ID2212 Network Programming with Java
Lecture 6

Distributed Objects.
Java IDL (CORBA) and Java RMI

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Outline

- Revisited: Distributed Computing
  - Architectures
  - Implementation Approaches
- Basics of a Distributed Object Architecture
- Java IDL (CORBA)
- Java RMI: Remote Method Invocation

Review: Architectures of Distributed Applications

- Two-tier architecture: Clients and Servers
- Three-tier architecture:
  - First tier: clients with GUI
  - Middle tier: business logic
  - Third tier: System services (databases)
- Peer-to-peer architecture: Equal peers

Existing Implementation Approaches

- Message passing via sockets
- RPC: Remote Procedure Calls
- Distributed objects (RMI)
  - DCOM: Distributed Component Object Model (Microsoft, homogeneous implementation)
  - CORBA: Common Object Request Broker Architecture (OMG, heterogeneous)
  - Java RMI (Oracle, homogeneous)
  - Enterprise Java Beans (EJB) – Distributed component architecture for building integrated enterprise services

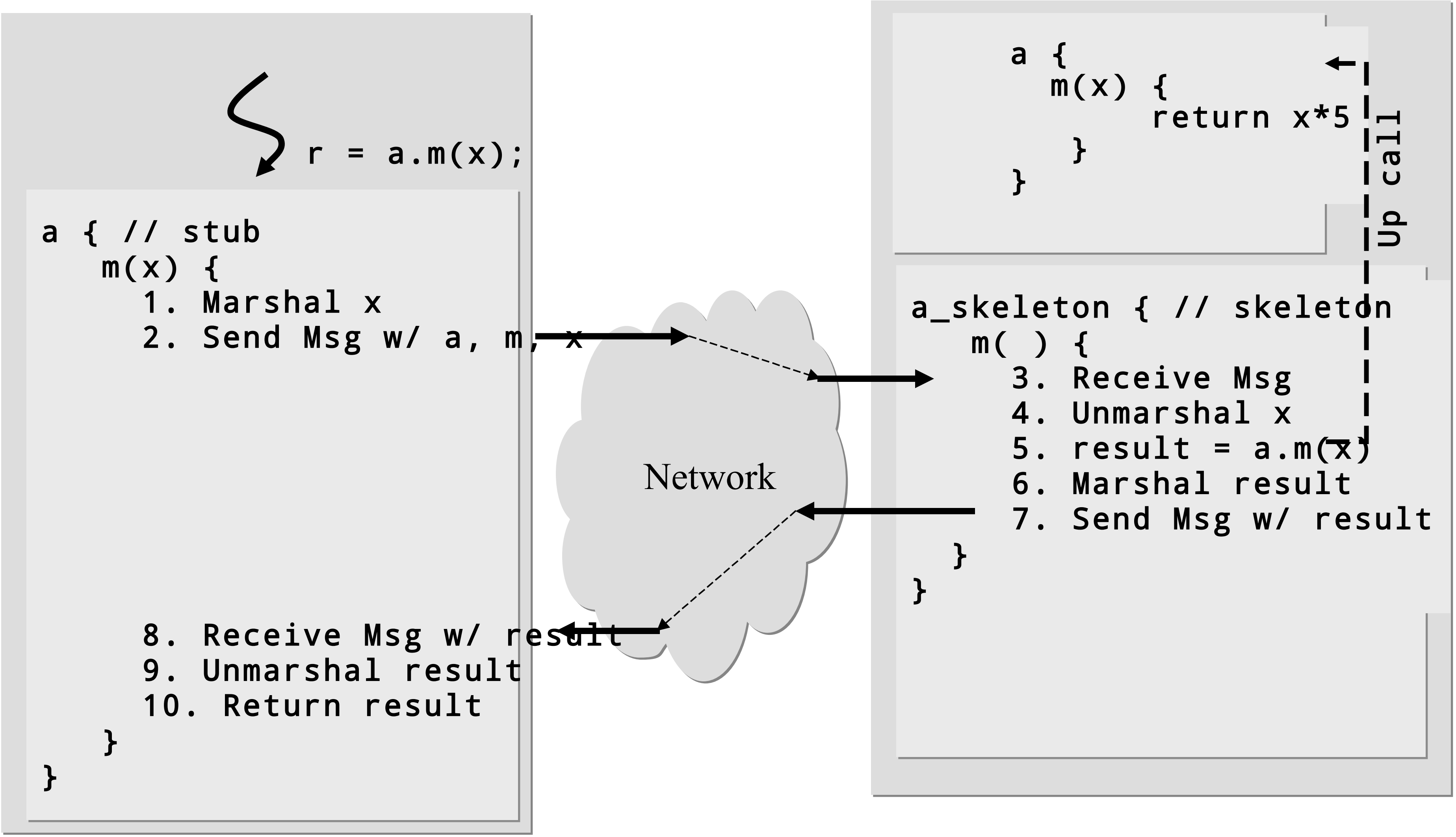
Motivation for RPC and RMI

- Message passing over socket connections is somewhat low level for distributed applications
  - Typically, client/server interaction is based on a request/response protocol
  - Requests are typically mapped to procedures or method invocations on objects located on the server
- A better approach for client/server applications is to use
  - Remote Procedure Calls
    - Rendezvous (like in ADA, Concurrent C)
  - Remote Method Invocation – in OO environment

Remote Method Invocation (RMI)

- ***Remote method invocation*** (RMI) is the mechanism to invoke a method in a remote object
  - the object-oriented analog of RPC in an distributed OO environment, e.g. OMG CORBA, Java RMI, DCOM
  - RPC allows calling procedures over a network
  - RMI invokes object's methods over a network
- Location transparency: invoke a method on a stub like on a local object (via stack)
- Location awareness: the stub makes remote call across a network and returns a result via stack

Remote Method Invocation



```
r = a.m(x);
```

```
a { // stub
   m(x) {
     1. Marshal x
     2. Send Msg w/ a, m, x




     8. Receive Msg w/ result
     9. Unmarshal result
     10. Return result
   }
}
```

```
a {
  m(x) {
       return x*5
   }
}
```

```
a_skeleton { // skeleton
   m( ) {
     3. Receive Msg
     4. Unmarshal x
     5. result = a.m(x)
     6. Marshal result
     7. Send Msg w/ result
   }
}
```

Parameter Passing

- Parameters are passed in an RMI message and not via a local stack
  - data of primitive types are passed by values
  - objects are passed either by values (replication) or by references
- Objects can be heterogeneous
  - different implementation languages
  - different target virtual machines and operation systems
- Different representations of primitive types
  - convert data representation across different implementation
- Composite Types (e.g., structures, objects)
  - need to be flattened and reconstructed (marshal / unmarshal)

Marshaling/Unmarshaling

- Marshaling:
  - done by client (i.e., caller)
  - packing the parameters into a message
  - flatten structures
  - perform representation conversions if necessary
  - also done by server (i.e., callee) for results
- Unmarshaling:
  - done by receiver of message to extract parameters or results

Stubs and Skeletons

- Encapsulate marshaling and communication
  - Enable application code in both client and server to treat call as local
- ***Stub*** is a proxy for the real object on the client
  - represents the real object as a local object on the client
  - contains information to locate the real object
  - implements original interface with the same method signatures but the methods perform remote calls to the real object
- ***Skeleton*** is on the server
  - receives, unmarshals parameters
  - calls original routine on the real object
  - marshals and sends result (data, acknowledgment or exception) to the client

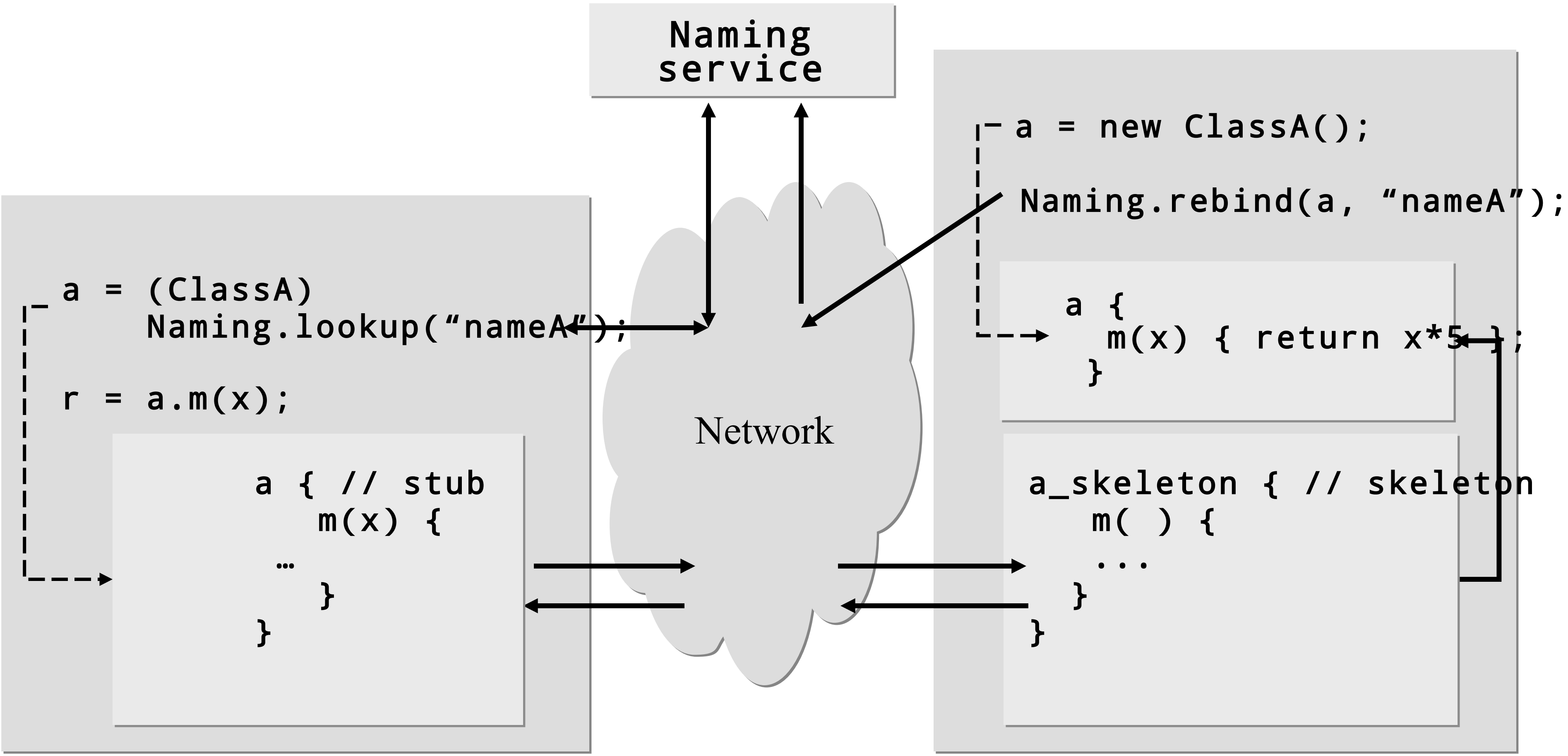
Synchronous versus Asynchronous Invocation

- Void methods do not require a result to be sent to the caller
- Asynchronous invocation
  - The method locally invoked on the stub immediately returns and the calling thread proceeds as soon as the request is on its way to the remote object
  - The request is executed by the underlying layer in a separate thread
  - Problem: exceptions
- Synchronous invocation
  - The calling thread is suspended waiting for the remote invocation to complete (for the invoked method to return)
  - The calling thread proceeds as soon as it gets acknowledgement from the remote object

Locating Objects

- How does the caller get a reference to the remote object, i.e. stub?
- One approach is to use a distributed ***Naming Service***:
  - Associate a unique name with a remote object and bind the name to the object at the Naming Service.
    - The name must be unique in current context.
    - The record typically includes name, class name, object reference
    - The object reference contains location information.
  - The object name is used by the client to lookup the Naming Service for the object reference (stub).
  - Problem of the primary reference: How does the client locate the Naming Service? – configuration issues
- Another way to get a reference to a remote object is to get it as ***a parameter or a return*** in remote method invocation
- Third way: to make a reference (***IOR: Interoperable Object Reference***) and store/send it in a file

Use of the Naming Service



Naming service

```
a = (ClassA)
      Naming.lookup(“nameA”);

r = a.m(x);
```

```
a { // stub
   m(x) {
  …
   }
}
```

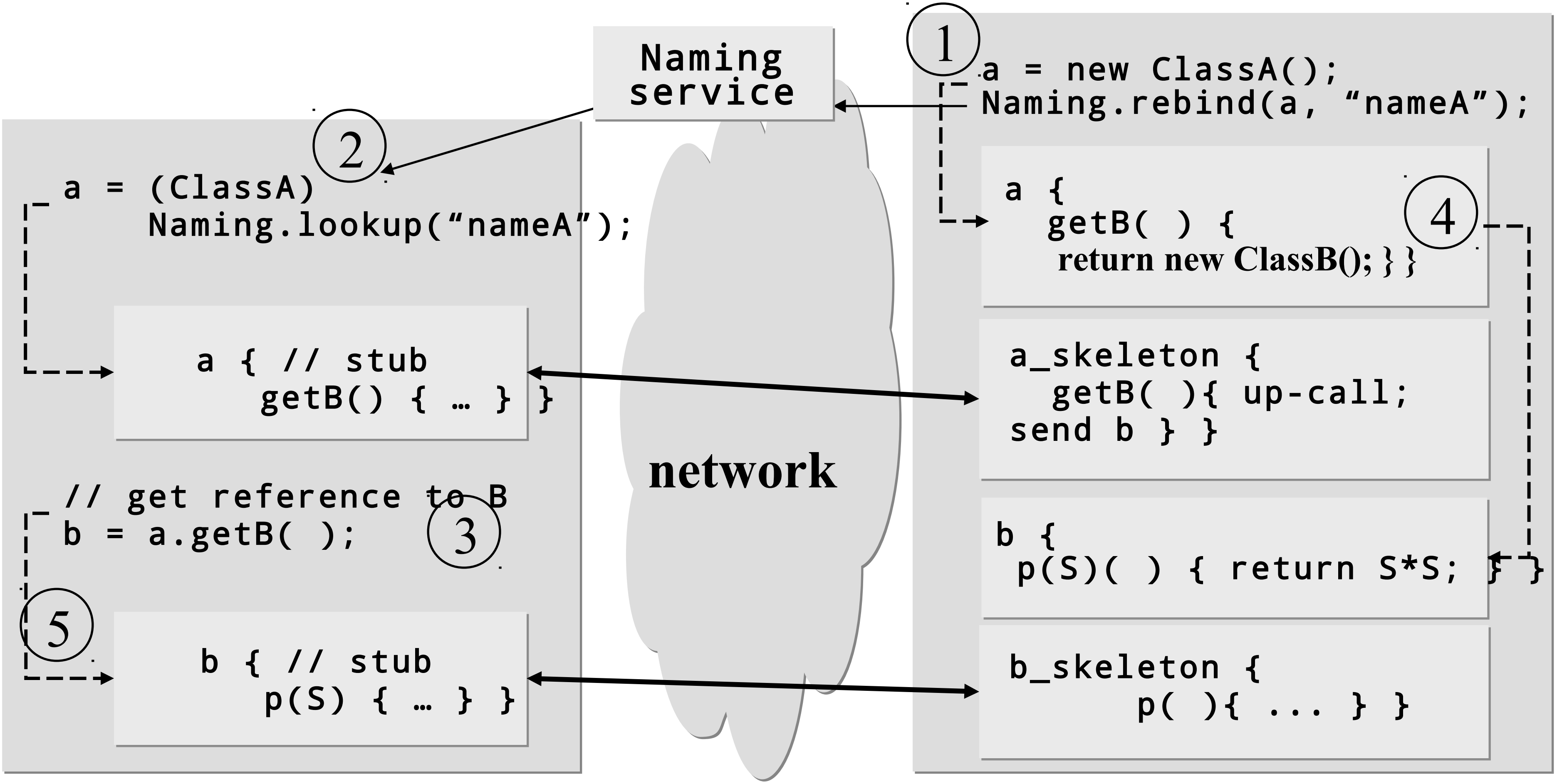
Network

```
a = new ClassA();

Naming.rebind(a, “nameA”);
```

```
a {
  m(x) { return x*5 };
 }
```

```
a_skeleton { // skeleton
   m( ) {
   ...
  }
}
```

Remote Reference in Return



Naming service

```
a = new ClassA();
Naming.rebind(a, “nameA”);
```

```
a = (ClassA)
    Naming.lookup(“nameA”);
```

```
a {
  getB( ) {
   return new ClassB(); } }
```

```
a { // stub
   getB() { … } }
```

```
a_skeleton {
  getB( ){ up-call;
send b } }
```

```
// get reference to B
b = a.getB( );
```

```
b {
 p(S)( ) { return S*S; } }
```

```
b { // stub
   p(S) { … } }
```

```
b_skeleton {
       p( ){ ... } }
```

Separate Interface from Implementation. Interface Definition Language (IDL)

- A remote object is remotely accessed via its remote interfaces.
- Objects can be heterogeneous
  - different implementation languages
  - different target virtual machines and operation systems
- Separate interface definition from implementation:
  - Implementation may change, as long as the interface is respected
- ***Interface Definition Language (IDL)***
  - Describe interface for RMI

Generating Stubs and Skeleton. IDL Mappings

- Where do Stubs and Skeletons come from?
  - writing (un)marshaling code is bugprone
  - communication code has many details
  - structure of code is very mechanical
- Answer:
  - Stubs and Skeletons can be generated from IDL definitions
- Mapping from IDL to OO-language
  - generates code for Stubs and Skeletons
  - IDL to Java, C++, Smalltalk, COBOL, Ada
  - Allows cross language invocations

Java IDL (CORBA)

Reference implementation of OMG CORBA in Java for Java

`org.omg.CORBA`

Four Components of OMA (Object Management Architecture)

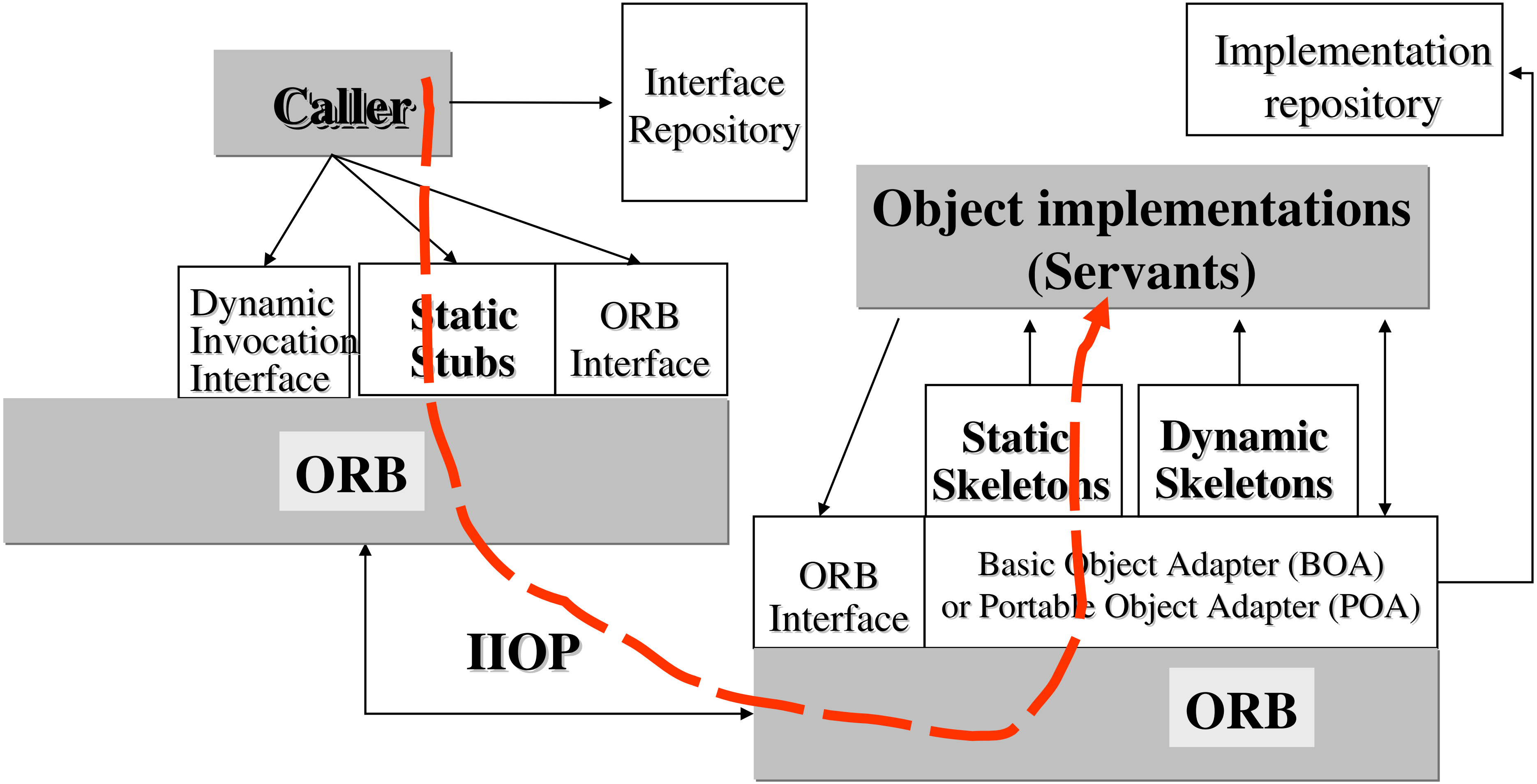
- By the Object Management Group (OMG) consortium that operates since 1989. See: http://www.omg.org

1. ***Object Model*** (Glossary of terms)
   - Concepts: class, object, attribute, method, inheritance, etc.
   - UML (Unified Modeling Language) is a standard for object modeling.
     - See: UML modeling with IBM Rational software: http://www-306.ibm.com/software/rational/uml/
2. ***CORBA*** (Common Object Request Broker Architecture)
   - A mechanism for communication between objects
   - Specification, related APIs and tools
   - Object Request Broker (ORB) is implementation of CORBA

Four Components of OMA (cont)

3. ***CORBA Services***
   - Horizontal services common for any objects: Naming, Security, Life Cycle, Transactions, Events, etc.
4. ***CORBA Facilities***
   - High level functionality for integrating objects
     - User interface: drag-and-drop, compound documents
     - System Management
     - Task Management / Workflow
   - Vertical services supporting particular industries
     - Finance, Oil and Gas Exploration, Telecommunications (TMN/TINA-C) , 10 other
       - TMN is Telecommunications Management Network;
       - TINA-C is Telecommunications Information Networking Architecture Consortium

The Architecture of CORBA


Caller
Interface Repository
Implementation repository
Object implementations (Servants)
Dynamic Invocation Interface
Static Stubs
ORB Interface
Static Skeletons
Dynamic Skeletons
ORB
ORB Interface
Basic Object Adapter (BOA) or Portable Object Adapter (POA)
IIOP
ORB

CORBA Anatomy

- ***ORB: Object Request Broker***
  - makes it possible for CORBA objects to communicate with each other by connecting objects making requests (clients) with objects servicing requests (servants).
- ***BOA: Basic Object Adapter***
  - accepts call requests (as a meta-call),
  - instantiates objects,
  - initiates up-calls on skeletons,
  - manages the Implementation Repository,
  - different ORB vendors have completely different implementation of BOA
- ***POA: Portable Object Adapter***
  - like BOA but portable between different ORB products

(cont'd) CORBA Anatomy

- A ***stub*** on the client side provides a static interface to remote object services.
  - resolves the remote object's location
  - performs remote method invocation via a local ORB
    - Sends the object reference, the method name and parameters to the destination ORB (skeleton) by using IIOP (Internet Inter-ORB Protocol)
    - Receives and unmarshals data in return
- A ***skeleton*** on the server side performs up-calls on a real object
  - transforms the call and parameters into the required format and calls the object
  - marshals result (or exception) and sends it over ORB connection.

ORB Protocols

- CORBA 2.0 defines standard protocols:
- GIOP: General Inter ORB Protocol
  - Defines standard message format
- ***IIOP: Internet Inter ORB Protocol***
  - IIOP is the implementation of GIOP over TCP/IP
  - IIOP-to-HTTP gateway and HTTP-to-IIOP gateway allow CORBA clients to access Web resources and Web clients to access CORBA resources.
- ESIOP: Environment Specific Inter ORB Protocol
  - Allows ORBs to run on top of other standards (such as DCE: Distributed Computing Environment consisting of standard APIs: naming, DFS, RPC, etc.)

IDL: Interface Definition Language

- ***IDL*** is a purely declarative language: interface declarations
- An IDL interface describes the attributes and methods (operations) that are exported on the ORB.
  - An interface can have several implementations.
  - An object can implement several interfaces.
- IDL-to-language compilers are based on mapping from IDL to the language (Java, C++, Smalltalk, COBOL, Ada)
- A compiler generates
  - An interface(s),
  - A stub (a client proxy for remote calls),
  - A skeleton (a server proxy for translating incoming calls to up-calls)

IDL Concepts

- ***Interface***
  - Similar to a class, but only defines the interface of an object, without information on its representation in memory
- ***Operation***
  - Similar to a method or member function
  - The direction of parameter must be specified: in, out, inout
- ***Attribute***
  - Does not define an attribute in memory
  - Defines two operations for getting and setting the value
  - readonly is used to suppress the function setting the value

Basic Data Types

- No int type
- No pointer type
- IDL types are defined in terms of their semantics

IDL	Java
short	short
long	int
unsigned short	short
unsigned long	int
float	float
double	double
char	char
boolean	boolean
octet	byte
any	class any
string	String

Complex Types

- Build complex types from basic types in IDL:
  - `struct`, `enum`, `union`, `typedef`
  - `array` – fixed length collection
  - `sequence` – variable length collection
  - `Object` – reference to an IDL object (proxy)
- Mapping to Java
  - `sequence` and `array` are mapped to the Java `array` type.
  - `enum`, `struct`, and `union` are mapped to a final Java class that implements the semantics of the IDL type.
  - For example, array of bytes can be defined as:

```
typedef sequence <octet> bytes;
bytes getBytes(in string from)
  raises(cannotget);
```

- The Java class generated should have the same name as the original IDL type.

Passing Parameters and Returns

- CORBA sends all types across the network by value, except objects
  - Objects are passed by reference
  - A proxy is constructed on the receiving end
- The OMG added a new specification called ”Pass-by-Value”
  - Include Object by Value mapping
  - Initiators were Sun and IBM
  - Motivation: support for object migration and replication
  - RMI over IIOP

Java IDL (`org.omg.CORBA`)

- Java IDL is a reference implementation of CORBA in Java
- Oracle delivers Java IDL in the Java SDK, SE
  - IDL-to-Java compiler
  - Multi-protocol ORB (classes)
  - Support for Java clients and servers (Name service, etc.)
- Java IDL is not a sophisticated product on the server side:
  - Doesn't have CORBA scalability and security features
  - No CORBA Services except of Naming
- Java IDL will be useful on the client
  - Avoid downloading the ORB client

Other Implementations of CORBA

- CORBA platforms from Progress Software
  - http://web.progress.com/en/Product-Capabilities/corba.html
- The Micro Focus's solution for CORBA Technology (VisiBroker)
  - http://www.microfocus.com/products/visibroker/index.aspx
- CORBA typically comes as a part of an enterprise (application) server

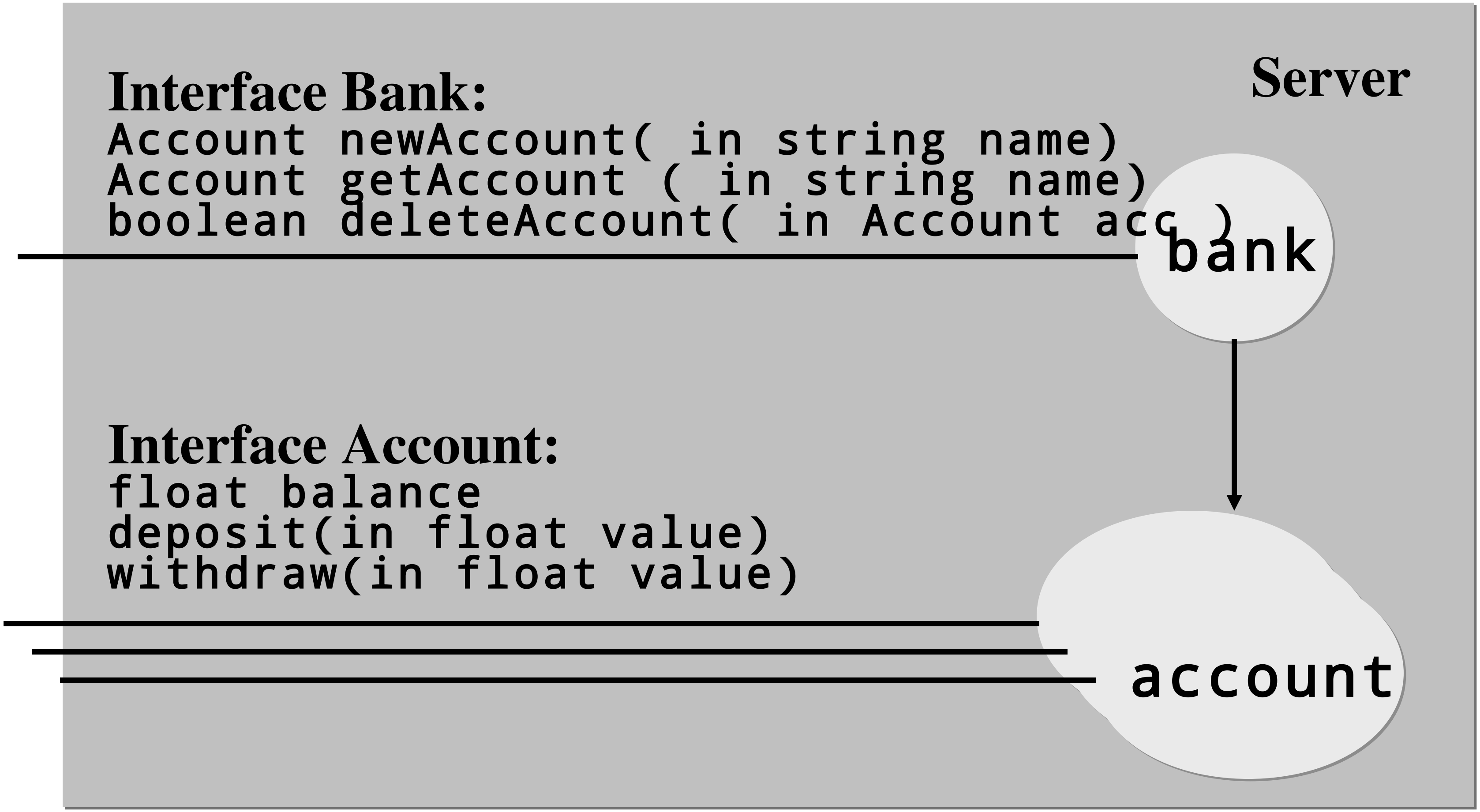
Developing a Distributed Application with Java IDL

1. Define interfaces with IDL
2. Compile the interfaces using `idlj`, which generates the Java bindings for a given IDL file.
3. Develop an implementation for the interfaces (servants)
4. Develop a server (a container for servants) that initializes ORB and creates the servants
5. Develop a client
6. Compile the client, the servants and the server (using `javac`)
7. Start the Naming Service `tnameserv`, which is the Common Object Services (COS) Name Service
8. Start the server
9. Run the client

Step 1. Sample IDL Interfaces (see Example 4.3: Bank)

```
module bankidl {
    interface Account {
  readonly attribute float balance;
  exception rejected { string reason; };
  void deposit(in float value) raises (rejected);
  void withdraw(in float value) raises (rejected);
    };
    interface Bank {
  exception rejected { string reason; };
  Account newAccount( in string name) raises
  (rejected);
  Account getAccount ( in string name);
  boolean deleteAccount( in string acc );
    };
};
```

The IDL Interfaces (cont’d)



Interface Bank:

```
Account newAccount( in string name)
Account getAccount ( in string name)
boolean deleteAccount( in Account acc )
```

Interface Account:

```
float balance
deposit(in float value)
withdraw(in float value)
```

Step 2. Compiling IDL to Java

- The IDL to Java compiler (`idlj`) generates:
  - Interfaces:
    - `Bank.java`, `Account.java`
  - Stubs for the client side:
    - `_BankStub.java`, `_AccountStub.java`
  - Skeletons for the server side:
    - When using BOA (backwards compatible to J2SE 1.4) `BankImplBase.java`, `AccountImplBase.java`
    - When using POA: `BankPOA.java, AccountPOA.java`
    - Implementations of the interfaces should extend the skeletons.
  - Helpers used to narrow a remote reference to its remote interface:
    - `BankHelper`, `AccountHelper`

Step 3. Implementing The Interfaces.

- A servant is a class that implements the interface(s) generated by a IDL to Java compiler.
- The servant class may extend an appropriate skeleton (implementation base) class, for example:

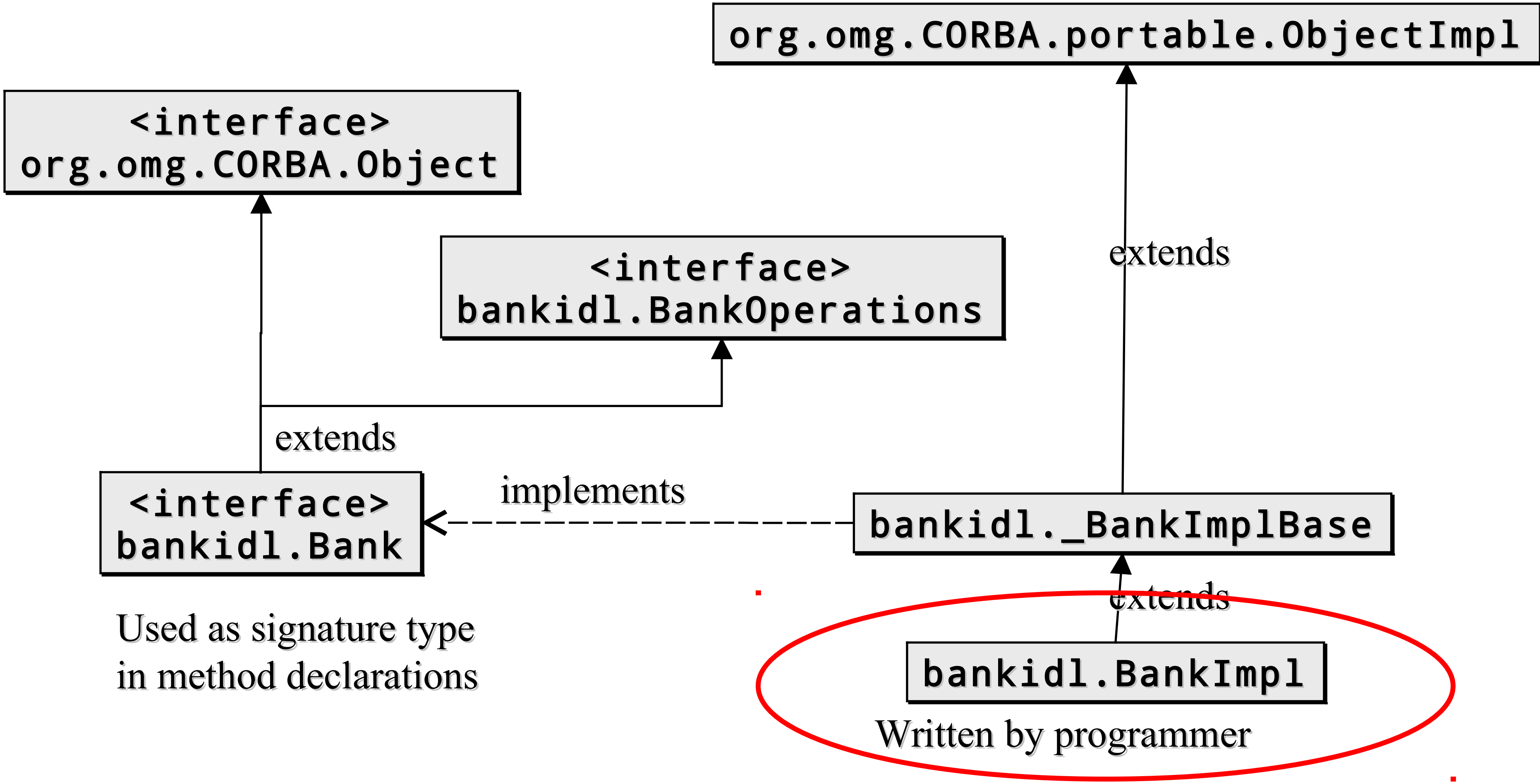
  ```
  public class BankImpl extends
  _BankImplBase
  ```

  or (when using POA)

  ```
  public class BankImpl extends BankPOA
  ```

  - In this way the servant implements the interface and encapsulates the skeleton that accepts (remote) calls

Inheritance Structure



Used as signature type in method declarations

Example 4.3 Bank Implementation

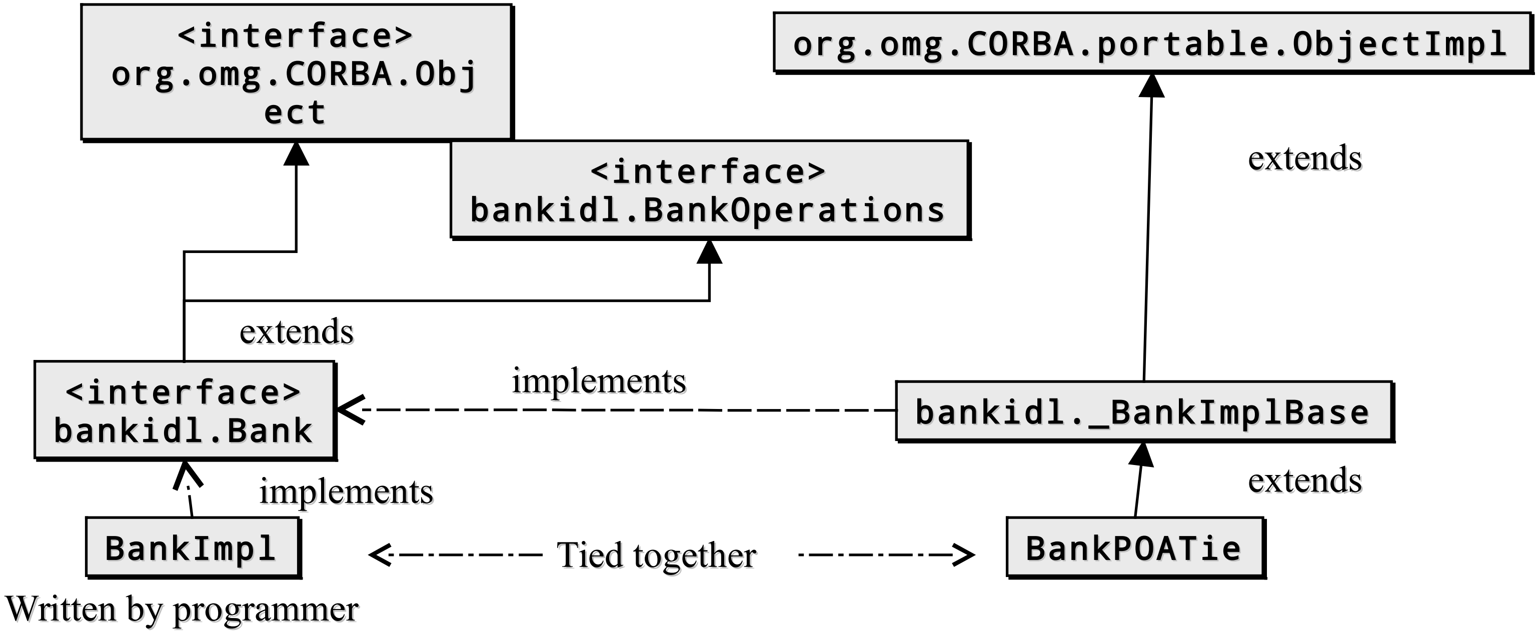
```
package bankidl;
import java.util.Hashtable;
import bankidl.BankPackage.rejected;
public class BankImpl extends _BankImplBase {
   private String bankname = null;
    private Hashtable accounts = new Hashtable();
    public BankImpl(String name) {
        super();
        bankname = name;
    }
   public Account newAccount(String name) throws rejected {

        AccountImpl account = (AccountImpl) accounts.get(name);
        if (account != null) throw new rejected(
   "Rejected: Account for: " + name + " already exists");
        }
        account = new AccountImpl(name);
        accounts.put(name, account);
       return (Account)account;
    }
public Account getAccount(java.lang.String name) {
        return (Account) accounts.get(name);
    }
public boolean deleteAccount(String name) {
        AccountImpl account = (AccountImpl) accounts.get(name);
        if (account == null) return false;
        accounts.remove(name);
        return true;
    }
}
```

Example 4.3 Account Implementation

```
package bankidl;
import bankidl.AccountPackage.rejected;
public class AccountImpl extends _AccountImplBase {
    private float balance = 0;
    private String name = null;
public AccountImpl(java.lang.String name) {
        super();
        this.name = name;
    }
    public void deposit(float value) throws rejected {
       if (value < 0)
           throw new rejected("Rejected: Illegal value: ” +
   value);
      balance += value;
    }
    public void withdraw(float value) throws rejected {
       if (value < 0)
   throw new rejected("Rejected:  Illegal value: ” + value);
      if ((balance - value) < 0)
   throw new rejected("Rejected: Negative balance”));
      balance -= value;
    }
    public float balance() {
        return balance;
    }
}
```

Inheritance Structure with POATie. The Tie Delegation Model.

- An IDL to Java compiler can generate a `<interface>POATie` class that extends the skeleton.
- The implementation class may inherit from a different class and implement the remote interface.
- Remote calls received by the tie object are directed to the implementation object.



Design Options (1/2)

- Choose an ORB implementation that suits you (price, efficiency, etc.)
- Use either POA (standard Portable Object Adapter) or BOA (non-standard Basic Object Adapter, which could be more efficient)

1. To generate both client and server-side POA bindings, use

   ```
   idlj -fall My.idl
   ```

   - Generates `MyPOA.java` given an interface `My` defined in `My.idl`.
   - You must implement `My` in a class that must inherit from `MyPOA`.

2. To generate BOA bindings backwards compatible to J2SE 1.4, use

   ```
   idlj -fall -oldImplBase My.idl
   ```

   - Generates `_MyImplBase.java` given an interface `My` defined in My.idl.
   - You must implement `My` in a class that must inherit from `_MyImplBase`.

Design Options (2/2)

- Use a tie class when it is not convenient or possible to have your implementation class inherit from either of the skeletons `MyPOA` or `_MyImplBase`.

```
idlj -fallTIE My.idl
```

  - Generates the tie class

- Wrap your implementation within `My_Tie`.
- For example:

```
MyImpl myImpl = new MyImpl ();
My_Tie tie = new My_Tie (myImpl);
orb.connect (tie);
```

Step 4. Server

Example 4.3

(Using BOA backwards compatible to J2SE 1.4)

```
package bankidl;
import org.omg.*;
import org.omg.CORBA.ORB;
public class Server {
    public static void main(String args[]) {
        if (args.length != 3) {
            System.out.println(
    "usage: java Server <bankname> <-ORBInitialPort port>");
            System.exit(1);
        }
        try {
            ORB orb = ORB.init(args, null);
            BankImpl bankRef = new BankImpl(args[0]);
            orb.connect(bankRef);
            org.omg.CORBA.Object objRef =
   orb.resolve_initial_references( "NameService” );
            NamingContext ncRef =
   NamingContextHelper.narrow(objRef);
            NameComponent nc = new NameComponent(args[0], "");
            NameComponent path[] = {nc};
            ncRef.rebind(path, bankRef);
            orb.run();
        } catch (Exception e) {    }
    }
}
```

Step 5. Client

```
package bankidl;
import org.omg.CosNaming.*;
import org.omg.CORBA.ORB;
public class SClient {
    static final String USAGE =
   "java bankidl.SClient <bank> <client> <value> <-ORBInitialPort
   port>";
    Account account;
    Bank bankobj;
    String bankname = "SEB";
    String clientname = "Vladimir Vlassov";
    float value = 100;
    public static void main(String[] args) {
        if ((args.length > 0) && args[0].equals("-h")) {
            System.out.println(USAGE);
            System.exit(0);
        }
        new SClient(args).run();
    }
```

Step 5. Client (cont’d)

```
public SClient(String[] args) {
     if (args.length > 2) {
            try { value = (new Float(args[2])).floatValue();
            } catch (NumberFormatException e) {
                System.out.println(USAGE);
        System.exit(0);
            }
        }
        if (args.length > 1)  clientname = args[1];
        if (args.length > 0)  bankname = args[0];
   try {
            ORB orb = ORB.init(args, null);
            org.omg.CORBA.Object objRef =
   orb.resolve_initial_references("NameService");
            NamingContext ncRef = NamingContextHelper.narrow(objRef);
            NameComponent nc = new NameComponent(bankname, "");
            NameComponent[] path = {nc};
            bankobj = BankHelper.narrow(ncRef.resolve(path));
        } catch (Exception se) {
            System.out.println("The runtime failed: " + se);
            System.exit(0);
        }
        System.out.println("Connected to bank: " + bankname);
    }
```

Step 5. Client (cont’d)

```
public void run() {
        try {
            account = bankobj.getAccount(clientname);
            if (account == null) account =
   bankobj.newAccount(clientname);
            account.deposit(value);
            System.out.println(clientname +
   "'s account: $" + account.balance());
        } catch (org.omg.CORBA.SystemException se) {
            System.out.println("The runtime failed: " + se);
            System.exit(0);
        } catch (bankidl.AccountPackage.rejected e) {
            System.out.println(e.reason);
            System.exit(0);
        } catch (bankidl.BankPackage.rejected e) {
            System.out.println(e.reason);
            System.exit(0);
        }
    }
}
```

Locating Objects

- Using Name Service
  - The server creates the Bank object with the specified name, e.g. “Nordea”, and makes it persistent (ready).
  - To obtain the object reference, the client via the ORB contacts the Name Service of Java IDL `tnameserv`:

    ```
    tnameserv -ORBInitialPort 1050
    ```
- Using Interoperable Object References (IOR)
  - Server can store an object’s IOR (Interoperable Object Reference) as a string to a file.
  - Client can then fetch the reference from the file via a web server.

Example: Server Using IOR

```
package bankidl;
import org.omg.CORBA.ORB;
import java.io.*;
public class Serverl {
    public static final String USAGE =
    "usage: java bankidl.Serverl bankname dir";
    public static void main(String[] args) {
        if (args.length < 2) {
            System.out.println(USAGE); System.exit(1);
        }
        try {
            ORB orb = ORB.init(args, null);
            BankImpl bankRef = new BankImpl(args[0]);
            orb.connect(bankRef);
            File dir = new File(args[1]);
            if (!dir.exists()) dir.mkdir();
            String filename = dir +
    Character.toString(File.separatorChar)+
    args[0] + ".ior";
     File file = new File(filename);
            file.createNewFile();
            file.deleteOnExit();
            FileWriter writer = new FileWriter(file);
            writer.write(orb.object_to_string(bankRef));
            writer.close();
            orb.run();
        } catch (Exception e) {
    System.out.println(USAGE); System.exit(1);
        }
    }
}
```

Example: Client Using IOR

```
...
public class Clientl {
    static final String USAGE = "java bankidl.Client url
   <-ORBInitialPort port>";
    Account account;
    Bank bankobj;
    String bankname = "SEB";
    String clientname;
    public static void main(String[] args) {
        if ((args.length > 0) && args[0].equals("-h")) {
            System.out.println(USAGE); System.exit(0);
        }
        new Clientl(args).run();
    }
    public Clientl(String[] args) {
        if (args.length < 1) {
            System.out.println(USAGE); System.exit(1);
        }
        try {
            URL bankURL = new URL(args[0]);
            BufferedReader in = new BufferedReader(new
   InputStreamReader((InputStream)bankURL.getContent()));
            ORB orb = ORB.init(args, null);
            org.omg.CORBA.Object objRef =
   orb.string_to_object(in.readLine());
            bankobj = BankHelper.narrow(objRef);
        } catch (Exception se) {
            System.out.println("The runtime failed: " + se);
   System.exit(0);
        }
        System.out.println("Connected to bank: " + bankname);
    }
```

Java RMI (Remote Method Invocation)

`java.rmi`

Java RMI

- Java RMI is a Java native ORB (object request broker)
- The Java RMI facility allows applications or applets running on different JVMs, to interact with each other by invoking remote methods.
  - Remote reference (stub) is treated as local object.
  - Method invocation on the reference causes the method to be executed on the remote JVM.
  - Serialized arguments and return values are passed over network connections.
  - Uses Object streams to pass objects "by value".

Some RMI Classes and Interfaces

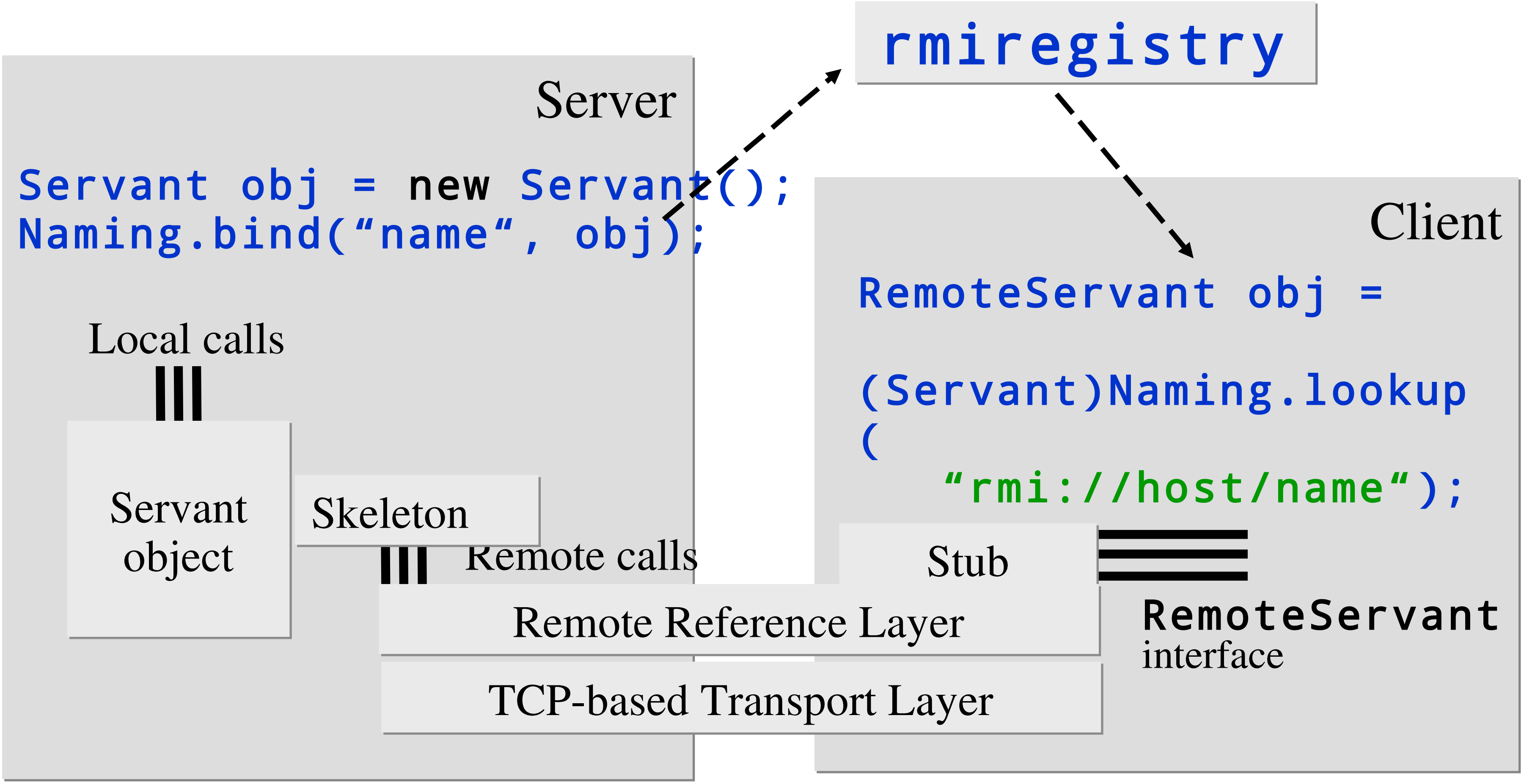
- `java.rmi.Remote`
  - Interface that indicates interfaces whose methods may be invoked from a non-local JVM -- remote interfaces.
- `java.rmi.Naming`
  - The RMI Naming Service client that is used to bind a name to an object and to lookup an object by name at the name service `rmiregistry`.
- `java.rmi.RemoteException`
  - The common superclass for a number of communication-related RMI exceptions.
- `java.rmi.server.UnicastRemoteObject`
  - A class that indicates a non-replicated remote object.

Developing a Distributed Application with Java RMI

- Typical steps:
  1. Define a remote interface(s) tha extends `java.rmi.Remote`.
  2. Develop a class (a.k.a. servant class) that implements the interface.
  3. Develop a server class that provide a container for servants, i.e. creates the servants and registers them at the Naming Service.
  4. Develop a client class that gets a reference to a remote object(s) and calls its remote methods.
  5. Compile all classes and interfaces using `javac`.
  6. (*optional*) Generate stub classes for classes with Remote interfaces using `rmic`

     Since 1.5, stubs are generated dynamically by JIT
  7. Start the Naming service `rmiregistry`
  8. Start the server on a server host, and run the client on a client host.

Architecture of a Client-Server Application with Java RMI



```
rmiregistry
```

Server

```
Servant obj = new Servant();
Naming.bind("name", obj);
```

Local calls

Servant object

Skeleton

Remote calls

Client

```
RemoteServant obj =

(Servant)Naming.lookup
(
   "rmi://host/name");
```

Stub

`RemoteServant` interface

Remote Reference Layer

TCP-based Transport Layer

Declaring and Implementing a Remote Interface (1/2)

- A remote interface must extend the `java.rmi.Remote`
  - Each method must throw `java.rmi.RemoteException`
- A class may implement one or several remote interface
  - The class should extend the `UnicastRemoteObject` class or must be exported via the static call `UnicastRemoteObject.exportObject(Remote obj)`

Declaring and Implementing a Remote Interface (2/2)

- An object of the class that implements the remote interface is called a ***servant***.
  - A servant is created by a server and lives until the server dies.
  - The servant and the server can be encapsulated into one class (typically, a primary class).
- A ***stub*** and a ***skeleton*** are generated from a servant class by JIT

The Naming Service rmiregistry. The Naming Client Naming

- A Remote object can be registered with a specified name at the Naming service, rmiregistry, provided in J2SE.
  - A registered object can be pointed to by a URL of the form `rmi://host:port/objectName`
  - The URL indicates host/port of rmiregistry – default `localhost:1099`.
- The Naming class provides a static client of the RMI registry.

- A server binds a name to an object:

```
try {
   Bank bankobj = new
   BankImpl(“CityBank”);
  Naming.rebind(“rmi://” + host + ”:” +
   port + ”/CityBank”, bankobj);
  System.out.println(bankobj + " is
   ready.");
} catch (Exception e) {
   e.printStackTrace();
}
```

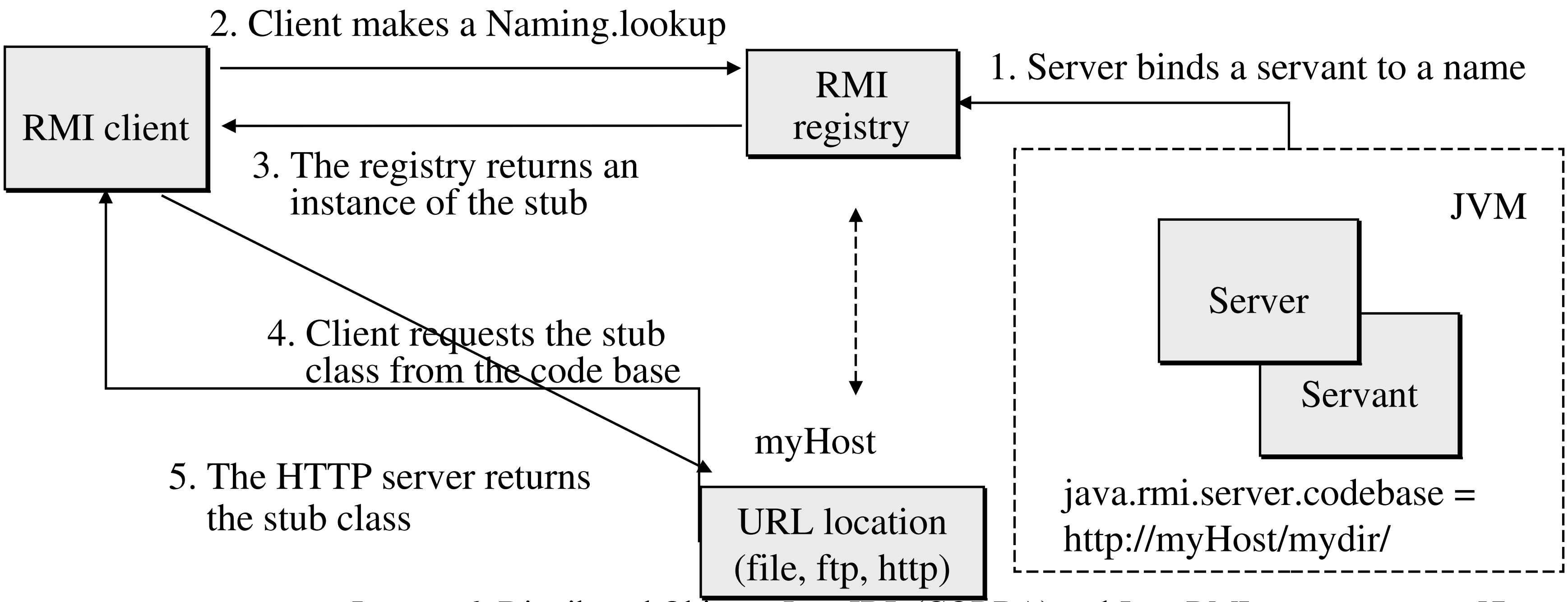
- A client looks up a remote reference:

```
String bankURL =
   “rmi://theHost/CityBank”;
try {
 bankobj = (Bank) Naming.lookup(bankURL);
} catch (Exception e) {
  System.out.println("The runtime failed:
   "+ e);
  System.exit(0);
}
```

Loading Stub Classes

- Stubs are dynamically loaded when needed either from the local file system or from the network using the URL specified on server side using the `java.rmi.server.codebase` property.
  - The property can be set in a command line of an application, for example:

    ```
    -Djava.rmi.server.codebase=http://webvector/export/
    ```
  - See: http://docs.oracle.com/javase/8/docs/technotes/guides/rmi/javarmiproperties.html


2. Client makes a Naming.lookup
RMI client
RMI registry
1. Server binds a servant to a name
3. The registry returns an instance of the stub
JVM
Server
Servant
4. Client requests the stub class from the code base
myHost
5. The HTTP server returns the stub class
URL location (file, ftp, http)
java.rmi.server.codebase = http://myHost/mydir/

Starting rmiregistry programmatically

- Before rebind/bind

```
try { LocateRegistry.getRegistry(1099).list();
catch (RemoteException e) {
     LocateRegistry.createRegistry(1099);
  }
```

Parameters and Returns in Java RMI

- Primitive data types and non-remote `Serializable` objects are passed by values.
  - If an object is passed by value, it is cloned at the receiving JVM, and its copy is no longer consistent with the original object.
  - The class name collision problem. Versioning.
- Remote objects are passed by references.
  - A remote reference can be returned from a remote method. For example:

```
try {
    // lookup for the bank at rmiregistry
    Bank bankobj = (Bank)Naming.lookup(bankname);
    // create a new account in the bank
    Account account = bankobj.newAccount(clientname);
    account.deposit(value);
} catch (Rejected e) { handle the exception }
…
```

  - A remote object reference can be passed as a parameter to a remote method.

Example: A Bank Manager

- An application that controls accounts.
- Remote interfaces:
  - `Account` – deposit, withdraw, balance;
  - `Bank` – create a new account, delete an account, get an account;
- Classes that implement the interfaces:
  - `BankImpl` – a bank servant class that implements the `Bank` interface used to create, delete accounts;
  - `AccountImpl` – a account servant class that implements the `Account` interface to access accounts.

Bank and Account Remote Interfaces

- The Bank interface:

```
package bankrmi;
import java.rmi.*;
import bankrmi.Account;
import bankrmi.RejectedException;
public interface Bank extends Remote {
    public Account newAccount(String name) throws
  RemoteException,RejectedException;
    public Account getAccount(String name) throws RemoteException;
    public boolean deleteAccount(String name) throws RemoteException;
    public String[] listAccounts() throws RemoteException;
}
```

- The Account interface

```
package bankrmi;
import java.rmi.Remote;
import java.rmi.RemoteException;
public interface Account extends Remote {
    public float getBalance() throws RemoteException;
    public void deposit(float value) throws RemoteException,
  RejectedException;
    public void withdraw(float value) throws RemoteException,
  RejectedException;
}
```

A Fragment of the Bank Implementation

```
package bankrmi;
import java.rmi.*;
import java.util.*;
public class BankImpl extends UnicastRemoteObject implements Bank {
    private String bankName;
    private Map<String, Account> accounts = new HashMap<String, Account>();
    public BankImpl(String bankName) throws RemoteException {
    super();
    this.bankName = bankName;
    }
    public synchronized Account newAccount(String name) throws RemoteException,
    RejectedException {
    AccountImpl account = (AccountImpl) accounts.get(name);
    if (account != null) {
    throw new RejectedException("Rejected: Bank: " + bankName +
    " Account for: " + name + " already exists: " + account);
    }
    account = new AccountImpl(name);
    accounts.put(name, account);
    return account;
    }
    public synchronized Account getAccount(String name) {
    return accounts.get(name);
    }
    public synchronized String[] listAccounts() {
    return accounts.keySet().toArray(new String[1]);
    }
...
}
```

The Account Implementation

```
package bankrmi;
import java.rmi.*;
public class AccountImpl extends UnicastRemoteObject implements Account {
    private float balance = 0;
    private String name;
   public AccountImpl(String name) throws RemoteException {
        super();
        this.name = name;
    }
    public synchronized void deposit(float value) throws RemoteException,
   RejectedException {
        if (value < 0)
            throw new RejectedException("Rejected: Account "+name+": Illegal value:
   "+value);
        balance += value;
   }
    public synchronized void withdraw(float value) throws RemoteException,
   RejectedException {
        if (value < 0)
            throw new RejectedException("Rejected: Account "+name+": Illegal value:
   "+value);
        if ((balance - value) < 0)
    throw new RejectedException("Rejected: Account "+ name +
   ": Negative balance on withdraw: " + (balance - value));
        balance -= value;
   }

    public synchronized float getBalance() throws RemoteException {
        return balance;
    }
}
```

The Server Application

```
package bankrmi;
public class Server {
   private static final String USAGE = "java bankrmi.Server
   <bank_rmi_url>";
   private static final String BANK = "Nordea";
   public Server(String bankName) {
   try {
   Bank bankobj = new BankImpl(bankName);
   java.rmi.Naming.rebind(bankName, bankobj);
   } catch (Exception e) {
   e.printStackTrace();
   }
   }
   public static void main(String[] args) {
   if (args.length > 1 || (args.length > 0 &&
   args[0].equalsIgnoreCase("-h"))) {
   System.out.println(USAGE);
   System.exit(1);
   }
   bankName = (args.length > 0) ? args[0] : BANK;
   new Server(bankName);
   }
}
```

A Fragment of a Simple Client

```
package bankrmi;
import bankrmi.*;
import java.rmi.*;
public class SClient {
    static final String USAGE = "java Client <bank_url> <client> <value>";
    String bankname = “Noname", clientname = “Noname"; // defaults
    float value = 100;
    public SClient(String[] args) {
    //... Read and parse command line arguments (see Usage above)
    try {
         Bank bankobj = (Bank) Naming.lookup( bankname );
          Account account = bankobj.newAccount( clientname );
         account.deposit( value );
        System.out.println ( clientname + "'s account: $" +
   account.balance() );
    } catch (Rejected e) {
       System.out.println(e); System.exit(0);
      } catch (Exception se) {
         System.out.println("The runtime failed: " + se); System.exit(0);
      }
    }
    public static void main(String[] args) {
      new SClient(args);
    }
}
```

Integrating Java RMI with CORBA

- RMI is an all-Java solution
  - A good programming model
- CORBA is an enterprise distributed architecture
  - A programming model not designed specifically for Java
  - A mature middleware infrastructure
- RMI can run on top of IIOP
  - The OMG adds a new specification called ”Pass-by-Value”
  - See: http://download.oracle.com/javase/7/docs/technotes/guides/rmi-iiop/index.html
  - Most of services in Java2EE application server implementations use either RMI or RMI/IIOP for communication