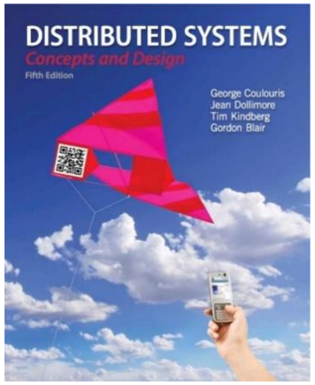
Distributed Objects Programming - Remote Invocation



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Some concepts are drawn from Chapter 5

Sun Java online tutorials:
http://java.sun.com/docs/books/tutorial/rmi/

别酒青门路，归轩白马津。相知无远近，万里尚为邻。
——（唐）张九龄

Review

- Q1. What are the 3 types of operating systems?

Review

- 1. Monolithic OS
- 2. Layered OS
- 3. Microkernel-based OS

Review

- Q2: What are advantages and disadvantages of Monolithic OS?

Review

- It is efficient (+):
  - Relative efficiency with which operations can be invoked is high because even invocation to a separate user-level address space on the same node is more costly.
- It is massive (-):
  - It performs all basic OS functions and takes up in the order of megabytes of code and data
- It is undifferentiated (-):
  - It is coded in a non-modular way (traditionally) although modern ones are much more layered.
- It is intractable (-):
  - Altering any individual software component to adapt it to changing requirements is difficult.

Review

- Q3: What are the advantages of microkernel-based OS?

Review

- A relative small kernel is more likely to be free of bugs than one that is larger and complex.
- Extensibility and its ability to enforce modularity behind memory protection boundaries

Review

- Q4: Give some examples of microkernel systems?

Review

- MACH, CMU (Carnegie Mellon University)
- QNX - Unix-like RTOS (Canada, BlackBerry)
- Windows NT – original design
- HarmonyOS (Huawei)

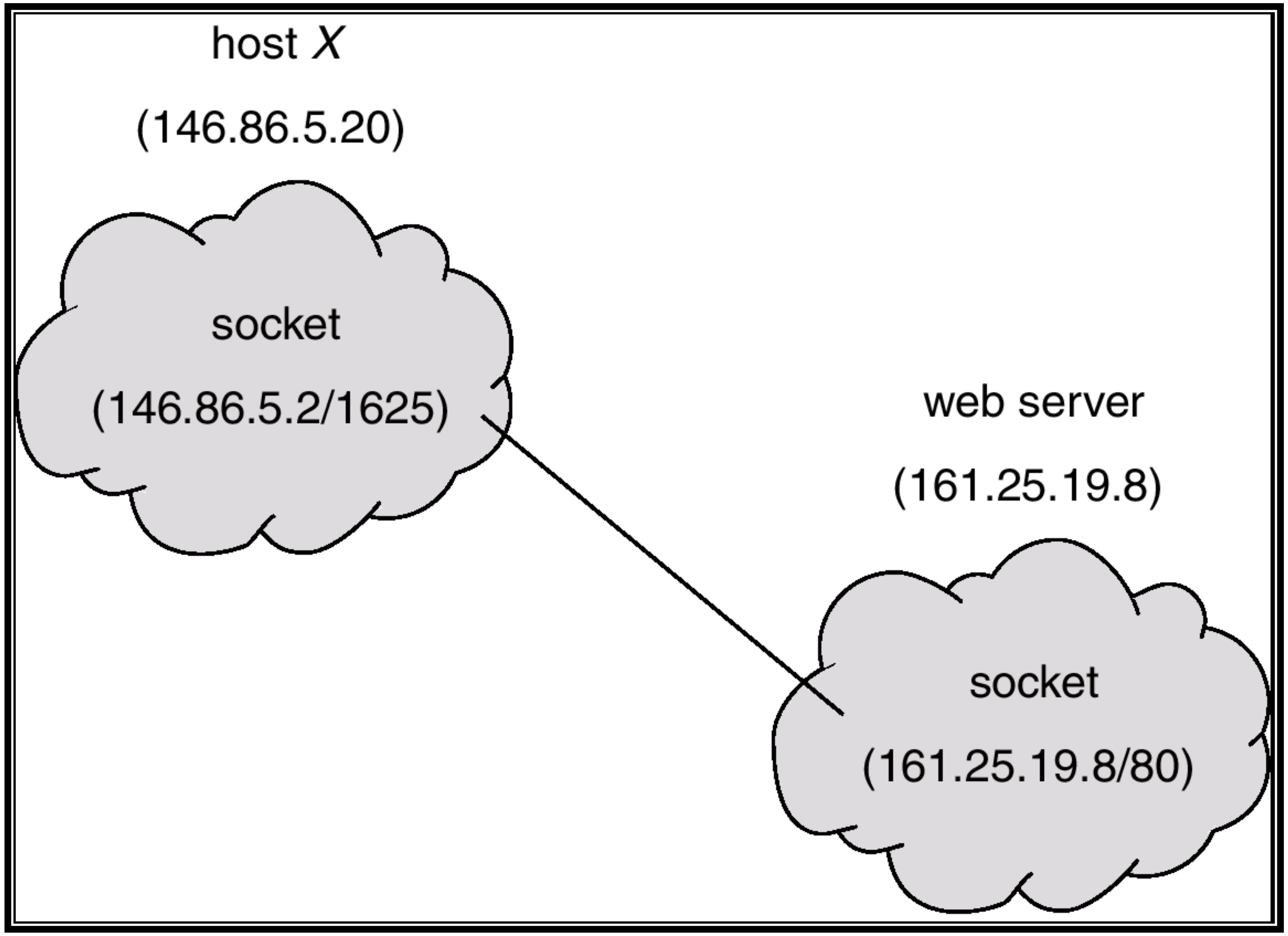
Outline

- Introduction to Distributed Objects
- Remote Method Invocation (RMI) Architecture
- RMI Programming and a Sample Example:
  - Server-Side RMI programming
  - Client-Side RMI programming
- Advanced RMI Concepts
  - Security Policies
  - Exceptions
  - Dynamic Loading
- A more advanced RMI application
  - Math Server
- RPC and Summary

Sockets

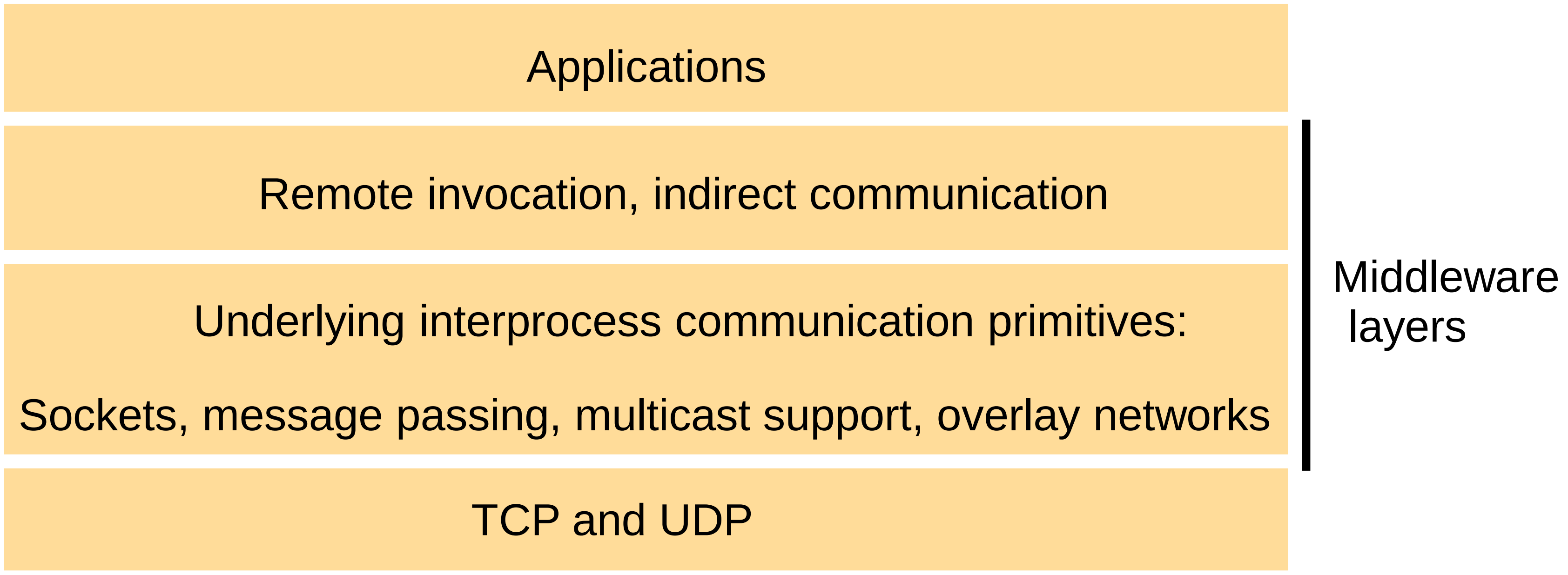
- A socket is defined as an *endpoint for communication*.
- Concatenation of IP address and port
- The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**
- Communication consists between a pair of sockets.
- Considered a low-level form of communication between distributed processes.
  - Sockets allow only an unstructured stream of bytes to be exchanged. It is the responsibility of the client or server application to impose a structure on the data.

Socket Communication



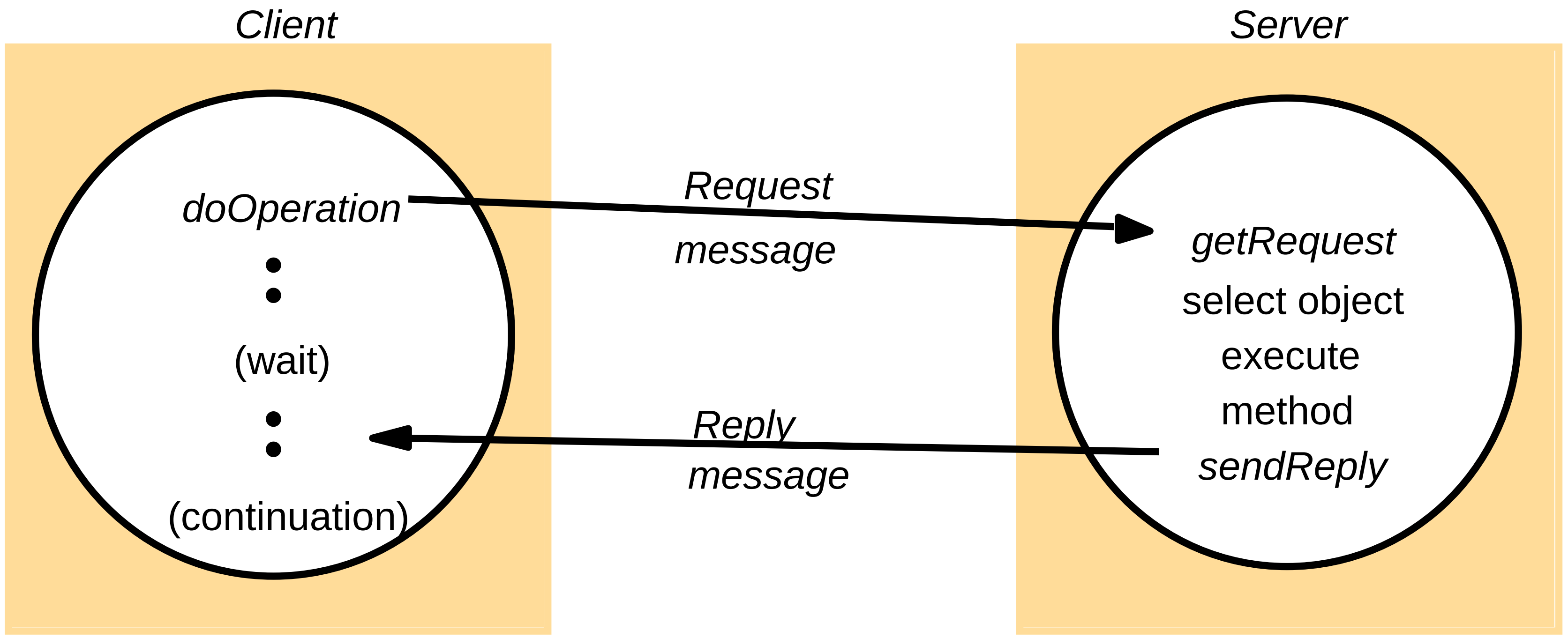
Introduction

- We cover high-level programming models for distributed systems. Two widely used models are:
  - *Remote Procedure Call (RPC)* - an extension of the conventional procedure call model
  - *Remote Method Invocation (RMI)* - an extension of the object-oriented programming model.


Applications
Remote invocation, indirect communication
Underlying interprocess communication primitives:
Sockets, message passing, multicast support, overlay networks
TCP and UDP
Middleware layers

Request-Reply Protocol

- Exchange protocol for the implementation of remote invocation in a distributed system.
- We discuss the protocol based on three abstract operations: doOperation, getRequest and sendReply



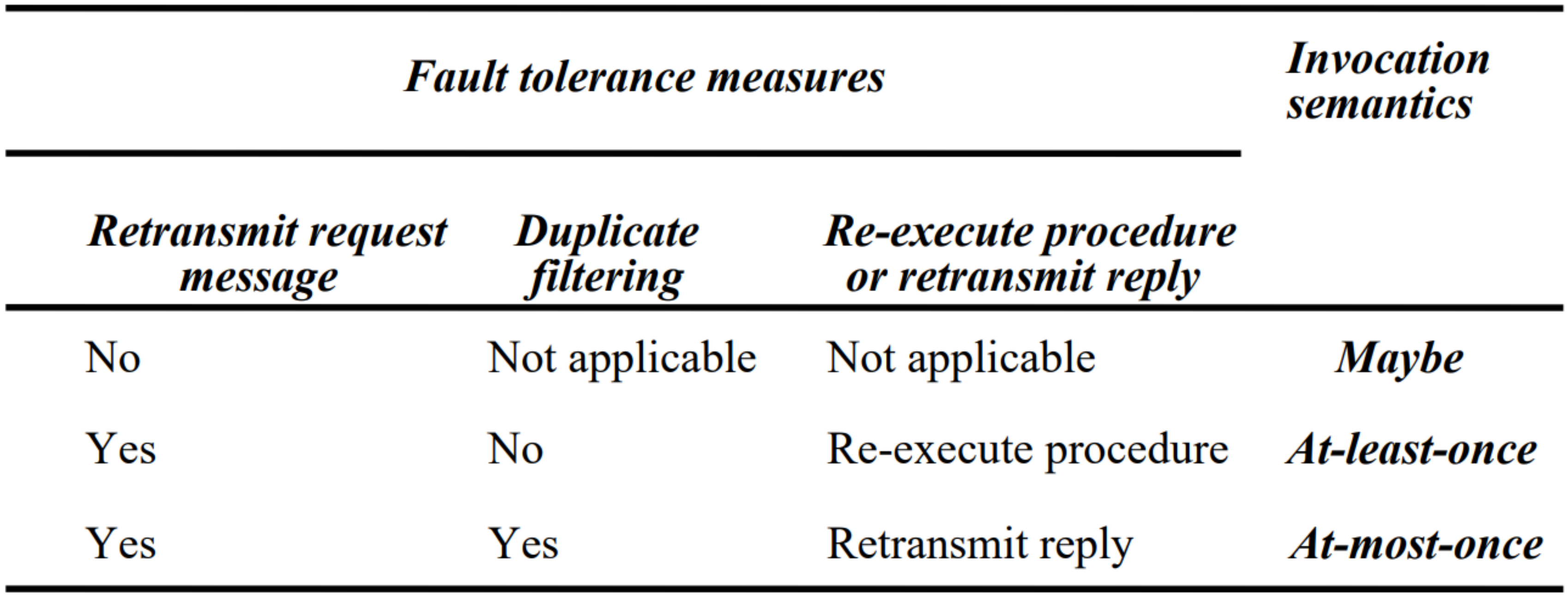
Request-Reply Operations

- **public byte[] doOperation (RemoteRef s, int operationId, byte[] arguments)**
  - Sends a request message to the remote server and returns the reply
  - The arguments specify the remote server, the operation to be invoked and the arguments of that operation
- **public byte[] getRequest ()**
  - Acquires a client request via the server port
- **public void sendReply (byte[] reply, InetAddress clientHost, int clientPort)**
  - Sends the reply message reply to the client at its Internet address and port

Remote Invocation Issues

- Local invocations
  - Executed exactly once
- Remote invocations
  - via Request-Reply
  - may suffer from communication failures
  - retransmission of request/reply
  - message duplication, duplication filtering
  - no unique semantics..

Invocation Semantics



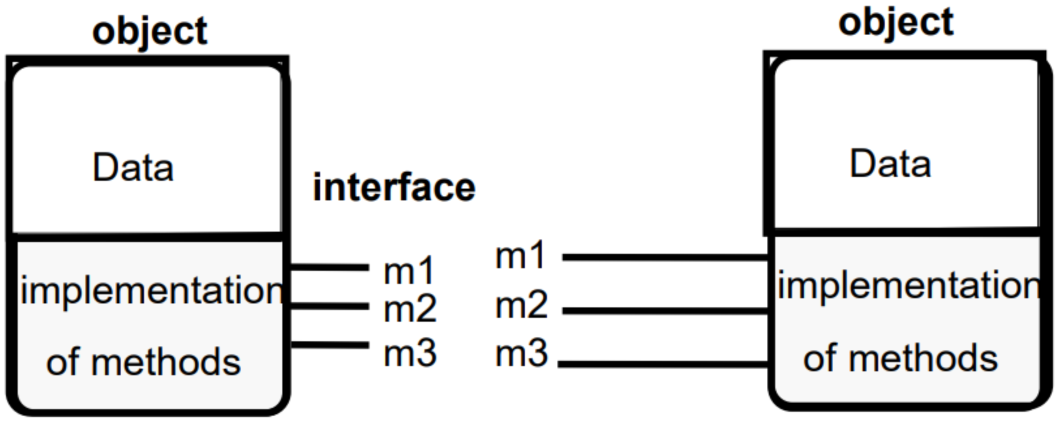
Fault tolerance measures			*Invocation semantics*
Retransmit request message	*Duplicate filtering*	*Re-execute procedure or retransmit reply*	
No	Not applicable	Not applicable	*Maybe*
Yes	No	Re-execute procedure	*At-least-once*
Yes	Yes	Retransmit reply	*At-most-once*

Invocation Semantics

- Middleware that implements remote invocation generally provides a certain level of semantics:
  - **Maybe**: The remote procedure call may be executed once or not at all. Unless the caller receives a result, it is unknown as to whether the remote procedure was called.
  - **At-least-once**: Either the remote procedure was executed at least once, and the caller received a response, or the caller received an exception to indicate the remote procedure was not executed at all.
  - **At-most-once**: The remote procedure call was either executed exactly once, in which case the caller received a response, or it was not executed at all and the caller receives an exception.
- Java RMI (Remote Method Invocation) supports at-most-once invocation.
  - It is supported in various editions including J2EE.
- Sun RPC (Remote Procedure Call) supports at-least-once semantics.
  - Popularly used in Unix/C programming environments

Objects

- Object = data + methods
  - – logical and physical encapsulation
  - – accessed by means of references
  - – first class citizens, can be passed as arguments
- Interaction via interfaces
  - – define types of arguments and exceptions of methods



The Object Model

- Programs are (*logically and physically*) partitioned into objects
  - distributing objects natural and easy
- Interfaces
  - the only means to access data
  - make them remote
- Actions – via method invocation
  - interaction, chains of invocations
  - may lead to exceptions -> part of interface
- Garbage collection
  - reduces programming effort, error-free (Java, not C++)

Distributed Objects

- A programming model based on Object-Oriented principles for distributed programming.
- Enables reuse of well-known programming abstractions (Objects, Interfaces, methods…), familiar languages (Java, C++, C#...), and design principles and tools (design patterns, UML…)
- Each process contains a collection of objects, some of which can receive both remote and local invocations:
  - Method invocations between objects in *different processes* are known as **remote method invocation,** *regardless the processes run in the same or different machines*.
- Distributed objects may adopt a client-server architecture, but other architectural models can be applied as well.

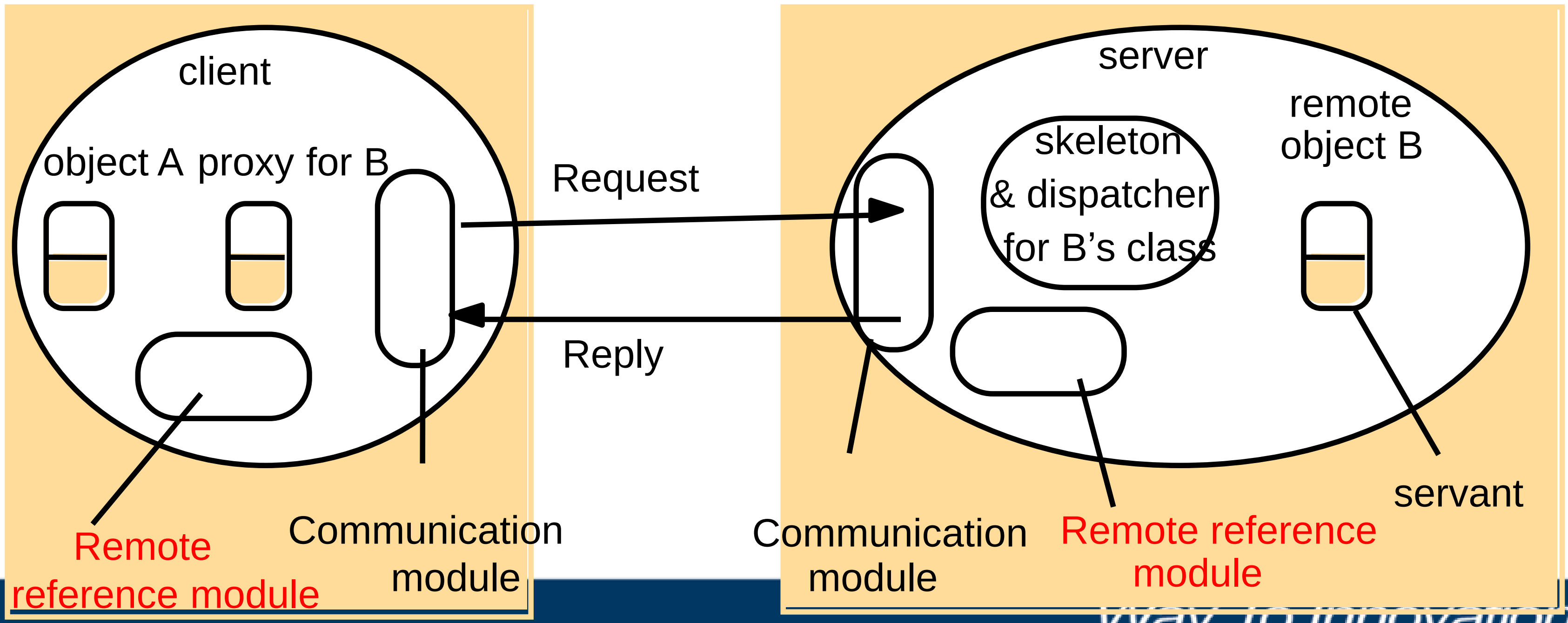
Outline

Java RMI

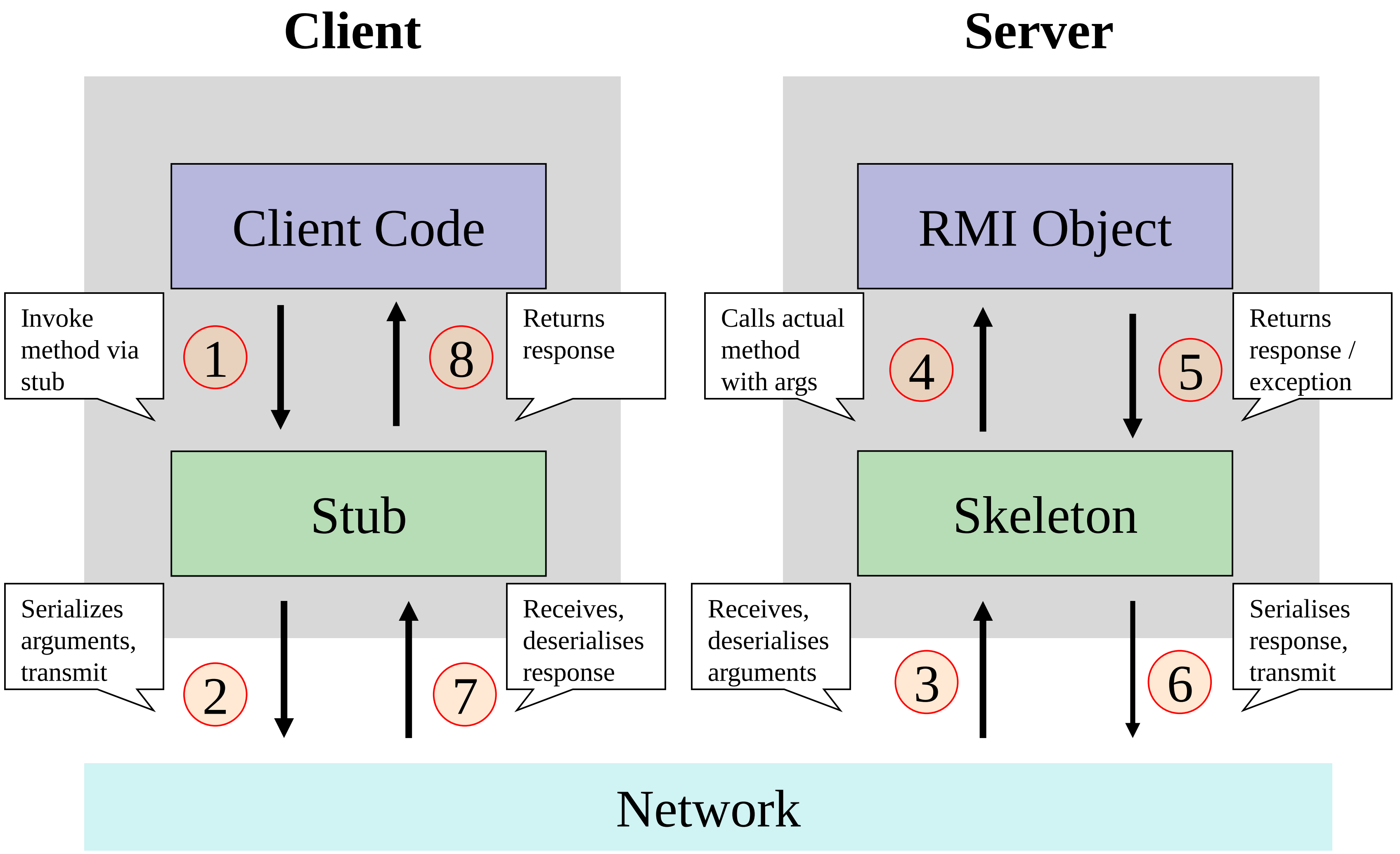
- Java Remote Method Invocation (Java RMI) is an extension of the Java object model to support distributed objects
  - methods of remote Java objects can be invoked from other Java virtual machines, possibly on different hosts
- Single-language system with a proprietary transport protocol (JRMP, java remote method protocol)
  - Also supports IIOP (Internet Inter-Orb Protocol) from CORBA
- RMI uses object serialization to marshal and unmarshal
  - Any serializable object can be used as parameter or method return
- **Releases of Java RMI**
  - Java RMI is available for Java Standard Edition (JSE), Java Micro Edition (JME), and Java Enterprise Edition (Java EE)

RMI Architecture and Components

- Remote reference module (at client & server) is responsible for providing addressing to the proxy (stub) object
- Proxy is used to implement a stub and provide transparency to the client. It is invoked directly by the client (as if the proxy itself was the remote object), and then marshal the invocation into a request
- Communication module is responsible for networking
- Dispatcher selects the proper skeleton and forward message to it
- Skeleton un-marshals the request and calls the remote object



Invocation Lifecycle


Client
Server
Client Code
RMI Object
Invoke method via stub
1
8
Returns response
Calls actual method with args
4
5
Returns response / exception
Stub
Skeleton
Serializes arguments, transmit
2
7
Receives, deserialises response
Receives, deserialises arguments
3
6
Serialises response, transmit
Network

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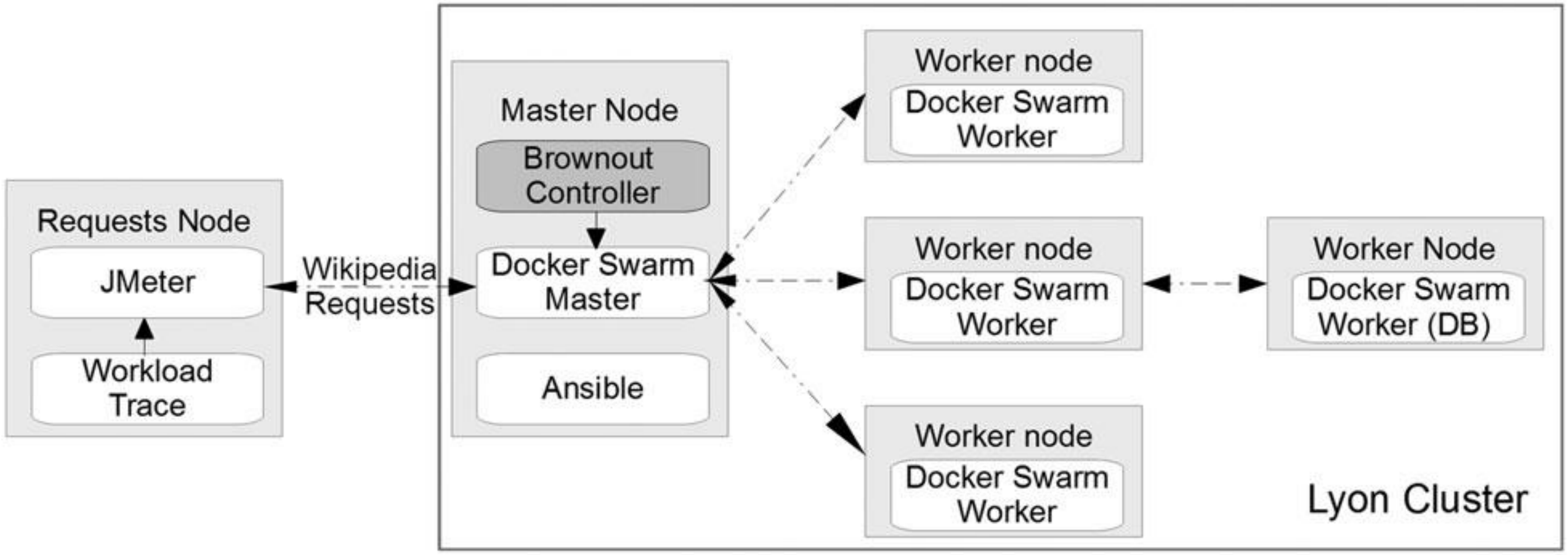
Case Study with RMI: iBrownout



- The prototype system can be installed on existing Docker Swarm cluster without modifying the configurations.
- System achieves transparency via the interactions with the public APIs of Docker Swarm.
- System components are deployed on both swarm master and worker nodes.

M. Xu and et al., iBrownout: An Integrated Approach for Managing Energy and Brownout in Container-based Clouds", *IEEE Transactions on Sustainable Computing*, 2019

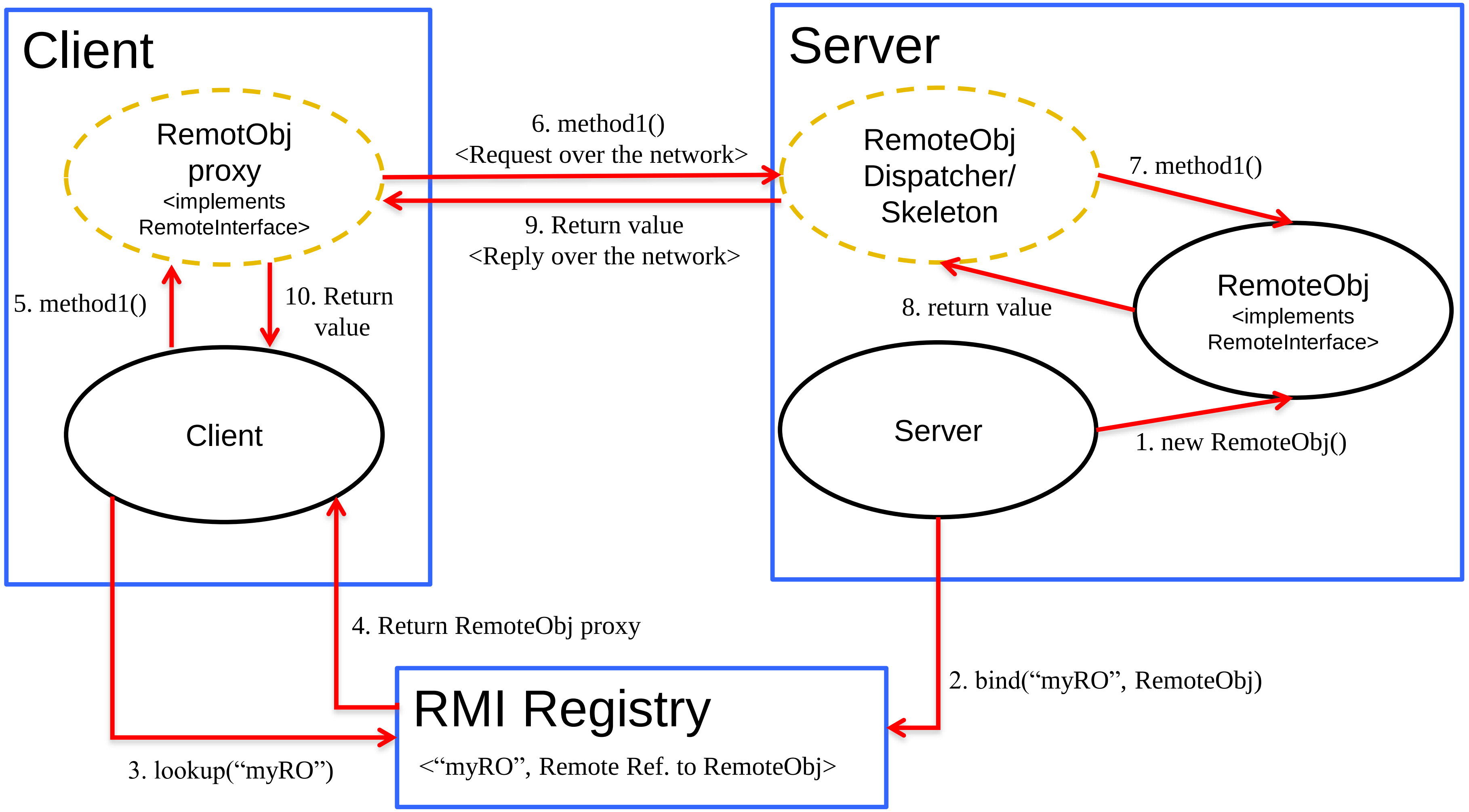
Steps for implementing an RMI application

- Design and implement the components of your distributed application
  - Remote interface
  - Servant program
  - Server program
  - Client program
- Compile source code and generate stubs
  - Client proxy stub
  - Server dispatcher and skeleton
- Make classes network accessible
  - Distribute the application on server side
- Start the application

RMI Programming and Examples

- Application Design
  - Remote Interface
    - Exposes the set of methods and properties available
    - Defines the contract between the client and the server
    - Constitutes the root for both stub and skeleton
  - Servant component
    - Represents the remote object (skeleton)
    - Implements the remote interface
  - Server component
    - Main driver that makes available the servant
    - It usually registers with the naming service
  - Client component

Java RMI



Client
RemotObj proxy <implements RemoteInterface>
5. method1()
10. Return value
Client
6. method1() <Request over the network>
9. Return value <Reply over the network>
Server
RemoteObj Dispatcher/ Skeleton
7. method1()
8. return value
RemoteObj <implements RemoteInterface>
Server
1. new RemoteObj()
4. Return RemoteObj proxy
2. bind("myRO", RemoteObj)
RMI Registry
<"myRO", Remote Ref. to RemoteObj>
3. lookup("myRO")

Example application – Hello World

- Server side
  - Create a HelloWorld interface
  - Implement HelloWorld interface with methods
  - Create a main method to register the HelloWorld service in the RMI Name Registry
  - Generate Stubs and Start RMI registry
  - Start Server
- Client side
  - Write a simple Client with main to lookup HelloWorld Service and invoke the methods

1. Define Interface of remote method

```
//file: HelloWorld.java
import java.rmi.Remote;
import java.rmi.RemoteException;

public interface HelloWorld extends Remote {
   public String sayHello(String who) throws RemoteException;
}
```

2. Define RMI Server Program

```
// file: HelloWorldServer.java
import java.rmi.Naming;
import java.rmi.Remote;
import java.rmi.RemoteException;
import java.rmi.server.UnicastRemoteObject;

public class HelloWorldServer extends UnicastRemoteObject  implements HelloWorld {
        public HelloWorldServer() throws RemoteException {
                super();
        }
        public String sayHello(String who) throws RemoteException {
                return "Hello "+who+" from your friend RMI 433-652 :-)";
        }
        public static void main(String[] args) {
                String hostName = "localhost";
                String serviceName = "HelloWorldService";
                if(args.length == 2){
                        hostName = args[0];
                        serviceName = args[1];
                }
                try{
                        HelloWorld hello = new HelloWorldServer();
                        Naming.rebind("rmi://"+hostName+"/"+serviceName, hello);
                        System.out.println("HelloWorld RMI Server is running...");
                }catch(Exception e){
                        e.printStackTrace();
                }
        }
}
```

3. Define Client Program

```
// file:  RMIClient.java
import java.rmi.Naming;
public class RMIClient {
   public static void main(String[] args) {
      String hostName = "localhost";
      String serviceName = "HelloWorldService";
      String who = “minxian";
      if(args.length == 3){
         hostName = args[0];
         serviceName = args[1];
          who = args[2];
       }
       else if(args.length == 1){
           who = args[0];
       }
       try{
        HelloWorld hello = (HelloWorld)Naming.lookup("rmi://"+hostName+"/"+serviceName);
        System.out.println(hello.sayHello(who));
       }catch(Exception e){
           e.printStackTrace();
       }
   }
}
```

Define Access Policy

- Example: File HelloPolicy to contain

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

Java RMI Example

- Running the Server and Client
  - Compile Client and Server classes
  - Develop a security policy file (e.g., HelloPolicy)
    - grant { permission java.security.AllPermission "", ""; };
  - Start RMI registry
    - rmiregistry &
  - Start server
    - java -Djava.security.policy=HelloPolicy HelloWorldServer
  - Run a client program
    - java -Djava.security.policy=HelloPolicy RMIClient
    - java -Djava.security.policy=HelloPolicy RMIClient Pascal

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Security Manager

- Java's security framework
  - *java.security.-*
  - Permissions, Principle, Domain etc.
  - Security manager, for access control (file, socket, class load, remote code etc)
  - *$JAVA_HOME/jre/lib/security/java.policy*
- Use security manager in RMI
  - RMI recommends to install a security manager, or RMI may not work properly while encountering security constraints.
  - A security manager ensures that the operations performed by downloaded code go through a set of security checks.
    - Eg. Connect and accept ports for RMI socket and allowing code downloading

Security Manager (cont.)

- Two ways to declare security manager
  - Use System property java.security.manager

```
java –Djava.security.manager HelloWorldImpl
```

  - Explicit declare in the source code

```
public static void main(String[]args){
    //check current security manager
    if(System.getSecurityManager()==null){
            System.setSecurityManager(new SecurityManager ());
    }
    …
    //lookup remote object and invoke methods.
}
```

- Use customized policy file instead of java.policy
  - Usage

```
java -Djava.security.manager -Djava.security.policy=local.policy HelloWorldImpl
```

File: “local.policy” contents

Specific permissions:

```
grant {
    permission java.net.SocketPermission   "*:1024-65535","connect,accept";
    permission java.io.FilePermission       "/home/globus/RMITutorial/-", "read";
};
```

Grant all permissions:

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

Exceptions

- The only exception that could be thrown out is *RemoteException*
- All RMI remote methods **have** to throw this exception
- The embedded exceptions could be:
  - java.net.UnknownHostException or java.net.ConnectException: if the client can't connect to the server using the given hostname. Server may not be running at the moment
  - java.rmi.UnmarshalException: if some classes not found. This may because the codebase has not been properly set
  - Java.security.AccessControlException: if the security policy file java.policy has not been properly configured

Passing objects

- Restrictions on exchanging objects
  - Implementing *java.io.serializable*
  - All the fields in a serializable object must be also serializable
  - Primitives are serializable
  - System related features (e.g. *Thread*, *File*) are non-serializable
- How about the socket programming issues?
  - Where are sockets and corresponding input, output streams?
  - How to handle object passing?
  - Who does all the magic?

RMI Dynamic Class Loading

- Ability to download bytecode (classes) from Remote JVM
- New types can be introduced into a remote virtual machine without informing the client
  - Extend the behavior of an application dynamically
  - Removes the need to deploy stubs manually
- Explicit set property to support dynamic class load
  - Specify system property *java.rmi.server.codebase* to tell the program where to download classes

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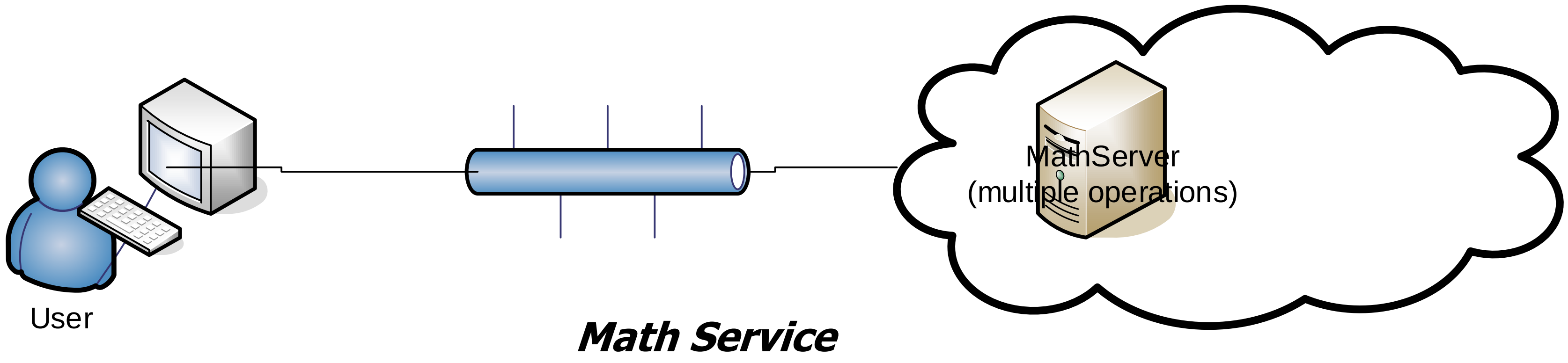
A Simple Math Server in RMI



Java RMI Example

- Specify the Remote Interface

```
public interface IRemoteMath extends Remote {
   double add(double i, double j) throws RemoteException;
   double subtract(double i, double j) throws RemoteException;
}
```

Java RMI Example

- Implement the Servant Class

```
public class RemoteMathServant extends UnicastRemoteObject implements IRemoteMath {
    public double add ( double i, double j ) throws RemoteException {
        return (i+j);
    }

    public double subtract ( double i, double j ) throws RemoteException {
        return (i-j);
    }
}
```

Java RMI Example

- Implement the server

```
public class MathServer {
    public static void main(String args[]){
        System.setSecurityManager(new RMISecurityManager());
        try{
            IRemoteMath remoteMath = new RemoteMathServant();
            Registry registry = LocateRegistry.getRegistry();
            registry.bind("Compute", remoteMath );
      System.out.println("Math server ready");
        }catch(Exception e) {
            e.printStackTrace();
        }
    }
}
```

Java RMI Example

- Implement the client program

```
public class MathClient {
    public static void main(String[] args) {
        try {
            if(System.getSecurityManager() == null)
                System.setSecurityManager( new RMISecurityManager() );

            LocateRegistry.getRegistry("localhost");
            IRemoteMath remoteMath = (IRemoteMath) registry.lookup("Compute");

            System.out.println( "1.7 + 2.8 = ” + math.add(1.7, 2.8) );
            System.out.println( "6.7 - 2.3 = ” + math.subtract(6.7, 2.3) );
        }
        catch( Exception e ) {
            System.out.println( e );
        }
    }
}
```

Java RMI Example

- Running the Server and Client
  - Compile Client and Server classes
  - Develop a security policy file
    - grant { permission java.security.AllPermission "", ""; };
  - Start RMI registry
    - rmiregistry &
  - Start server
    - java -Djava.security.policy=policyfile MathServer
  - Start client
    - java -Djava.security.policy=policyfile MathClient

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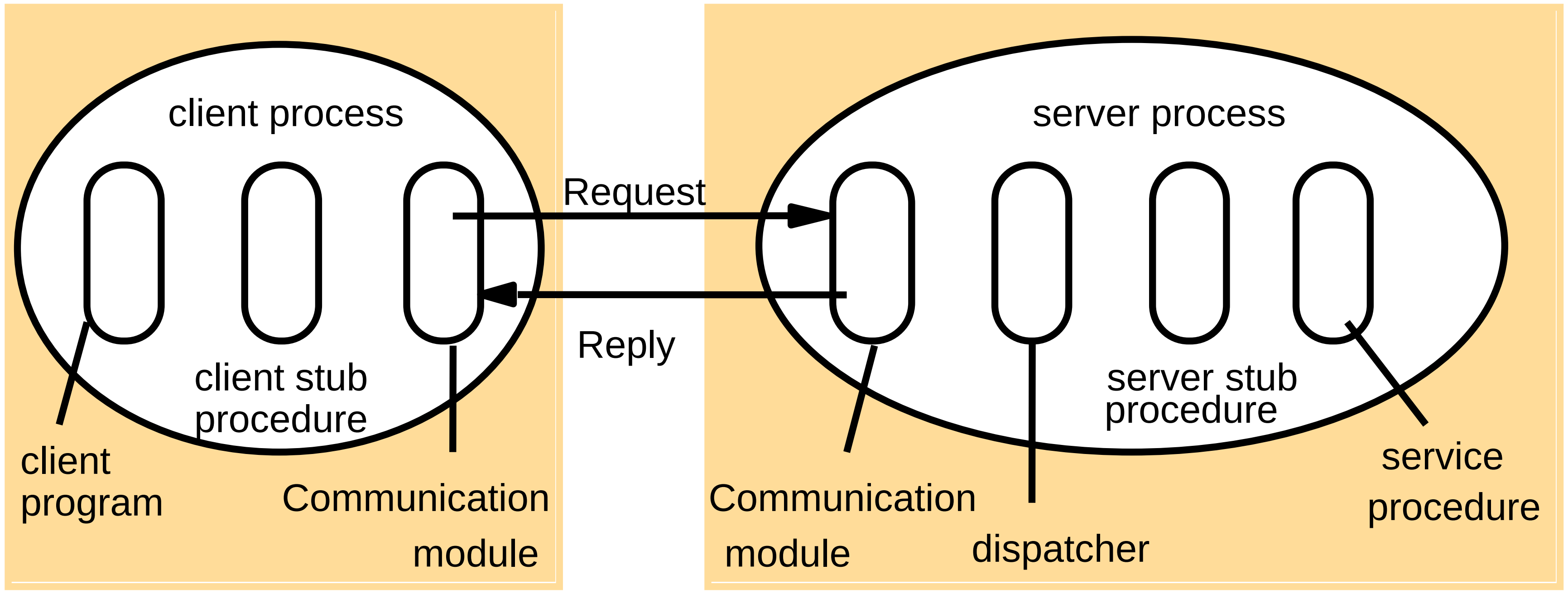
Remote Procedure Call (RPC) – used in C

- RPCs enable clients to execute procedures in server processes based on a defined service interface.



Remote Procedure Call (RPC)

- Communication Module
  - Implements the desired design choices in terms of retransmission of requests, dealing with duplicates and retransmission of results
- Client Stub Procedure
  - Behaves like a local procedure to the client. Marshals the procedure identifiers and arguments which is handed to the communication module
  - Unmarshalls the results in the reply
- Dispatcher
  - Selects the server stub based on the procedure identifier and forwards the request to the server stub
- Server stub procedure
  - Unmarshalls the arguments in the request message and forwards it to the service procedure
  - Marshalls the arguments in the result message and returns it to the client

Summary: RMI Programming

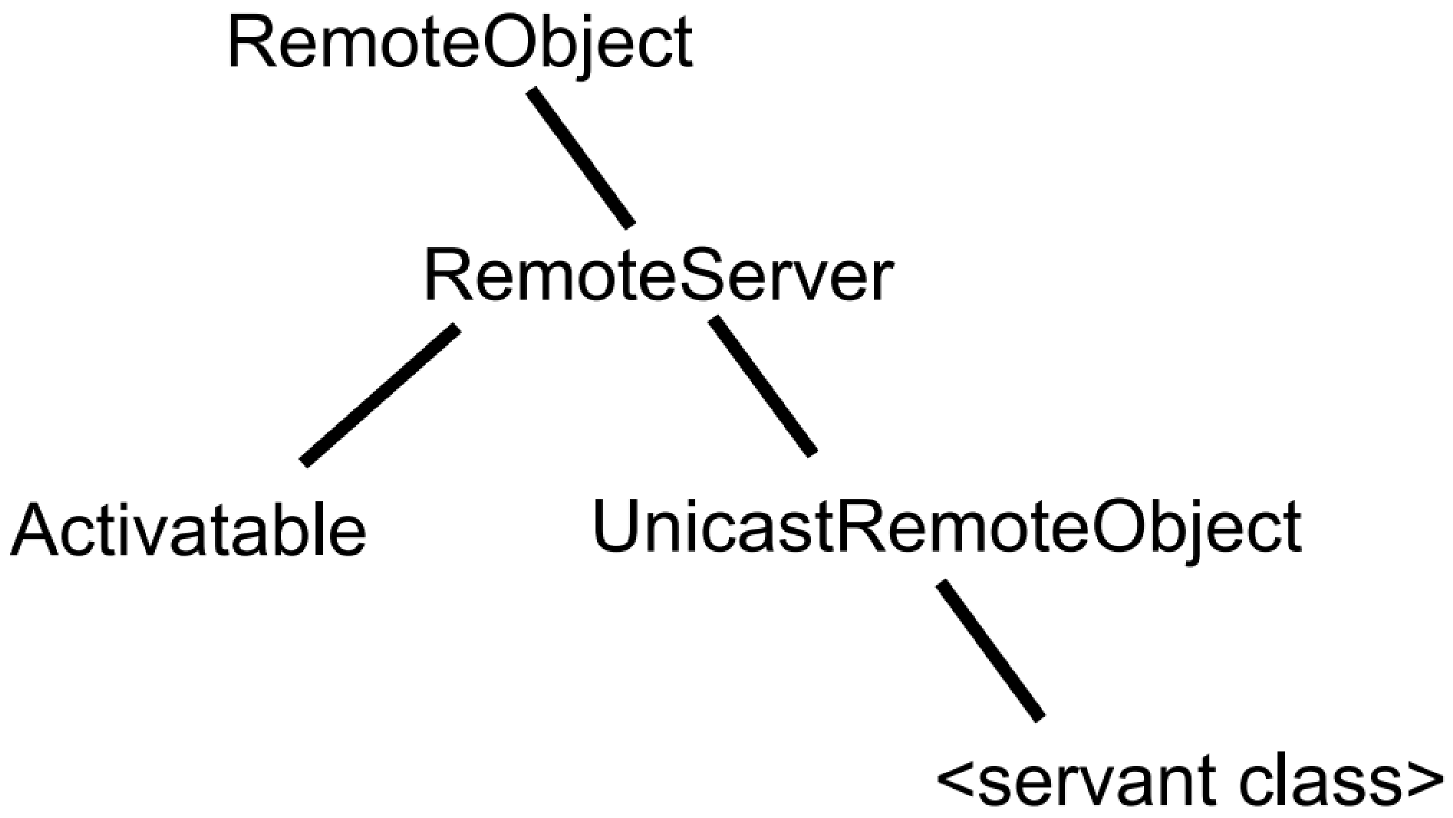
- RMI greatly simplifies creation of distributed applications (e.g., compare RMI code with socket-based apps)
- Server Side
  - Define interface that extend java.rmi.Remote
  - Servant class both implements the interface and extends java.rmi.server.UnicastRemoteObject
  - Register the remote object into RMI registry
  - Ensure both rmiregistry and the server is running
- Client Side
  - No restriction on client implementation, both thin and rich client can be used. (Console, Swing, or Web client such as servlet and JSP)

Binding and Activation

- Binder
  - mapping from textual names to remote references
  - used by clients as a look-up service (cf Java RMIregistry)
- Activation
  - objects active (available for running) and passive

    (= implementation of methods + marshalled state
  - activation = create new instance of class + initialise from stored state
- Activator
  - records location of passive objects
  - starts server processes and activates objects within them

Classes Supporting Java RMI



The Methods of the Naming Class

- void rebind (String name, Remote obj)
  - This method is used by a server to register the identifier of a remote object by name
- void bind (String name, Remote obj)
  - This method can alternatively be used by a server to register a remote object by name, but if the name is already bound to a remote object reference an exception is thrown.
- void unbind (String name, Remote obj)
  - This method removes a binding.
- Remote lookup (String name)
  - This method is used by clients to look up a remote object by name. A remote object reference is returned.
- String [] list()
  - This method returns an array of Strings containing the names bound in the registry.