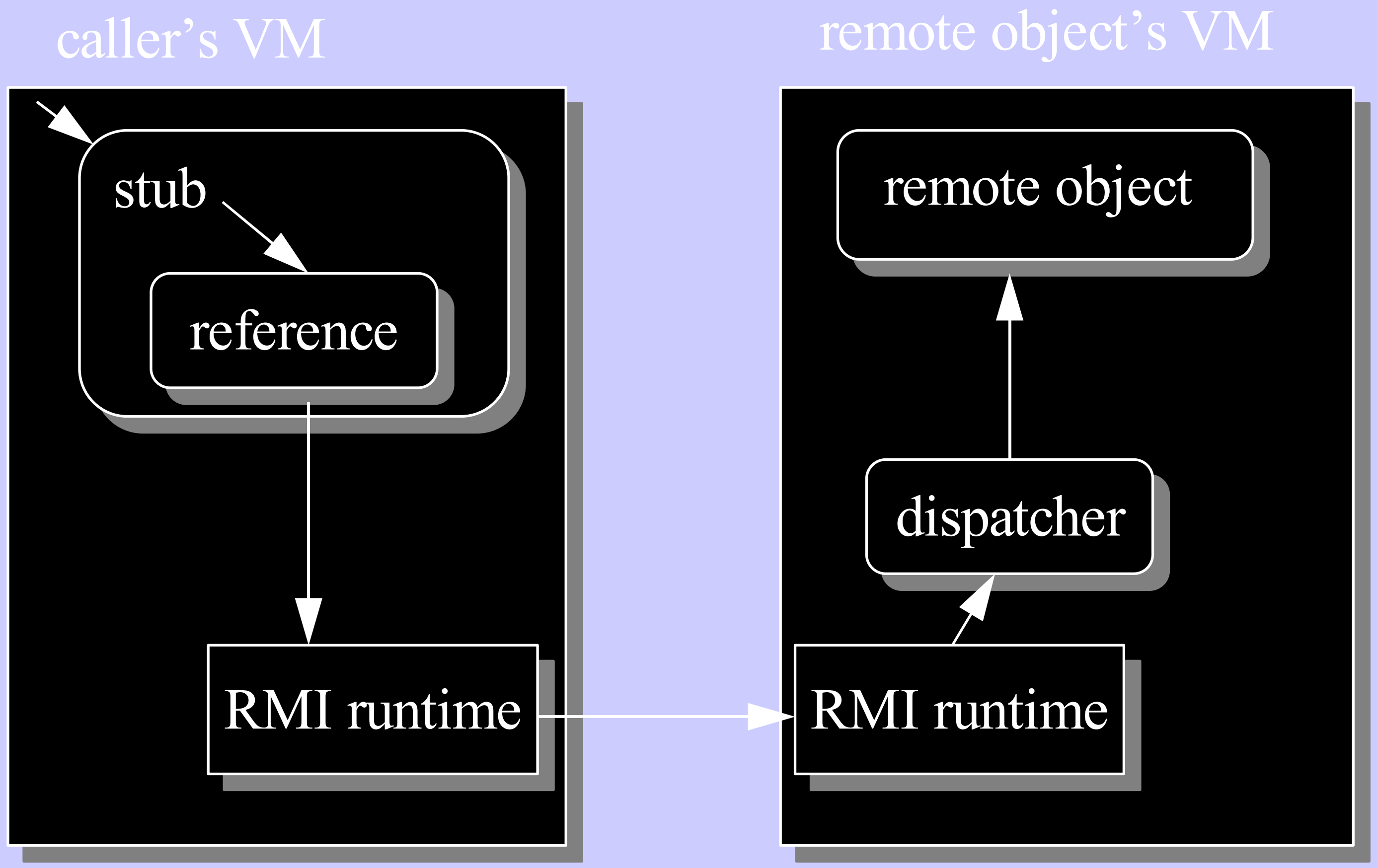
Remote Communication



Loading Classes



Method Invocation



RMI and Jini

RMI and Jini

- RMI Semantics is foundation of Jini
  - Specified in RMI specification
    - Does not dictate implementation
  - Code movement
  - Serialization
  - Activation
  - Marshaled Object
- RMI Implementation vs. Specification (Semantics)

RMI and Jini

- Jini specification vs. implementation
- Jini specification specifies
  - Service interface definitions
    - API's and Semantics of those APIs
    - Lookup service, Transaction, Remote events, Leasing
  - RMI-like semantics
    - Runtime code movement
- Jini specification does not dictate
  - Usage of any specific wire-protocol

RMI Limitation

- Client and server paradigm
  - Client has to know about the server
    - where the server is
    - how to reach the server
    - what the server can do
  - If the server becomes unavailable, the client generally fails too

Jini Value-propositions over RMI

- Client does not need to know where a particular service is located
- Client should not fail if the service is unavailable or becomes unavailable during execution
- Client and servers should be proactive in detecting failure conditions

Summary

- RMI is for invoking methods of remote Java object
- Enables the movement of data and code
  - Data (State of object) movement via serialized object
  - Code movement via class downloading