Imperial College London

Computer Networks and Distributed Systems

Object Interactions

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Outline

- Object interaction vs. RPC
- Java Remote Method Invocation (RMI)
- RMI Registry
- Security Manager

Introduction

- Objective: To support interoperability and portability of distributed OO applications by provision of enabling technology

References

- Latest Java documentation from
  - http://www.oracle.com/technetwork/java/index.html
- RMI Tutorials:
  - http://docs.oracle.com/javase/tutorial/rmi/
- Coulouris ch. 5, Tanenbaum 2.3

- Wollrath, A, Riggs, R and J. Waldo. A Distributed Object Model for the Java System. Proc. Usenix 1996, Toronto

Object Interaction vs. RPCs

- Encapsulation via fine to medium grained objects (e.g. threads or C++ objects)
  - Data and state only accessible via defined interface operations
  - RPC based systems → encapsulation via OS processes
- Portability of objects between platforms
  - RPC clients and servers are not usually portable
- Typed interfaces
  - Object references typed by interface → bind time checking
  - RPC interfaces often used in languages which do not support type checking

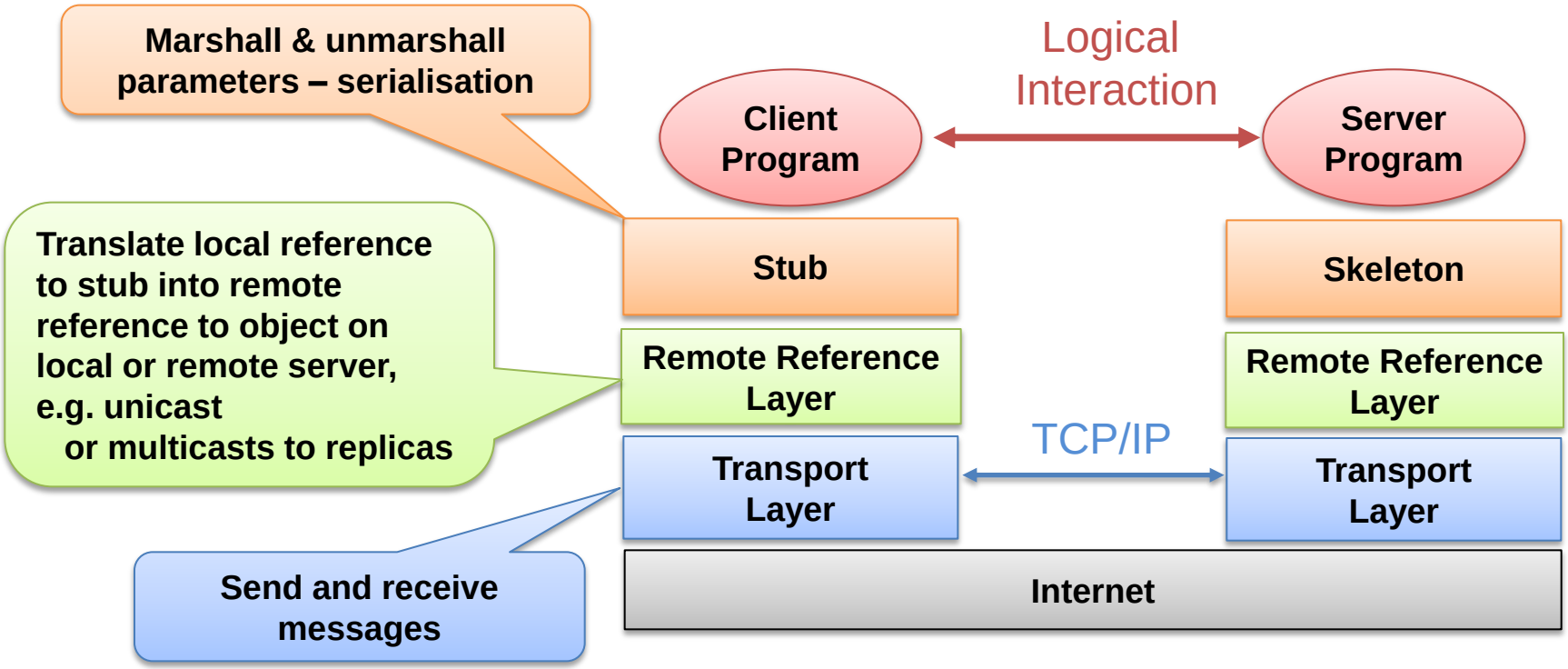
Object Interaction vs. RPCs

- Support for inheritance of interfaces
  - Use inheritance to extend, evolve, specialise behaviour
  - New server objects with extended functionality (subtypes) can replace existing object and still be compatible with clients
  - RPC replacements must have identical interface i.e., usually no inheritance
- Interaction Types
  - Two-way synchronous invocation c.f. RPC – Java
- Pass objects as invocation parameters (Java only)

Object Interaction vs. RPCs

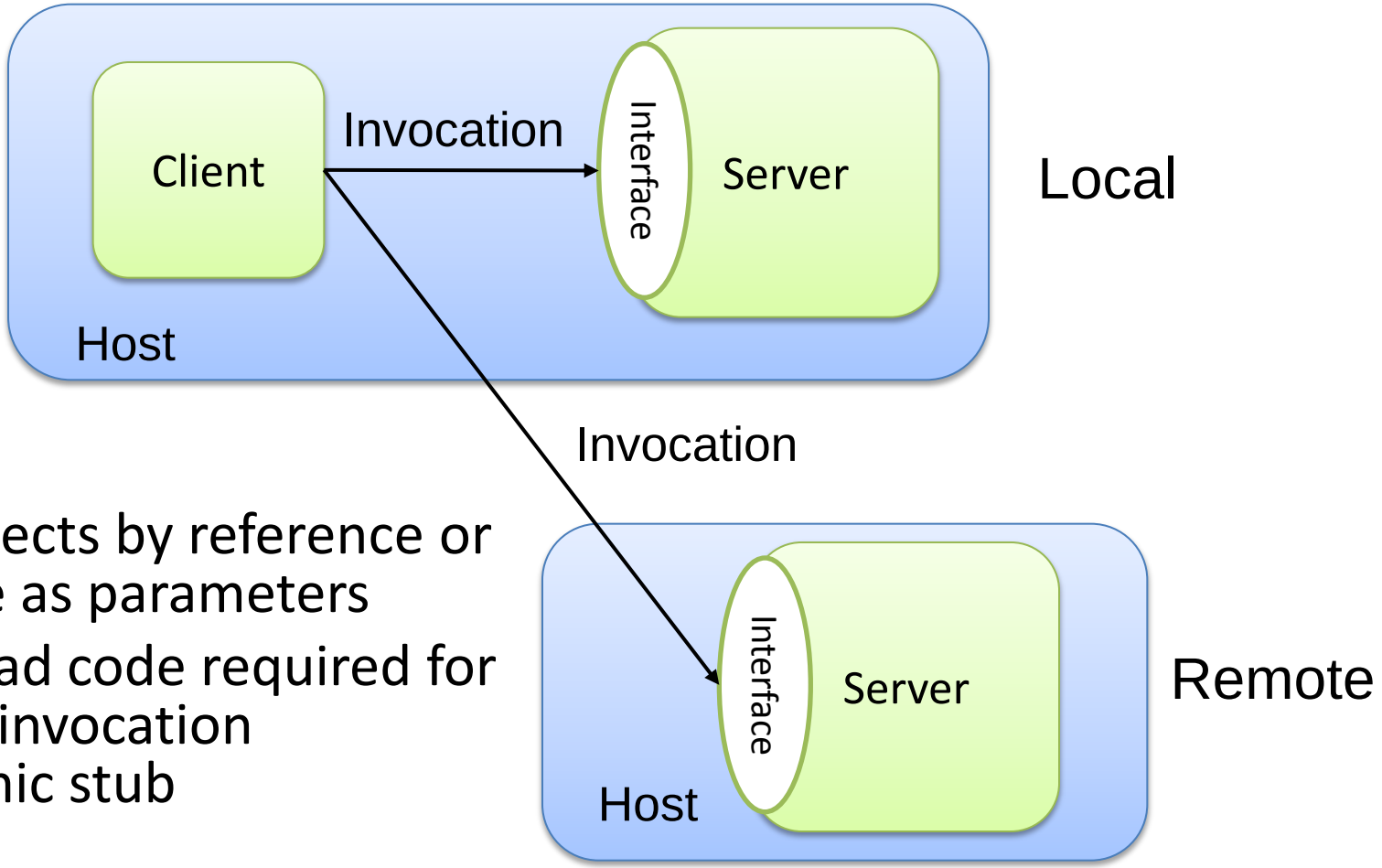
- Parameterised exceptions → Simpler error handling
- Location transparency
  - Service use orthogonal to service location
- Access transparency
  - Remote and co-located services accessed by same method invocation
  - RPC only used for remote access
- Use invocations to create/destroy objects
  - RPC systems (often) use OS calls to create/destroy processes

Java RMI Architecture



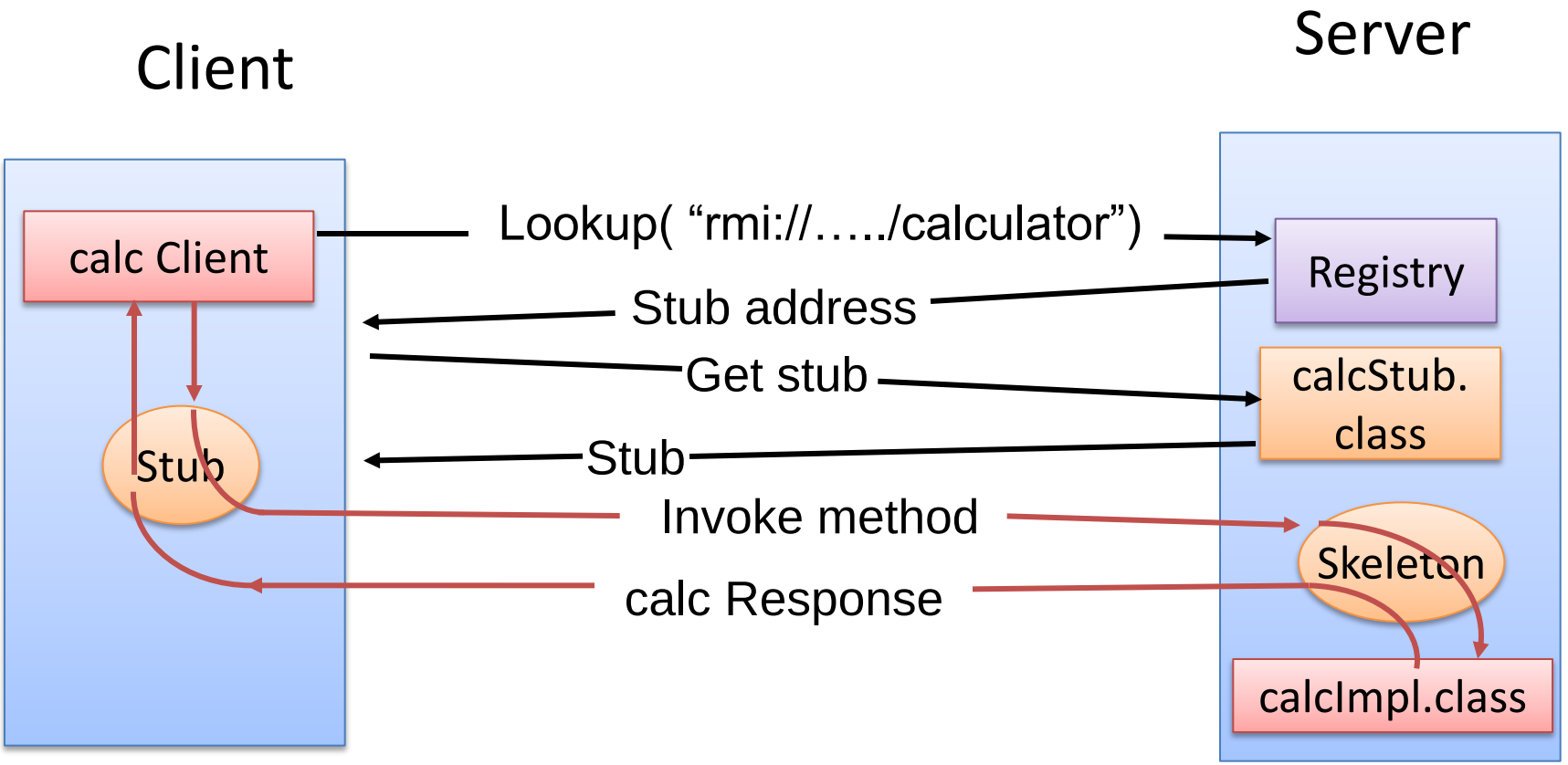
- See http://docs.oracle.com/javase/tutorial/rmi/index.html

Transparent Invocation



- Pass objects by reference or by value as parameters
- Download code required for remote invocation
  – dynamic stub

Client Server Interaction



Note: skeleton not needed in later versions of Java

Java Interfaces

- Java is a class-based OO programming language. Supports single inheritance
- A Java **interface** defines a new type
  - A collection of methods (and constant definitions)
  - Methods and constants declared in an interface are implicitly public
- An interface may be derived from **one or more** further interfaces
- A class can implement **one or more** interfaces
  - As well as being derived from at most one other class

Remote Interface

- A type whose interfaces may be invoked remotely is defined as a remote interface. A remote interface extends the `java.rmi.Remote` and must be public
- The methods of a remote interface must be defined to throw the exception `java.rmi.RemoteException` for comms failures

```
import java.rmi.*
public interface Calculator extends Remote {
    public long add (long a, long b) throws
RemoteException;
    public long sub (long a, long b) throws
RemoteException;
    public long mul (long a, long b) throws
RemoteException;
    public long div (long a, long b) throws
RemoteException;
}
```

Remote Objects

- **Remote objects** are instances of classes that implement **remote interfaces** e.g. `CalculatorImpl` implements `Calculator`. Coulouris calls them servants. A remote object class simply implements the methods defined in the remote interface

- Remote objects execute within a **server** which may contain multiple remote objects. An object is implicitly **exported** if its class derives from `java.rmi.server.UnicastRemoteObject`

- Note: operations invoked on remote objects, not on server containing them

Remote Object Implementation

```
import javarmi.*
public class CalculatorImpl
    extends UnicastRemoteObject
    implements Calculator {


  public CalculatorImpl() throws RemoteException {
        super();
    }


    public long add(long a, long b) throws RemoteException {
        return a + b;
    }
    public long sub(long a, long b) throws RemoteException {
        return a - b;
    }
       . . .
 }
```

UnicastRemoteObject constructor exports the object as single server – not replicated

Call to super activates code in UnicastRemoteObject for RMI linking & object initialisation

Server Implementation

- A server program creates one or more remote objects as part of mainline code. For simple single object applications it is possible to combine server and object implementation

- A server may advertise references to objects it hosts via the local RMI registry

- Registry allows a binding between a URL and an object reference to be made and subsequently queried by potential clients

Server Implementation

- The server listens for incoming invocation requests which are dispatched to appropriate objects

- Note: there may be multiple servers and multiple clients within an application. Client is not created within a server

Server Mainline code

```
import java.rmi.Naming;
public class CalculatorServer {
  public static void main(String args[]) {
     if (System.getSecurityManager() == null) {
        System.setSecurityManager (new RMISecurityManager
   ());
     }
     try {
       Calculator c = new CalculatorImpl();
       Naming.rebind("rmi://localhost/CalcService", c);
     }
      catch (Exception e) {
      System.out.println("Trouble: " + e);
     }
  }
}
```

Create security manager

Create server object

Register it with the local registry: URL-reference binding

Calculator Client Implementation

```
import java.rmi.*;
import Calculator;
public class CalculatorClient {

   public static void main(String[] args) {
     try {
           if System.getSecurityManager() == null {
              System.setSecurityManager (new
                  RMISecurityManager ());
              Calculator c = (Calculator) Naming.lookup(
                        "rmi://remotehost/CalcService");
           System.out.println( c.sub(4, 3) );
           . . .   other calls ;
         } catch (RemoteException e) {
           System.out.println(" Exception:" + e);
    }
}
```

Get ref to CalcServer stub from remote registry

Invoke sub operation on remote calculator

http://www.cs.uic.edu/~troy/fall04/cs441/rmi/calc/index.html

RMIRegistry

- Must run on every server computer hosting remote objects
- Advertises availability of Server's remote objects
- Name is a URL formatted string of form **`//host:port/name`**
  - Both host and port are optional

- Functions
  - lookup (String name) → called by a remote client
    - Returns remote object bound to name
  - bind (String name, Remote obj) → called by a server
    - Binds name to remote object obj, Exception if name exists
  - rebind (String name, Remote obj)
    - Binds name to object obj and discards previous binding of name
    - Safer than bind
  - unbind (String name)
    - Removes a name from the registry
  - String [] list ()
    - Returns an array of strings of names in registry

Using Registry

- Server remote object making itself available

```
Registry r = Locateregistry.getRegistry();
r.rebind (“myname”, this)
```

- Remote client locating the remote object

```
Registry r =
    LocateRegistry.getRegistry(“thehost.ac.uk”);
RemObjInterface remobj =
    (RemObjInterface) r.lookup (“myname”);
remobj.invokemethod ();
```

RMI Security Manager

- Single constructor with no arguments

```
System.setSecurityManager(new RMISecurityManager());
```

- Needed in server and in client if stub is loaded from server

- Checks various operations performed by a stub to see whether they are allowed e.g.
  - Access to communications, files, link to dynamic libraries, control virtual machine, manipulate threads etc.

- In RMI applications, if no security manager is set, stubs and classes can only be loaded from local classpath – protect application from downloaded code

Parameter Passing

- Clients always refer to remote object via remote interface type not implementation class type
- A reference to a remote object can be passed as a parameter or returned as a result of any method invocation
- Remote objects passed by reference – stub for remote object is passed

Parameter Passing

- Given two references, r1 and r2, to a remote object (transmitted in different invocations):
  - r1 == r2 is false → different stubs
  - r1.equals (r2) is true → stubs for same remote object

- Parameters can be of any Java type that is serialisable
  - Primitive types, remote objects or objects implementing `java.io.serializable`
  - Non-remote objects can also be passed and returned by value i.e. a copy of the object is passed → new object created for each invocation

Garbage Collection of Remote Objects

- RMI runtime system automatically deletes objects no longer referenced by a client
  - When live reference enters Java VM, its reference count is incremented
  - First reference sends “referenced” message to server
  - After last reference discarded in client “unreferenced” message sent to server
  - Remote object removed when no more local or remote references exist
- Network partition may result in server discarding object when still referenced by client, as it thinks client crashed

Dynamic Invocation

- Single method interface
- Invocation identifies method to be called + parameters
- User programs marshalls/demarshalls parameters
- Optional invocation primitive for object environments such as CORBA and for Web services

Dynamic Invocation

```
public byte[]
   doOperation (RemoteObjectRef o, int
   methodId, byte[] arguments)
```

- Sends a request message to the remote object and returns the reply
- The arguments specify the remote object, the method to be invoked and the arguments of that method
- Server has to decode request and call method

Summary

- RMI provides access transparency, object oriented concepts for IDL specification, object invocations and portability
- Inheritance supports reuse → high level programming concepts
- High implementation overheads due to
  - Byte code interpretation in Java
  - Marshalling/Demarshalling of parameters
  - Data copying
  - Memory management for buffers etc.
  - Demultiplexing and operation dispatching