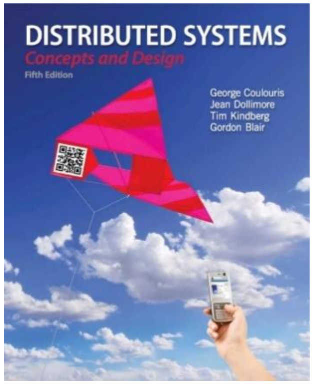
Distributed Objects Programming - Remote Invocation



Some concepts are drawn from Chapter 5

Sun Java online tutorials:

http://java.sun.com/docs/books/tutorial/rmi/

Dr. Minxian Xu
Associate Professor
Research Center for Cloud Computing
Shenzhen Institute of Advanced Technology, CAS
http://www.minxianxu.info/dcp

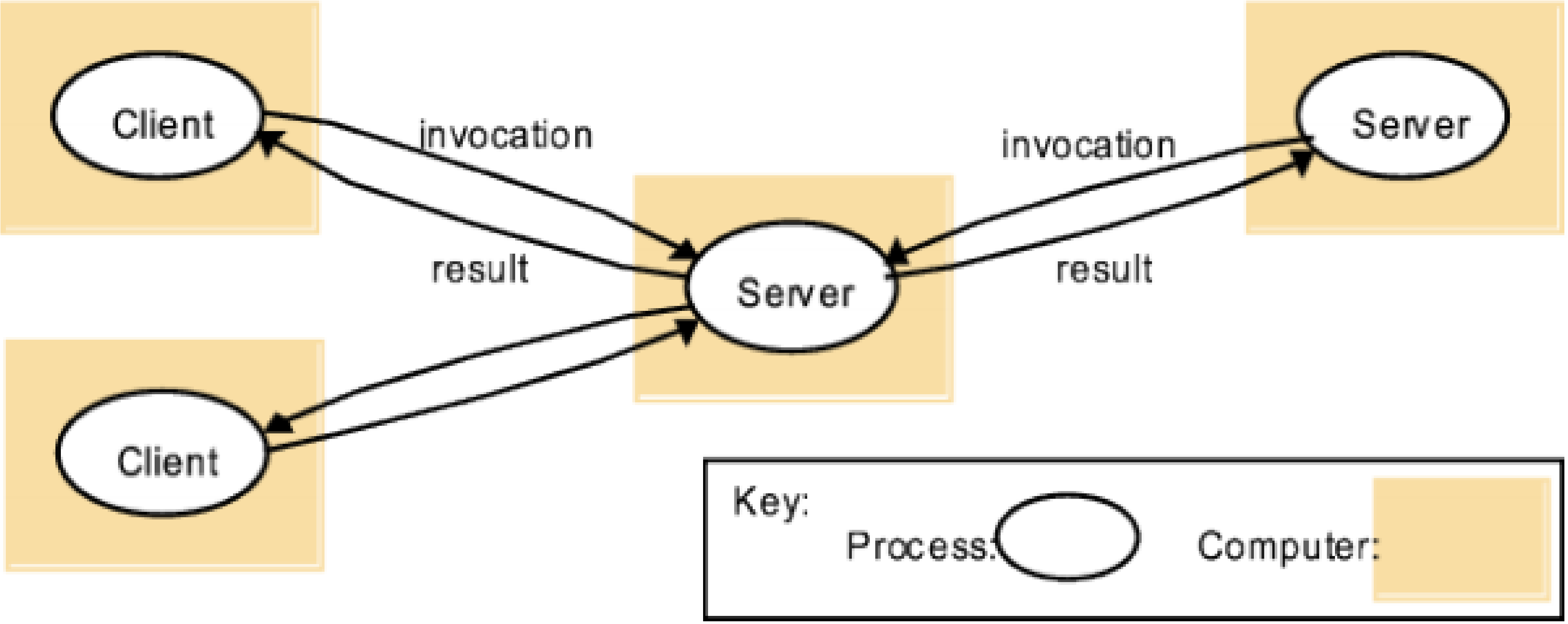
> 别酒青门路，归轩白马津。相知无远近，万里尚为邻。
> ——（唐）张九龄

Review

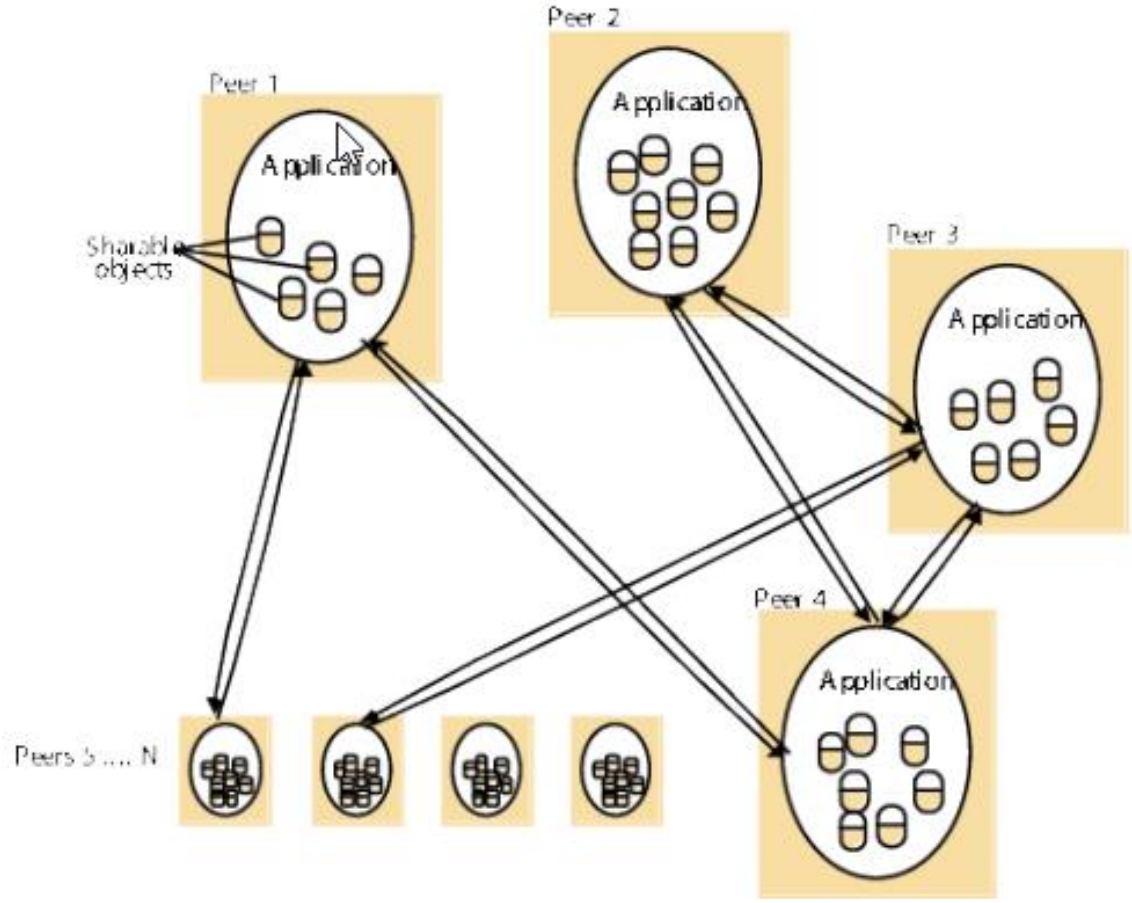
- Q1. Briefly explain the difference between a client-server architecture and a peer-to-peer architecture.

Review

Client-server



Peer-to-Peer


Peer 2
Application
Peer 1
Application
Sharable objects
Peer 3
Application
Peer 4
Application
Peers 5 .... N

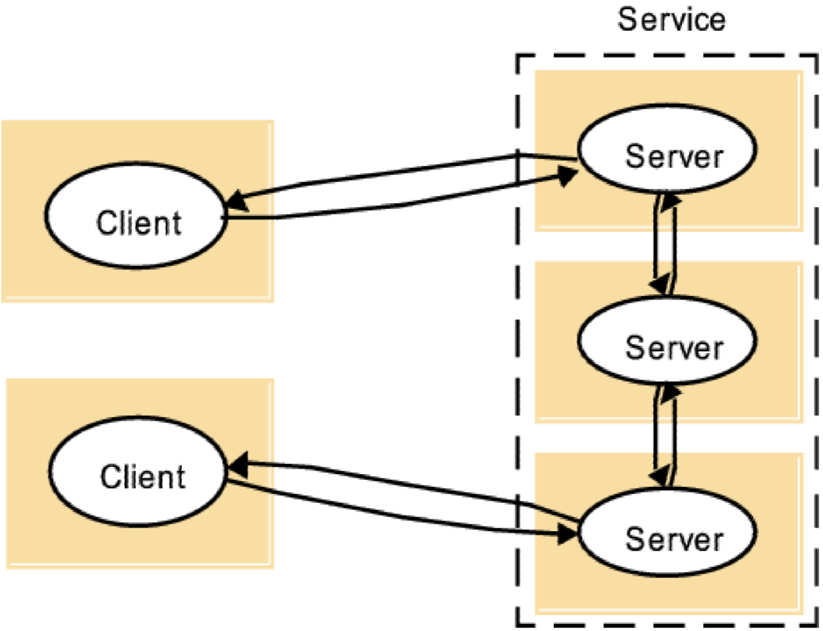
Review

- Q2. Briefly explain each of the following distributed system architecture variations, giving also a reason or a benefit for its use:

- Services provided by multiple servers
  - Proxy servers and caches
  - Mobile code and Mobile Agents
  - Network computers
  - Thin clients
- Tiered Architecture

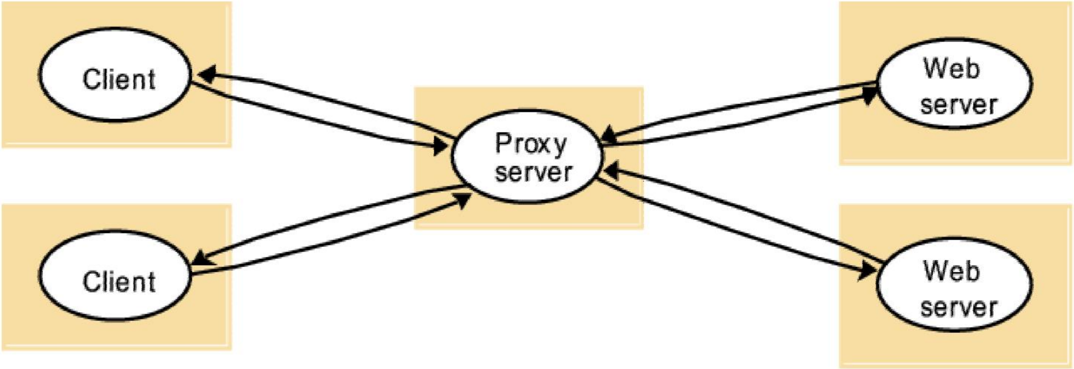
Services provided by multiple servers

- Services may be implemented as several server processes in separate host computers interacting as necessary to provide a service to client processes
- Servers may
  - Partition the set of objects on which the service is based and distribute those objects between themselves
  - Maintain replicated copies of them on several hosts
- Improve performance and reliability



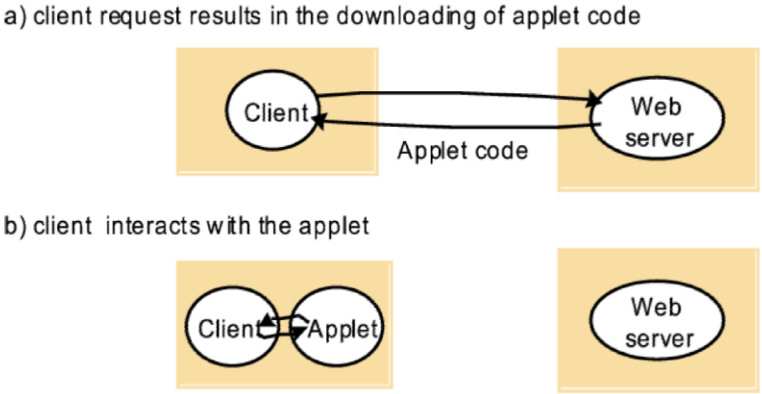
Proxy servers and caches

- Cache
  - A store of recently used data objects that is closer to the client
  - They may be co-located with each client or they may be located in a *proxy server* that can be shared by several clients
- Increase the availability and performance of the service by reducing the load on the wide area network and web servers
- Proxy servers can take on other roles --- better reliability
- Improved security
- Access restriction
- Privacy protection



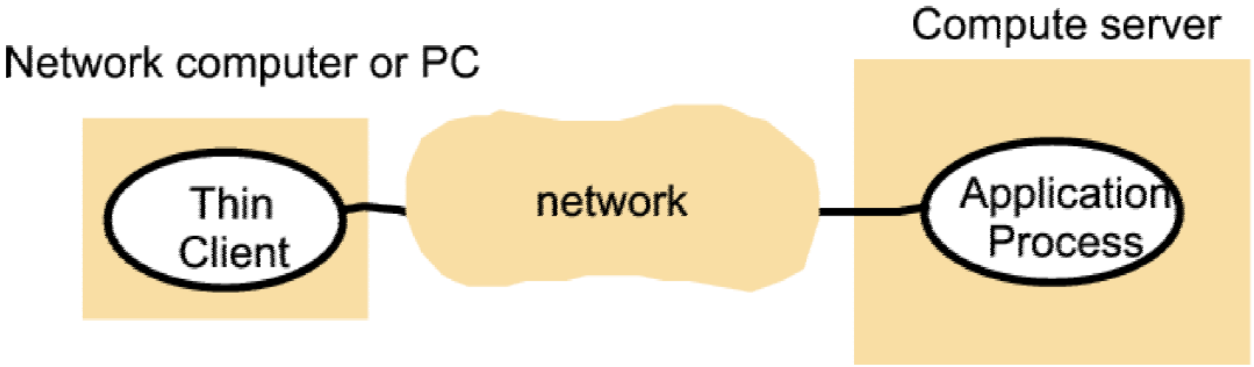
Mobile code and mobile agents

- Mobile code
  - Mobile Code is downloaded to the client and is executed on the client (e.g. applet).
  - Good interactive response
  - Security threat
- Mobile agents
  - Mobile agents are running programs that includes both code and data that travels from one computer to another.
  - They process data at the data source, rather than fetching it remotely
    - Less communication overhead by replacing remote invocations with local ones
  - Security threat



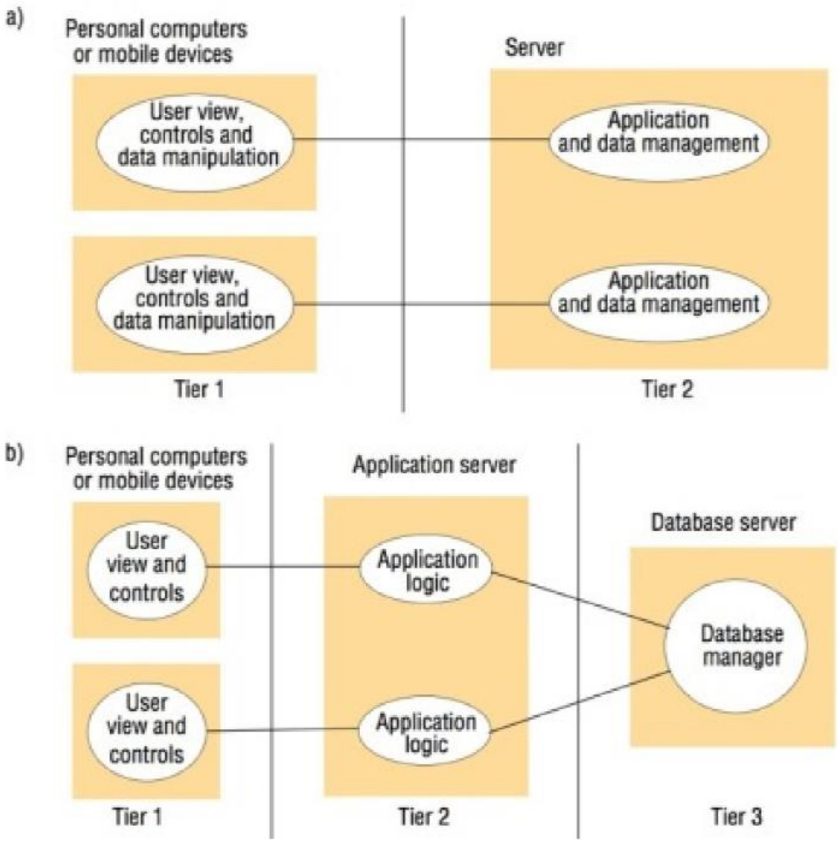
Network computers and thin clients

- Network Computers
  - Download their operating system and application software from a remote file system. Applications are run locally.
- Thin clients
  - Move complexity away from the end-user device
  - Local user interface, remote services or applications
  - Few assumptions or demands on the client device



Tiered Architecture

- Tiered architectures are complementary to layering, which deals with horizontal organization of services.
- Layering deals with vertical organization of services



Review

- Q3. Briefly explain the purpose of the following fundamental models and explain two important considerations for each:
- Interaction Model.
- Failure Model.
- Security Model.

Review

- Interaction Model
  - Models the interaction between processes of a distributed system - e.g. interaction between clients and servers or peers.
- Failure Model
  - Classifies the failures of processes and communication channels in a distributed system
- Security Model
  - Identifies the possible threats to processes and communication channels, as well as protecting encapsulated objects against unauthorized access.

Review

Q4. Explain the difference between a synchronous protocol and an asynchronous protocol.

Review

- Synchronous communication blocks on both send and receive operations.
  - When a send is issued the sending process is blocked until the receive is issued.
  - Whenever the receive is issued the process blocks until a message arrives.
- In Asynchronous communication the send is nonblocking.
  - The sending process returns as soon as the message is copied to a local buffer and the transmission of the message proceeds in parallel.
  - Receive operation can be blocking or non-blocking (non-blocking receives are not normally supported in today's systems).

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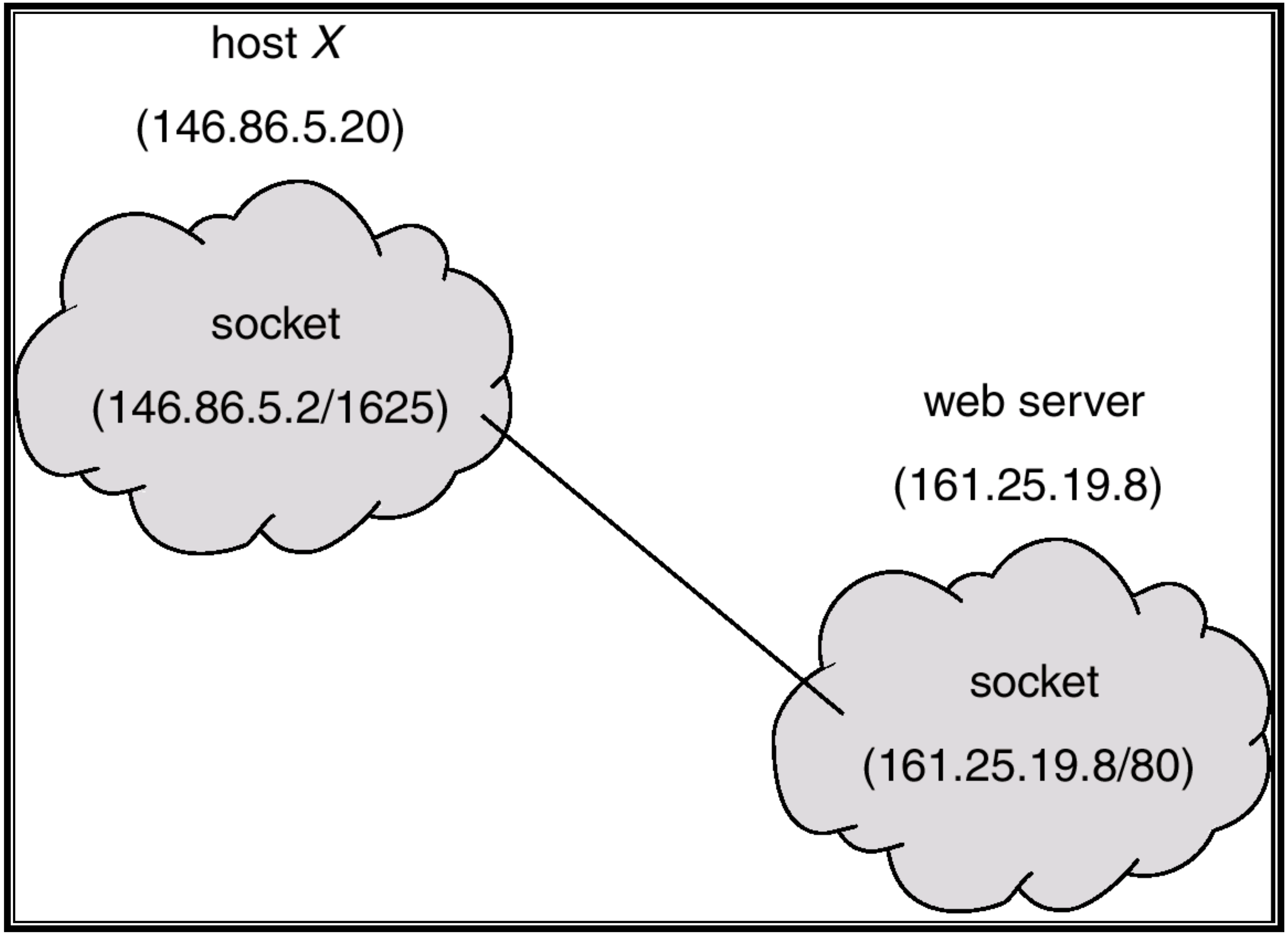
- Introduction to Distributed Objects
- Remote Method Invocation (RMI) Architecture
- RMI Programming and a Sample Example:
  - Server-Side RMI programming
  - Client-Side RMI programming
- Advanced RMI Concepts
  - Security Policies
  - Exceptions
  - Dynamic Loading
- A more advanced RMI application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

Sockets

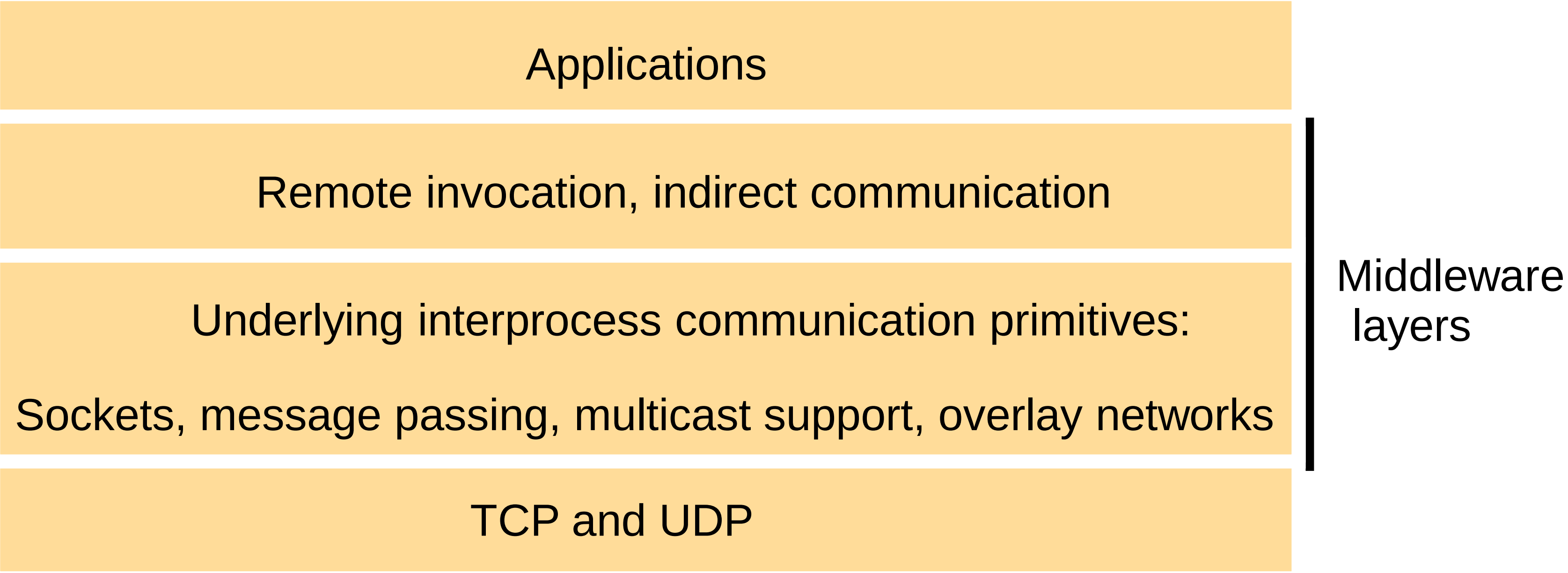
- A socket is defined as an *endpoint for communication*.
- Concatenation of IP address and port
- The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**
- Communication consists between a pair of sockets.
- Considered a low-level form of communication between distributed processes.
  - 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



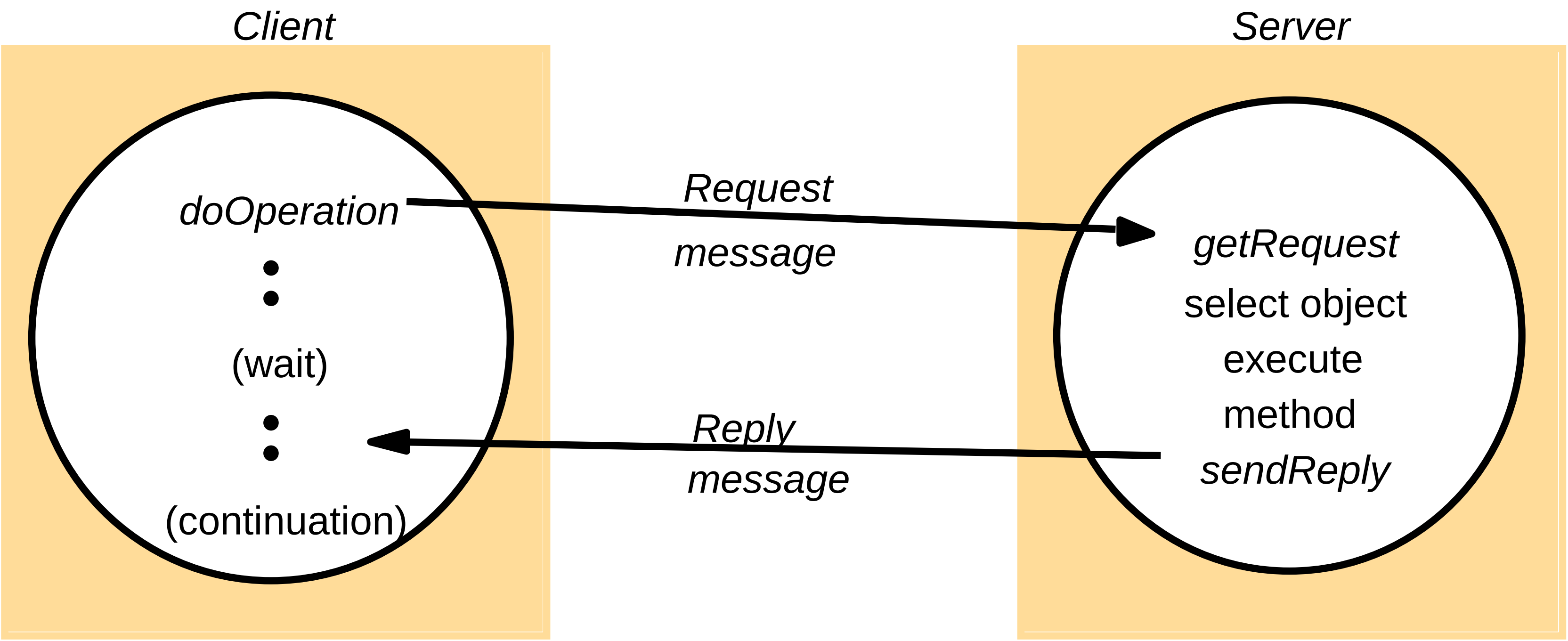
Introduction

- 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.



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

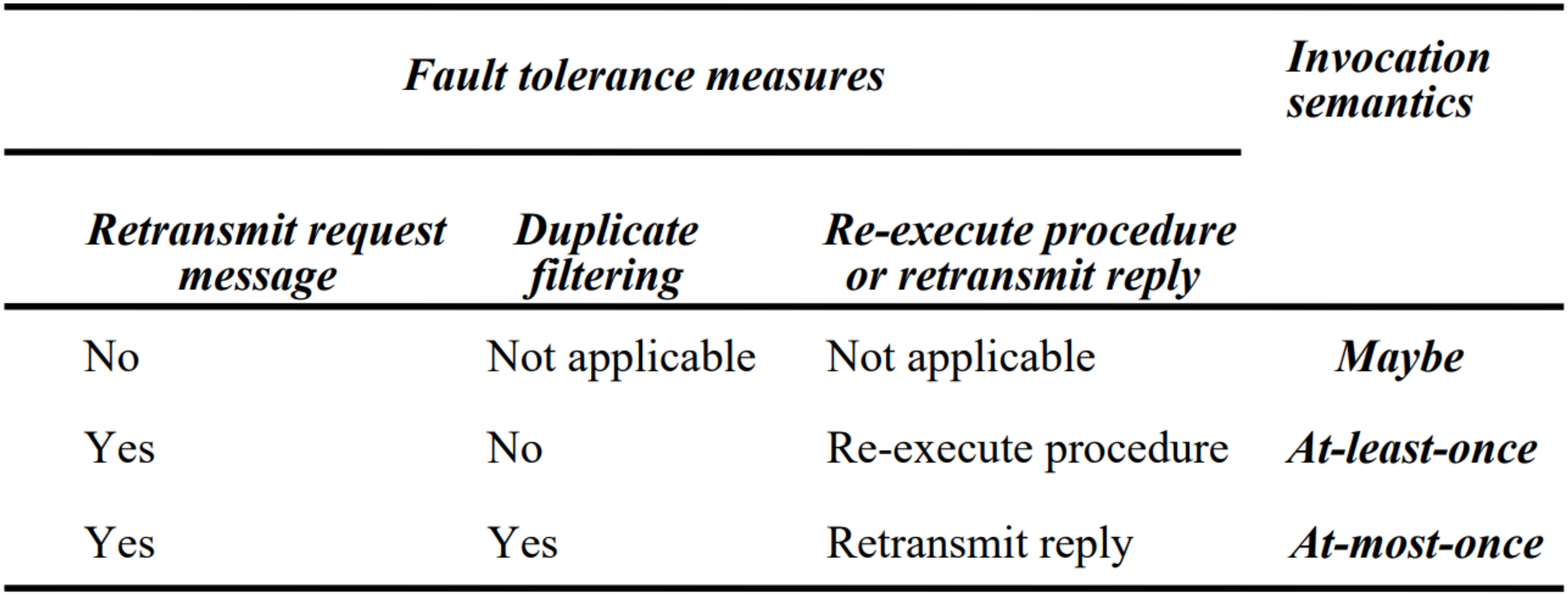
- **public void sendReply (byte[] reply, InetAddress clientHost, int clientPort)**
  - Sends the reply message reply to the client at its Internet address and port

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



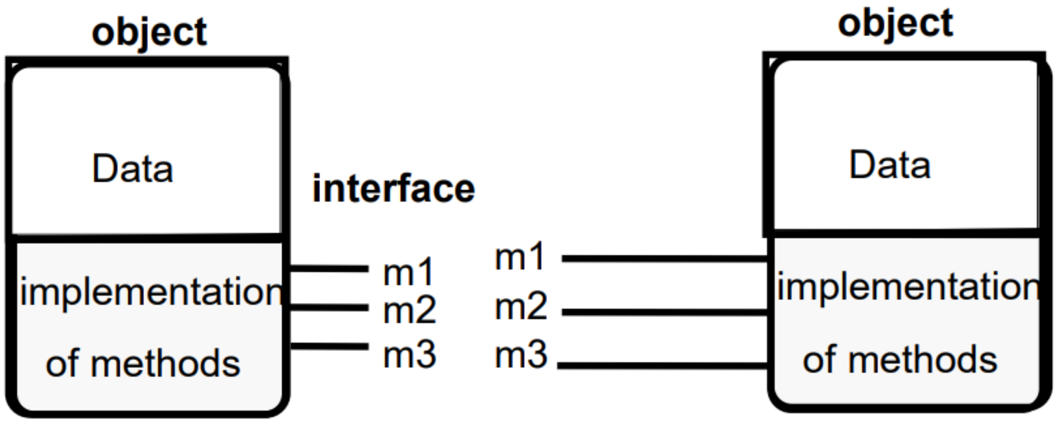
Fault tolerance measures			*Invocation semantics*
Retransmit request message	***Duplicate filtering***	***Re-execute procedure or retransmit reply***	
No	Not applicable	Not applicable	***Maybe***
Yes	No	Re-execute procedure	***At-least-once***
Yes	Yes	Retransmit reply	***At-most-once***

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.

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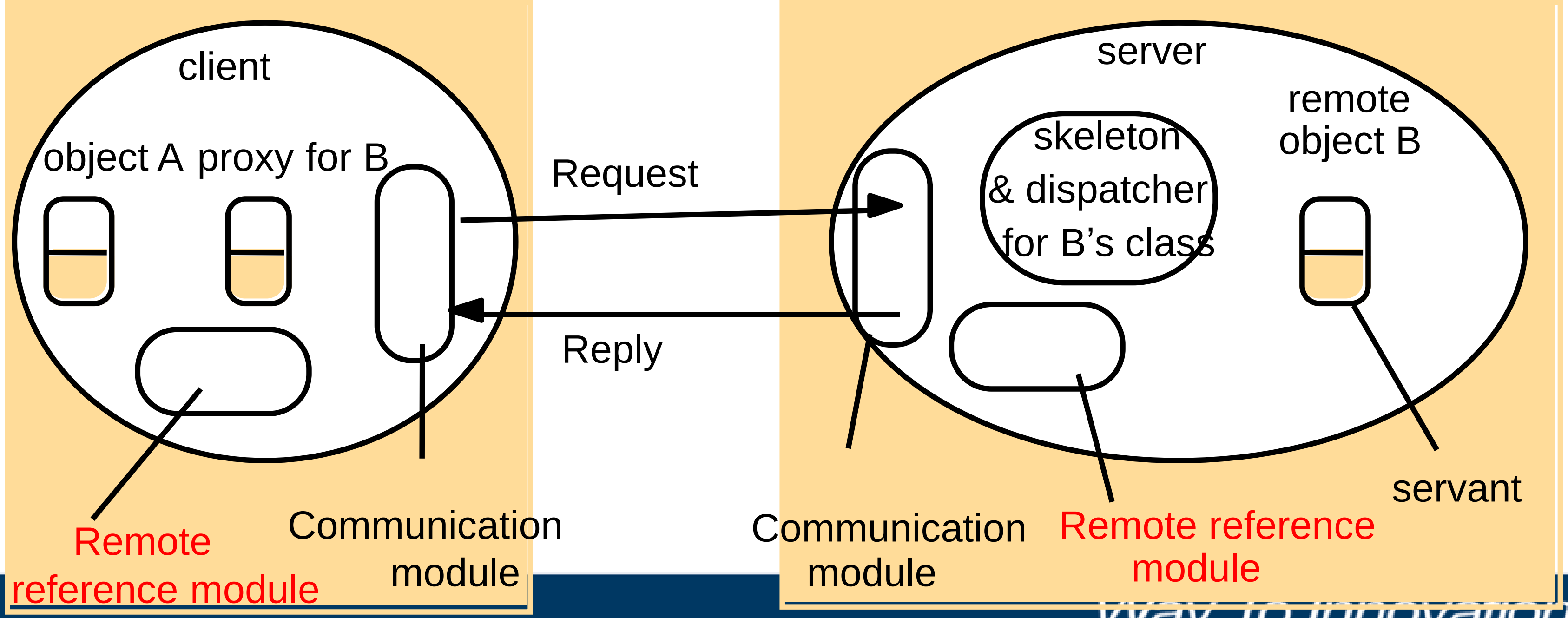
Java RMI

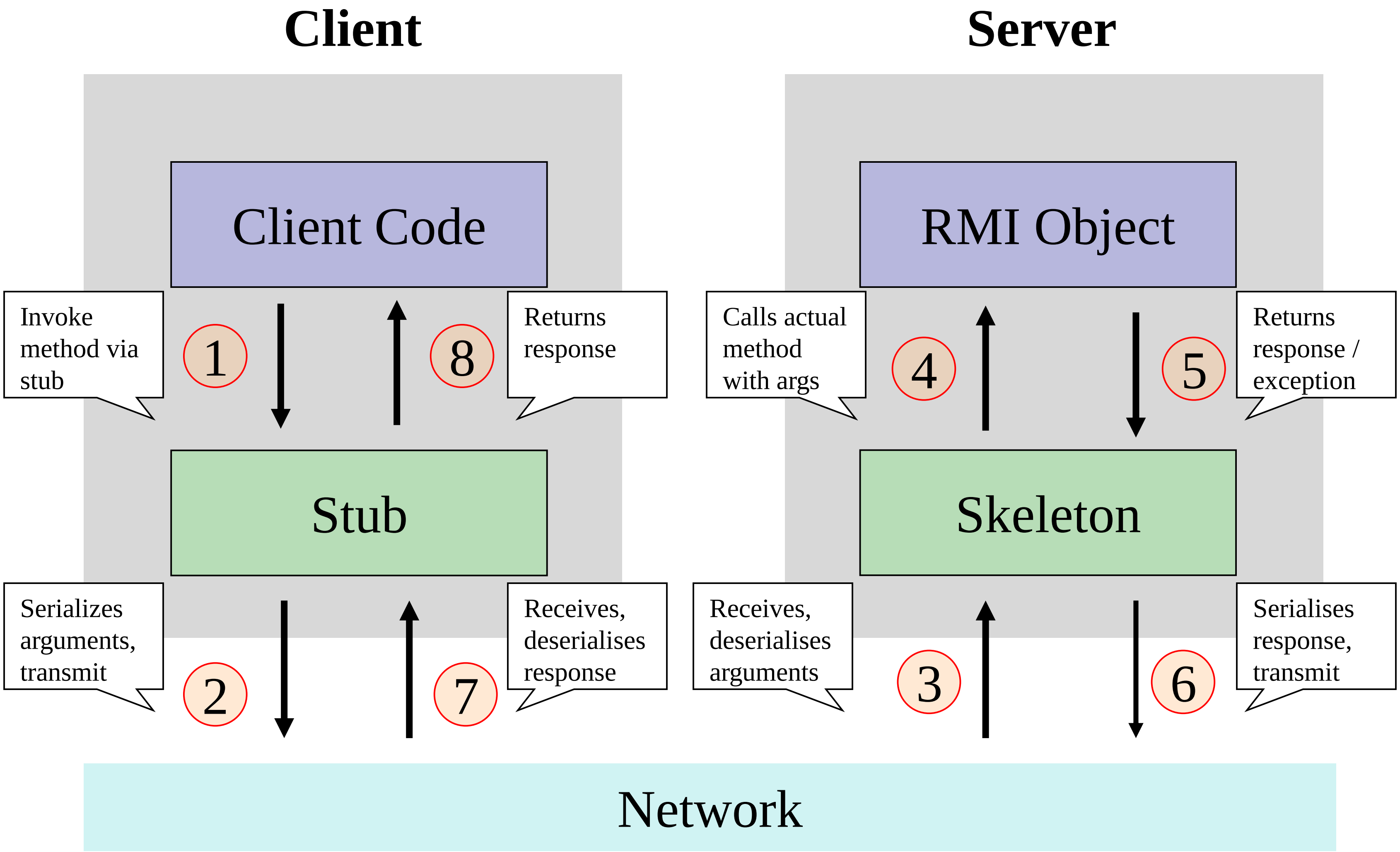
- Java Remote Method Invocation (Java RMI) is an extension of the Java object model to support distributed objects
    - methods of remote Java objects can be invoked from other Java virtual machines, possibly on different hosts
- Single-language system with a proprietary transport protocol (JRMP, java 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



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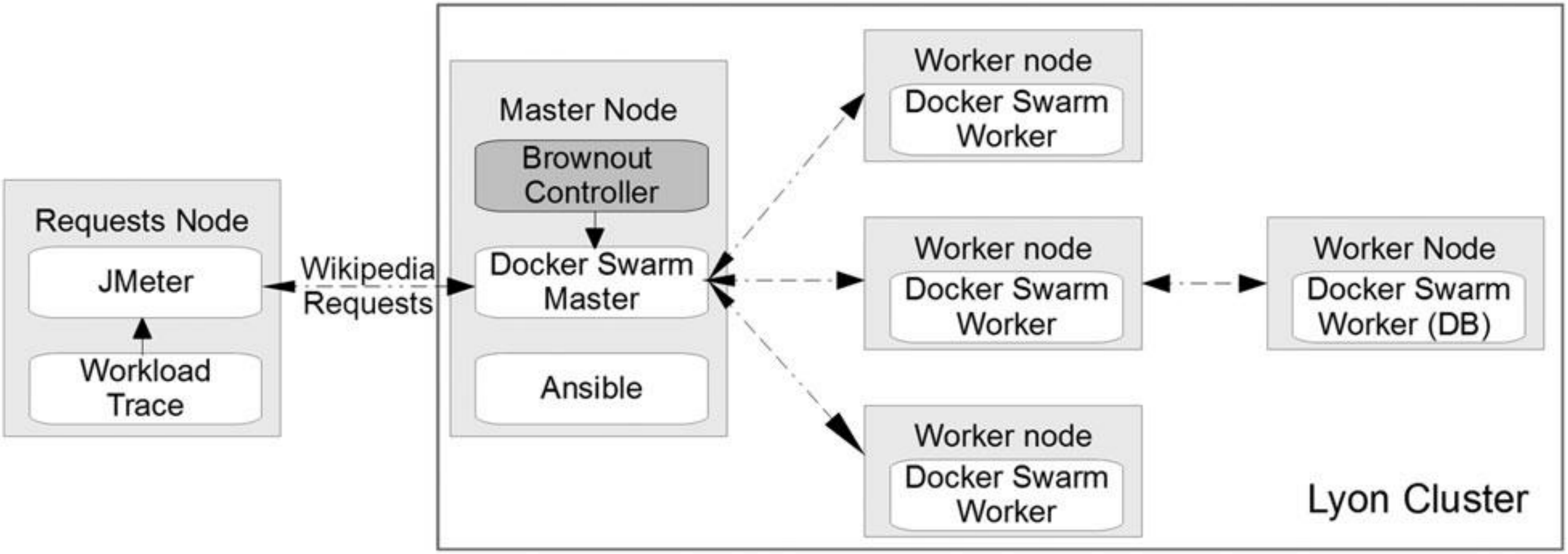
Case Study with RMI: iBrownout



- 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

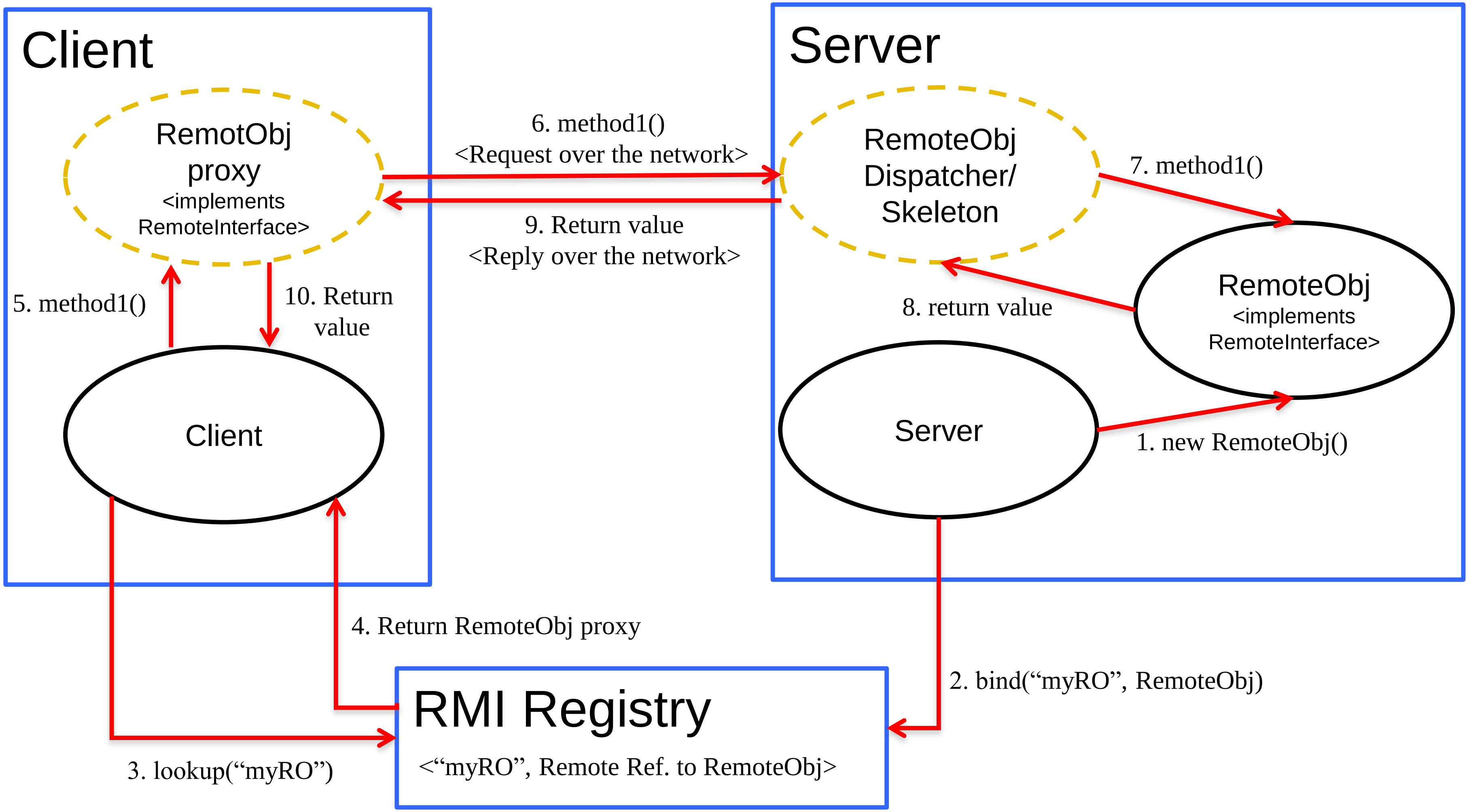
Steps for implementing an RMI application

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

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

```java
// 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?

Differences between RMI and Socket

RMI	Socket
Remote Method Invocation is basically an API which allows an object to invoke a method on an object running in a different machine's JVM.	Sockets are nothing but two-sided communication links between two programs (client and server) in a network.
RMI is remote method invocation which means methods are invoked remotely or accessing remote sites in client-server communication.	Sockets are like gateways which provide access points for programs through some specific port numbers.
RMI is built on top of sockets. without sockets, RMI wouldn't exist.	In this, we have to manage which sockets and protocols the application will use. Even though we can format messages travelling between client and server-side.
RMI is object-oriented	Whereas it is not.
RMI handles the formatting of messages between client and server.	Here we specify TCP or UDP type, we have to handle all the formatting of messages travelling between client and server.
RMI is a Java-specific technology.	Socket-based Communication is independent of programming languages.
RMI is for high-level java to java distributed computing.	Sockets are for low-level network communication.

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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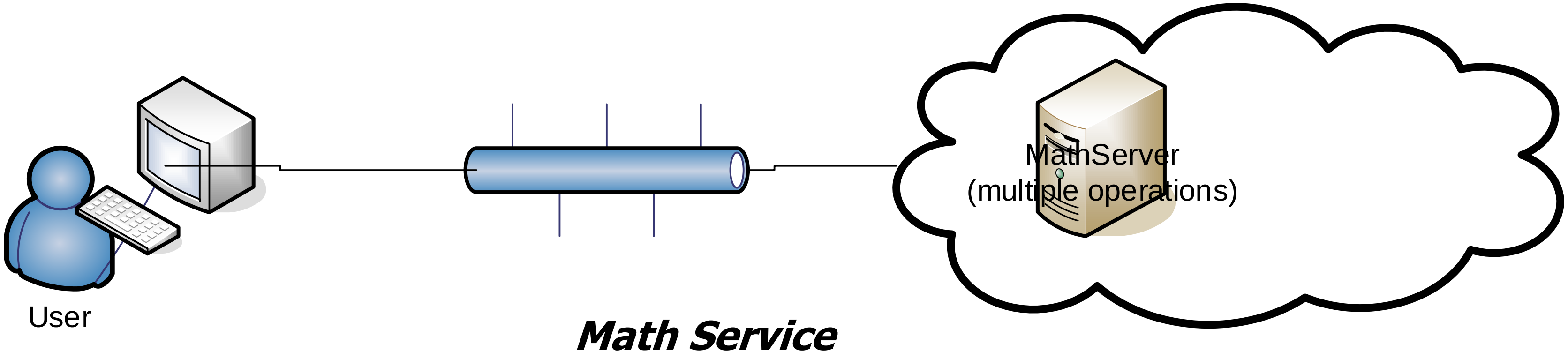
A Simple Math Server in RMI



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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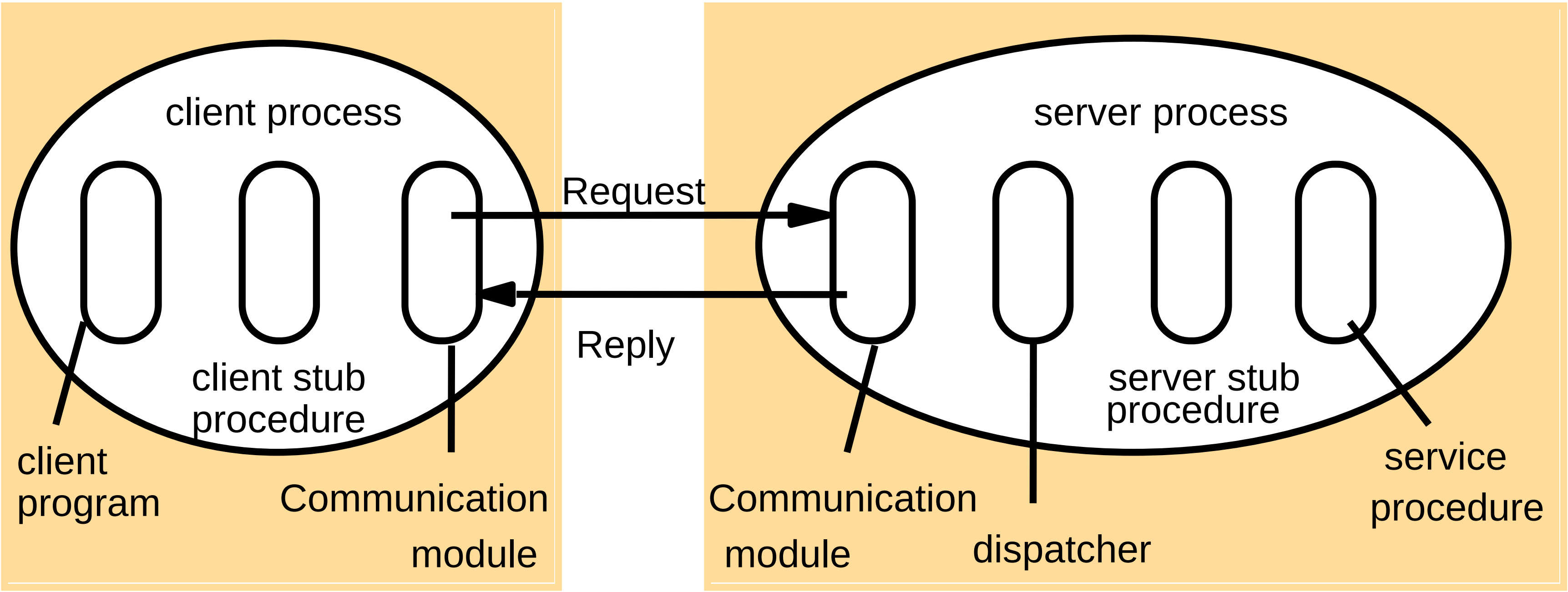
Remote Procedure Call (RPC) – used in C

- 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

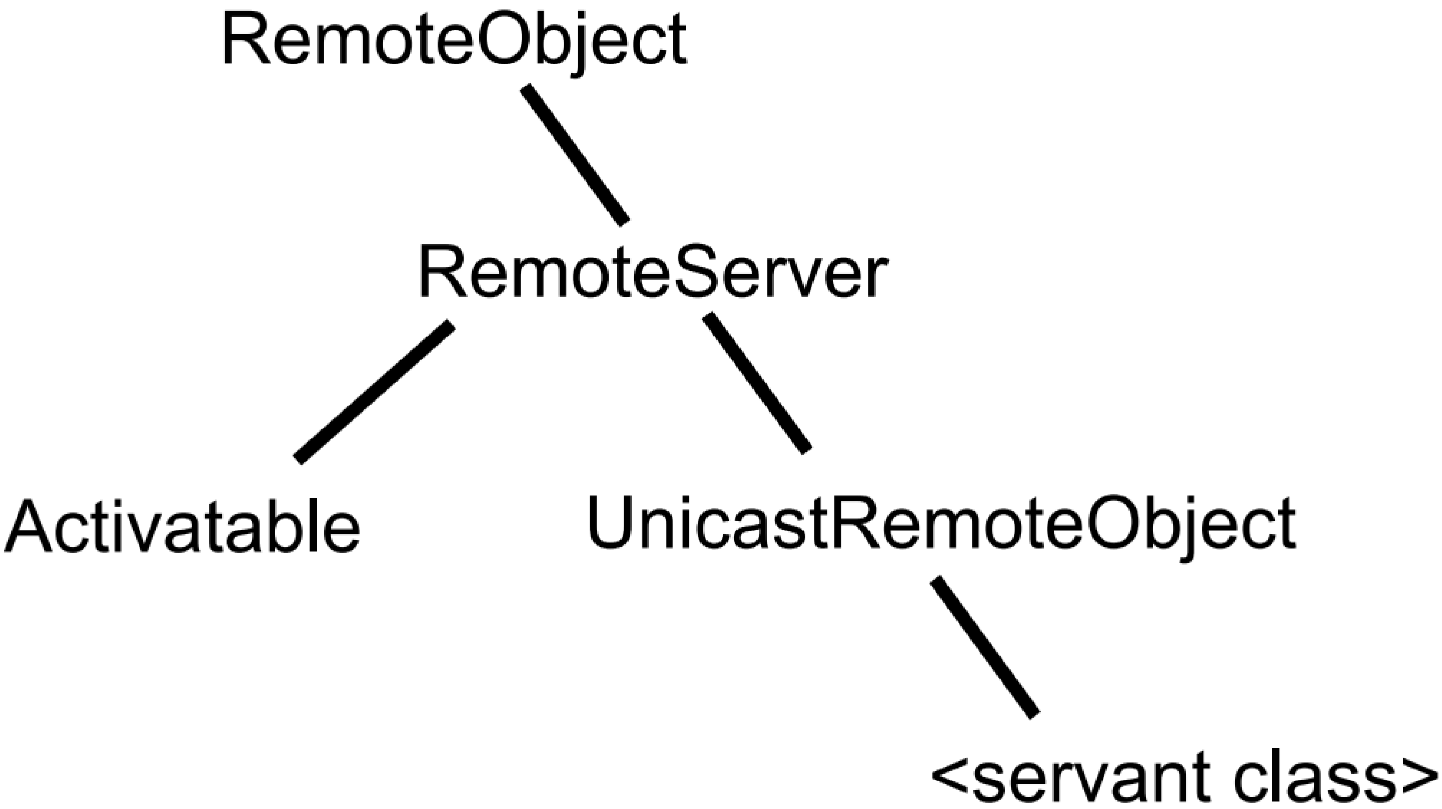
- RMI greatly simplifies creation of distributed applications (e.g., compare RMI code with socket-based apps)
- Server Side
  - Define interface that extend java.rmi.Remote
  - Servant class both implements the interface and extends java.rmi.server.UnicastRemoteObject
  - Register the remote object into 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



RemoteObject

RemoteServer

Activatable

UnicastRemoteObject

<servant class>

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.