CMSC 433 Fall 2014
Section 0101
Mike Hicks
(slides due to Rance Cleaveland)

UNIVERSITY OF MARYLAND

Lecture 17
Java Remote Method Invocation

Recall

- Concurrency

  Several operations may be in progress at the same time on the same machine

- Parallelism

  Several operations may be executing simultaneously on the same machine

- "Distributed-ness"

  Several machines may be working at the same time for the same application

So Far We Have Concentrated On:

- Concurrency in Java
  - Threads
  - Locks
  - Etc.
- Parallelism in Java
  - Performance tuning
  - Fork/Join
  - Etc.
- Focus has been on applications running inside a single Java Virtual Machine (JVM)

Remote Method Invocation (RMI)

- Java support for *distributed programming*
  - Applications may use several JVMs
  - JVMs may be on different nodes in a network
  - Key constraint: no shared memory!
- RMI enables methods in objects hosted by one JVM to be called from a different JVM
  - This approach to distributed-system design is often called the *distributed object model*
  - Other distributed object models
    - DCOM
    - CORBA
  - Other distributed models
    - Message passing
    - Event-based architectures

Some Distributed System Terminology

- Host

  Computer running in a distributed environment
- Port

  Communication channel used by hosts to exchange messages
- Network

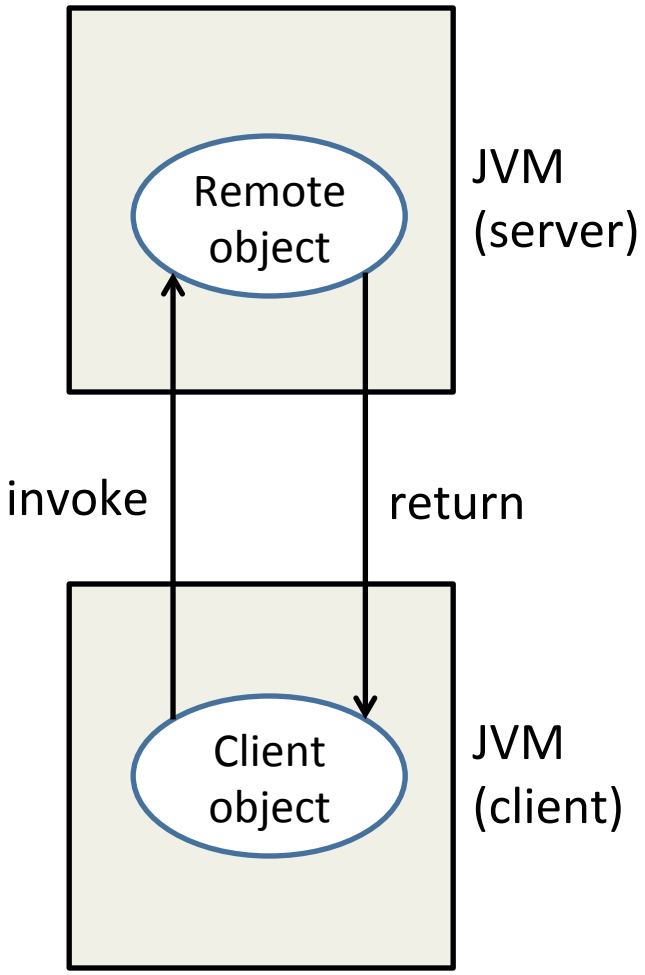
  System consisting of hosts, equipment used to connect hosts
- IP address

  Internet Protocol address: number assigned to a host connected to the internet so that other hosts may communicate with it
- MAC address

  Media Access Control address: number assigned to a host on a local-area network

RMI Distributed Object Model

- Remotely accessible objects reside on *servers* (= JVMs)
- Client objects can invoke methods in remote objects
- RMI protocol handles transfer of data to / from servers / clients



Questions

- How does the client object pass arguments to the remote object?
- How does the remote object return information to the client object?
- How do distributed objects find out about each other?
- How does the client object know what argument types to pass, and what return type to expect?
- How does the client object know if the remote object can be trusted (and vice versa)?

Exchanging Information Between Objects via RMI

- RMI uses *TCP / IP* to transfer information between objects
  - TCP = Transmission Control Protocol
  - IP = Internet Protocol
- TCP / IP is a protocol for exchanging data among computers connected to a network
  - TCP (inter-application) is connection-oriented
  - IP (inter-machine) is connection-less, packet-based
  - Data is passive (i.e. sequences of bytes)

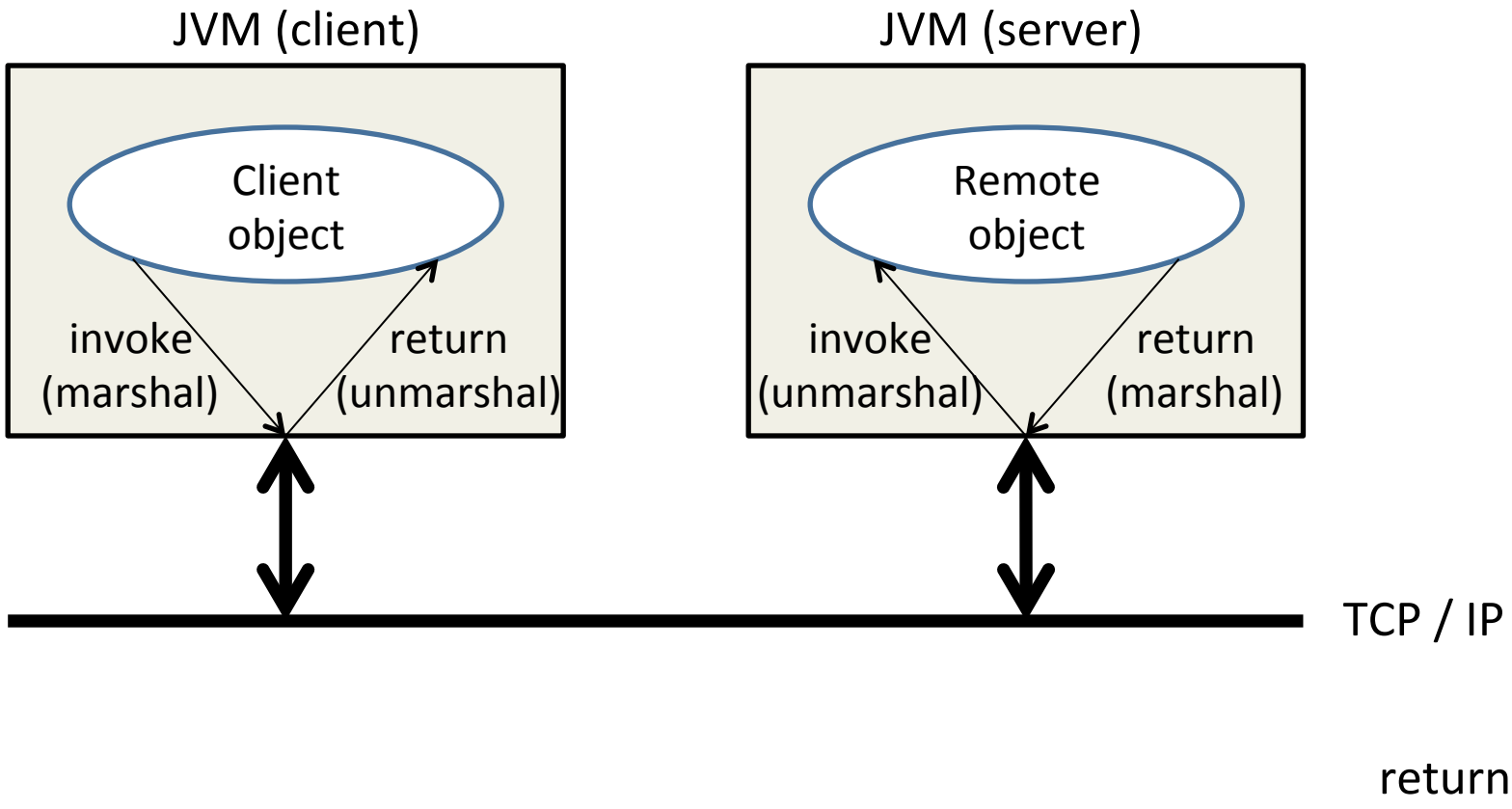
RMI and TCP / IP

- In Java one often calls a method with objects as parameters
- TCP / IP only deals with sequences of bytes
- To maintain the illusion of "objects flowing over the network", distributed-object models (including RMI) use *marshaling / unmarshaling*
  - Marshaling: translating objects into sequences of bytes
  - Unmarshaling: translating sequences of bytes back into objects

Marshaling / Unmarshaling in RMI

- Primitive types (int, boolean, etc.) can be handled easily
- Remote objects *passed by reference* (basically, by address)
- Java RMI uses *serialization / deserialization* to handle marshaling / unmarshalling of local objects, which are *passed by value*
  - Serialization: converting an object into a sequence of bytes
    - Bytes may be stored in a file / sent across network / etc.
    - Entire persistent state of object is stored
  - Deserialization: reconstruction of an object from a sequence of bytes
    - Persistent state of object is rebuilt from bytes
    - Exceptions thrown if bytes contain error, or class is unknown, etc.
- To support serialization, class must implement the `java.io.Serializable` interface, and all (non-transient) fields must be serializable
  - No methods in interface!
  - Implementing interface is just a signal to compiler that serializability must be checked
  - If you try to serialize / deserialize an object that is not serializable, `NotSerializableException` is thrown

RMI Distributed Object Model with (Un)Marshaling

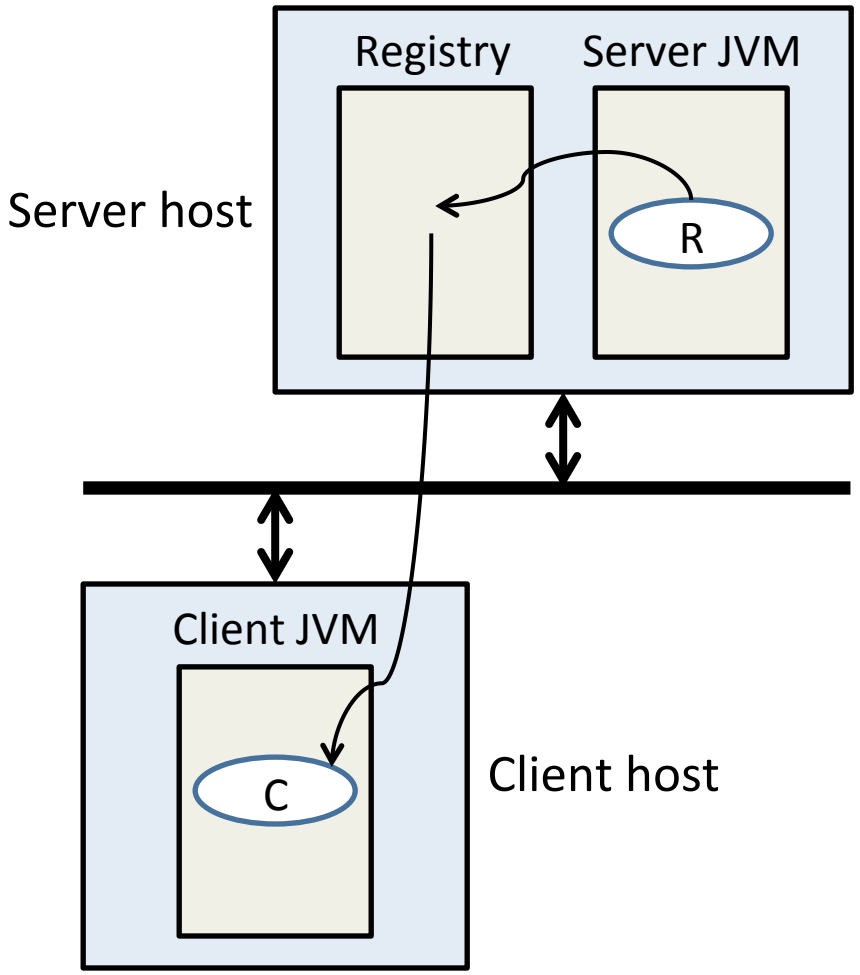


Locating Remote Objects: Object Registries

- The *Object Registry* is a name server that relates remotely accessible objects with (unique) names
  - Each server has an object registry on the same host computer
  - The registry associates each remotely accessible object on the server with a name
- A client wishing to access a remote object can do so by looking up the object name in a registry
- A server wishing to make an object available for RMI must register it with its object registry

RMI Architecture / Flow

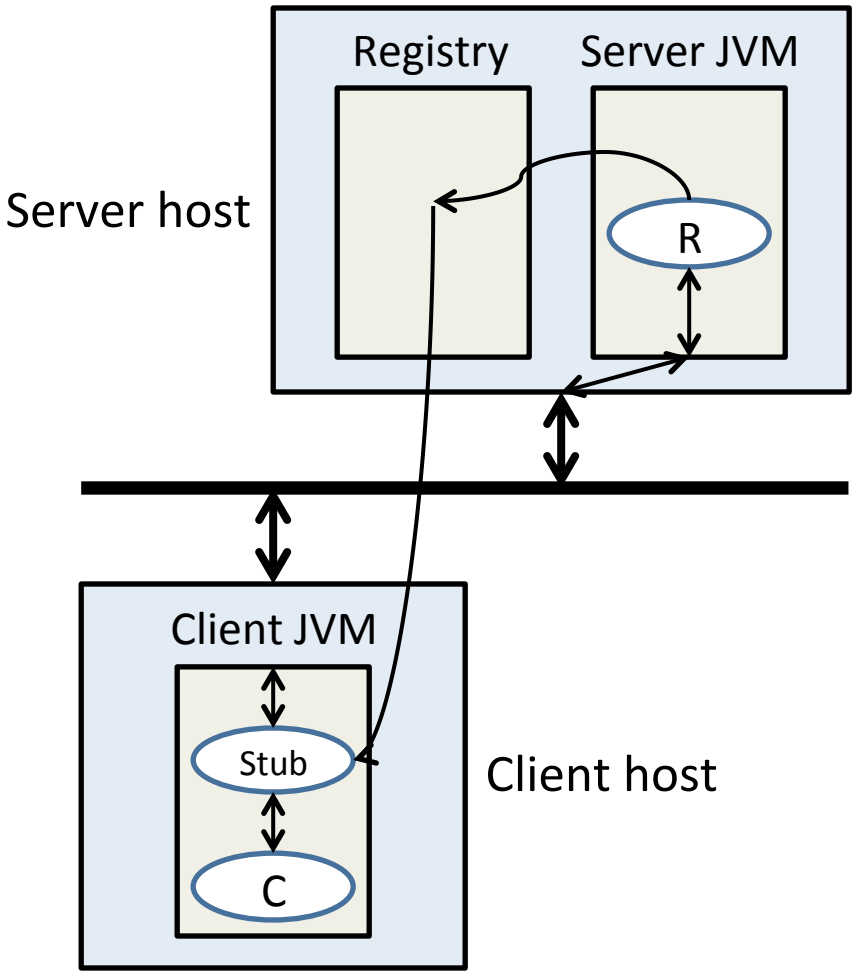
1. Server creates remotely accessible object
2. Server registers object with registry, giving it unique name
3. Client requests remote object by name from registry
4. Registry returns *stub* to client
5. Client invokes stub method
6. RMI mechanism uses marshaling / unmarshaling to transfer arguments to server, results to client



Stubs

- A *stub* for a remote object is a proxy that the client uses to initiate remote method invocations
  - When a client queries an object registry for an object, what is returned is a stub
  - The stub matches the same interface (more later) as the remote object
  - The stub handles marshaling of arguments, unmarshaling of results, and communication with runtime environment of remote object
- When a client obtains a stub for a remote object, any method the client invokes on the stub will result in corresponding method in remote object being invoked

RMI Architecture (Refined)



Warning

- The discussion of stubs is with respect to Java 5.0 and later
  - Earlier versions of RMI required the use of a separate compiler, `rmic`, to produce stubs
  - Disseminating stubs to clients was more complicated
  - In pre-5.0 Java there were also *skeletons*, which sat on the server side and handled communications with stubs
- The Java 5.0 and later approach is simpler, but you may still encounter legacy code using the older approach

The `java.rmi.Remote` Interface

- Classes of remote objects must implement the `Remote` interface in java.rmi
- Here is the interface

```
interface Remote { }
```

- ???
  - `Remote` is an example of a "marker interface" (like `Serializable`)
  - Marker interfaces indicate that classes implementing them are intended for special purposes
  - Remote objects will generally implement interfaces that extend `Remote`
    - Requirement on methods in such interfaces: they must throw `RemoteException`
    - This exception is raised when there are problems with the remote invocation (e.g. network disruptions, host problems, etc.)

Example: Test String Printing

- Application contains four files
  - TestString.java

    Remote interface for test-string objects
  - TestStringObject.java

    Remote object class
  - ClientLaunch.java

    Client code for accessing remote objects
  - ServerLaunch.java

    Code for creating, registering remote TestStringObject object
- Files must be compiled, then launched

Launching an RMI Application

- Launch registry (on server side)
- Launch server
- Launch client

Launching an RMI Registry

- Two approaches
  - Execute the command `rmiregistry` at the command prompt
    - In Windows: `start rmiregistry`
    - In Linux and Mac OS (terminal): `rmiregistry &`
    - The directory holding the `rmiregistry` executable must be in your path!
    - This registry may be shared by multiple servers
  - In your Java (server) program, execute `LocateRegistry.createRegistry();`
- In both cases the registry process will listen on port 1099 by default
- You can specify a different port by giving an optional argument to the command / Java method call
- The registry must know what the .class files are!
  - Can start the command in the relevant directory
  - We'll see other approaches later

Launching Test String Server, Client

- Execute `ServerLaunch` for server
  - Can be done from Eclipse
  - Can also be done from command line:

    ```
    java ServerLaunch
    ```
- Execute `ClientLaunch` for client
- Note: both applications need to know the .class files