ASSIGNMENT NO. 3

Problem Statement :

Develop a distributed system, to find sum of N elements in an array by distributing N/n elements to n number of processors MPI or OpenMP. Demonstrate by displaying the intermediate sums calculated at different processors.

Tools/Environment :

Java Programming Environment, JDK1.8 or higher, MPI Library (mpi.jar), MPJ Express (mpj.jar)

Theory:

Message passing is a popularly renowned mechanism to implement parallelism in applications; it is also called MPI. The MPI interface for Java has a technique for identifying the user and helping in lower startup overhead. It also helps in collective communication and could be executed on both **shared memory and distributed systems**. MPJ is a familiar Java API for MPI implementation. mpi Java is the near flexible Java binding for MPJ standards. Currently developers can produce more efficient and effective parallel applications using message passing.

A basic prerequisite for message passing is a good communication API. Java comes with various ready-made packages for communication, notably an interface to BSD sockets, and the Remote Method Invocation (RMI) mechanism. The parallel computing world is mainly concerned with
`symmetric' communication, occurring in groups of interacting peers. This symmetric model of communication is captured in the successful Message Passing Interface standard (MPI).

Message-Passing Interface Basics:

Every MPI program must contain the preprocessor directive:

```
#include <mpi.h>
```

The mpi.h file contains the definitions and declarations necessary for compiling an MPI program.

MPI_Init initializes the execution environment for MPI. It is a “share nothing” modality in which the outcome of any one of the concurrent processes can in no way be influenced by the intermediate results of any of the other processes. Command has to be called before any other MPI call is made, and it is an error to call it more than a single time within the program. **MPI_Finalize** cleans up all the extraneous mess that was first put into place by MPI_Init.

The principal weakness of this limited form of processing is that the processes on different nodes run entirely independent of each other. It cannot enable capability or coordinated

computing. **To get the different processes to interact, the concept of communicators is needed.** MPI programs are made up of concurrent processes executing at the same time that in almost all cases are also communicating with each other. To do this, an object called the "communicator" is provided by MPI. Thus the user may specify any number of communicators within an MPI program, each with its own set of processes. "**MPI_COMM_WORLD**" communicator contains all the concurrent processes making up an MPI program.
The size of a communicator is the number of processes that makes up the particular communicator. The following function call provides the value of the number of processes of the specified communicator:
int MPI_Comm_size(MPI_Commcomm, int _size).
The function "MPI_Comm_size" required to return the number of processes; int size. MPI_Comm_size(MPI_COMM_WORLD,&size); This will put the total number of processes in the MPI_COMM_WORLD communicator in the variable size of the process data context. Every process within the communicator has a unique ID referred to as its "rank". MPI system automatically and arbitrarily assigns a unique positive integer value, starting with 0, to all the processes within the communicator. The MPI command to determine the process rank is:
int MPI_Comm_rank (MPI_Commcomm, int _rank).

The sendfunction is used by the source process to define the data and establish the connection of the message. The send construct has the following syntax:

int MPI_Send (void _message, int count, MPI_Datatypedatatype, intdest, int tag, MPI_Commcomm)

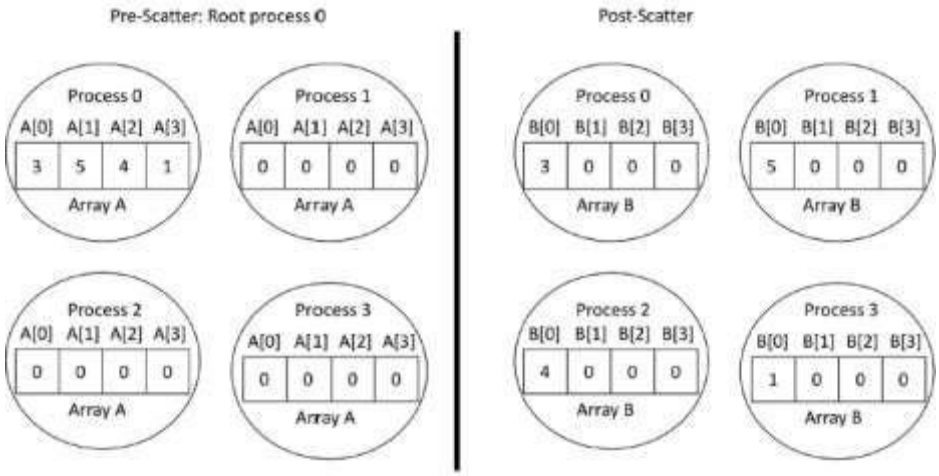
The first three operands establish the data to be transferred between the source and destination processes. The first argument points to the message content itself, which may be a simple scalar or a group of data. The message data content is described by the next two arguments. The second operand specifies the number of data elements of which the message is composed. The third operand indicates the data type of the elements that make up the message.

The receive command (MPI_Recv) describes both the data to be transferred and the connection to be established. The MPI_Recv construct is structured as follows:

int MPI_Recv (void _message, int count, MPI_Datatypedatatype, int source, int tag, MPI_Commcomm, MPI_Status _status)

The source field designates the rank of the process sending the message.

Communication Collectives: Communication collective operations can dramatically expand interprocess communication from point-to-point to n-way or all-way data exchanges.
The scatter operation: The scatter collective communication pattern, like broadcast, shares data of one process (the root) with all the other processes of a communicator. But in this case it partitions a set of data of the root process into subsets and sends one subset to each of the processes. Each receiving process gets a different subset, and there are as many subsets as there are processes. In this example the send array is A and the receive array is B. B is initialized to 0. The root process (process 0 here) partitions the data into subsets of length 1 and sends each subset to a separate process.



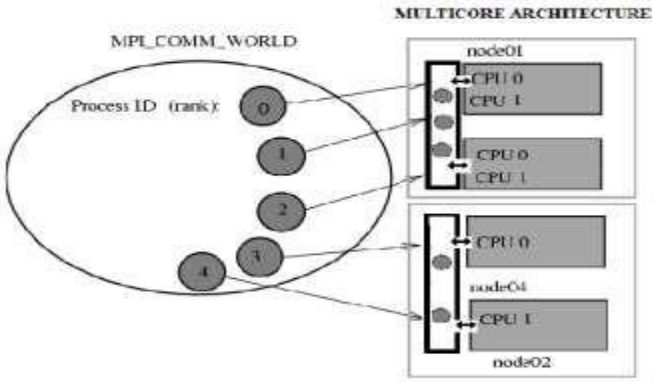
MPJ Express is an open source Java message passing library that allows application developers to write and execute parallel applications **for multicore processors and compute clusters / clouds.** The software is distributed under the MIT (a variant of the LGPL) license. MPJ Express is a message passing library that can be used by application developers to execute their parallel Java applications on compute clusters or network of computers.

MPJ Express is essentially a middleware that supports communication between individual processors of clusters. **The programming model followed by MPJ Express is Single Program Multiple Data (SPMD).**

The multicore configuration is meant for users who plan to write and execute parallel Java applications using MPJ Express on their desktops or laptops which contains shared memory and multicore processors. In this configuration, users can write their message passing parallel application using MPJ Express and it will be ported automatically on multicore processors. We except that users can first develop applications on their laptops and desktops using multicore configuration, and then take the same code to distributed memory platforms

Designing the solution:

While designing the solution, we have considered the multi-core architecture as per shown in the diagram below. The communicator has processes as per input by the user. MPI program will execute the sequence as per the supplied processes and the number of processor cores available for the execution.



Implementing the solution:

1. For implementing the MPI program in multi-core environment, we need to install MPJ express library.
    a. Download MPJ Express (mpj.jar) and unpack it.
    b. Set MPJ_HOME and PATH environment variables:
    c. export MPJ_HOME=/path/to/mpj/
    d. export PATH=$MPJ_HOME/bin:$PATH
2. Write Sum parallel Java program and save it as Sum.java
3. Compile a simple Sum parallel Java program
4. Running MPJ Express in the Multi-core Configuration.

Conclusion:

There has been a large amount of interest in parallel programming using Java. mpj is an MPI binding with Java along with the support for multicore architecture so that user can develop the code on its own laptop or desktop. This is an effort to develop and run parallel programs according to MPI standard.

ASSIGNMENT NO. 7

Problem Statement:
To create a simple web service and write any distributed application to consume the web service.

Tools / Environment:
Java Programming Environment, JDK 8, Netbeans IDE with GlassFish Server

Related Theory:

Web Service:
A web service can be defined as a collection of open protocols and standards for exchanging information among systems or applications.
A service can be treated as a web service if:

- The service is discoverable through a simple lookup
- It uses a standard XML format for messaging
- It is available across internet/intranet networks.
- It is a self-describing service through a simple XML syntax
- The service is open to, and not tied to, any operating system/programming language

Types of Web Services:
There are two types of web services:
1. SOAP: SOAP stands for Simple Object Access Protocol. SOAP is an XML based industry standard protocol for designing and developing web services. Since it's XML based, it's platform and language independent. So, our server can be based on JAVA and client can be on .NET, PHP etc. and vice versa.

2. REST: REST (Representational State Transfer) is an architectural style for developing web services. It's getting popularity recently because it has small learning curve when compared to SOAP. Resources are core concepts of Restful web services and they are uniquely identified by their URIs.Web service architectures:

As part of a web service architecture, there exist three major roles.
Service Provider is the program that implements the service agreed for the web service and exposes the service over the internet/intranet for other applications to interact with.
Service Requestor is the program that interacts with the web service exposed by the Service Provider. It makes an invocation to the web service over the network to the Service Provider and exchanges information.

Service Registry acts as the directory to store references to the web services.
The following are the steps involved in a basic SOAP web service operational behavior:

1. The client program that wants to interact with another application prepares its request content as a SOAP message.
2. Then, the client program sends this SOAP message to the server web service as an HTTP POST request with the content passed as the body of the request.
3. The web service plays a crucial role in this step by understanding the SOAP request and converting it into a set of instructions that the server program can understand.
4. The server program processes the request content as programmed and prepares the output as the response to the SOAP request.
5. Then, the web service takes this response content as a SOAP message and reverts to the SOAP

HTTP request invoked by the client program with this response.

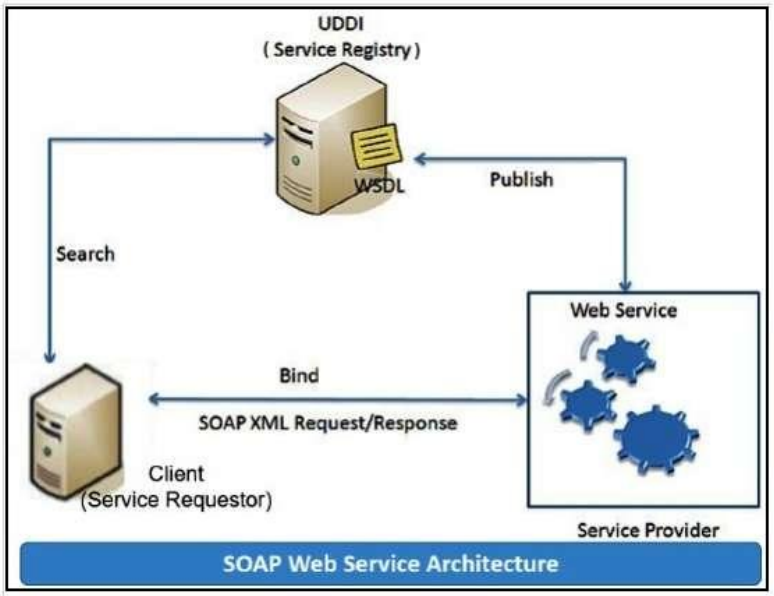
6. The client program web service reads the SOAP response message to receive the outcome of the server program for the request content it sent as a request.

SOAP web services:

Simple Object Access Protocol (SOAP) is an XML-based protocol for accessing web services. It is a W3C recommendation for communication between two applications, and it is a platform- and language-independent technology in integrated distributed applications.While XML and HTTP together make the basic platform for web services, the following are the key components of standard SOAP web services:

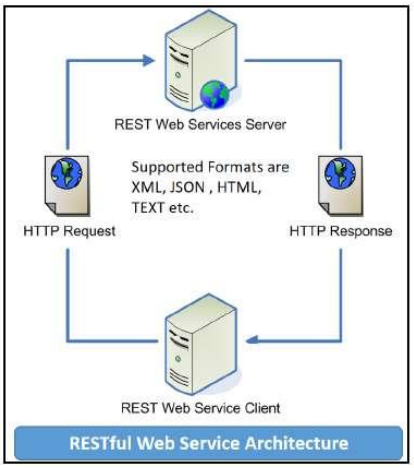
Universal Description, Discovery, and Integration (UDDI): UDDI is an XML based framework for describing, discovering, and integrating web services. It acts as a directory of web service interfaces described in the WSDL language.

Web Services Description Language (WSDL): WSDL is an XML document containing information about web services, such as the method name, method parameters, and how to invoke the service. WSDL is part of the UDDI registry. It acts as an interface between applications that want to interact based on web services. The following diagram shows the interaction between the UDDI, Service Provider, and service consumer in SOAP web services:



RESTful web services

REST stands for Representational State Transfer. RESTful web services are considered a performance-efficient alternative to the SOAP web services. REST is an architectural style, not a protocol. Refer to the following diagram



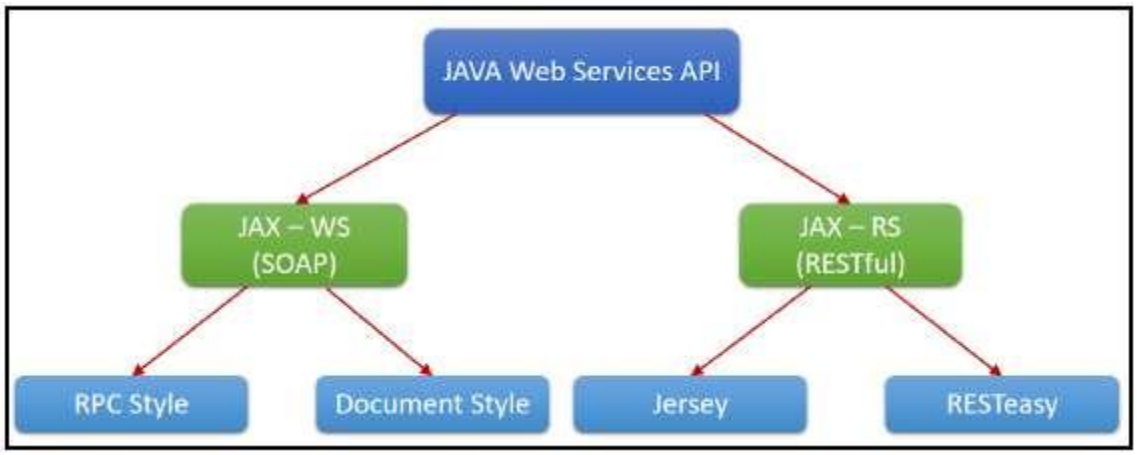
While both SOAP and RESTful support efficient web service development, the difference between these two technologies can be checked out in the following table :

SOAP	REST
SOAP is a protocol.	REST is an architectural style.
SOAP stands for Simple Object Access Protocol.	REST stands for REpresentational State Transfer.
SOAP can't use REST because it is a protocol.	REST can use SOAP web services because it is a concept and can use any protocol like HTTP, SOAP.
SOAP uses services interfaces to expose the business logic.	REST uses URI to expose business logic.
JAX-WS is the java API for SOAP web services.	JAX-RS is the java API for RESTful web services.
SOAP defines standards to be strictly followed.	REST does not define too much standards like SOAP.
SOAP requires more bandwidth and resource than REST.	REST requires less bandwidth and resource than SOAP.
SOAP defines its own security.	RESTful web services inherits security measures from the underlying transport.
SOAP permits XML data format only.	REST permits different data format such as Plain text, HTML, XML, JSON etc.
SOAP is less preferred than REST.	REST more preferred than SOAP.

1. JAX-WS: JAX-WS stands for Java API for XML Web Services. JAX-WS is XML based Java API to build web services server and client application.

2. JAX-RS: Java API for RESTful Web Services (JAX-RS) is the Java API for creating REST web services. JAX-RS uses annotations to simplify the development and deployment of web services.

Both of these APIs are part of standard JDK installation, so we don’t need to add any jars to work with them.



Students are required to implement both i.e. using SOAP and RESTful APIs.

Implementing the solution:

1. Creating a web service CalculatorWSApplication:

- Create New Project for CalculatorWSApplication.
- Create a package org.calculator
- Create class CalculatorWS.
- Right-click on the CalculatorWS and create New Web Service.
- IDE starts the glassfish server, builds the application and deploys the application on server.

2. Consuming the Webservice:

- Create a project with an CalculatorClient
- Create package org.calculator.client;
  add java class CalculatorWS.java, addresponse.java, add.java,
- CalculatorWSService.java and ObjectFactory.java

3. Creating servlet in web application

- Create a new JSP page for user interface.Write the code.
- Compiling and Executing the solution:
- Right Click on the Project and Choose Run.

Conclusion :

This assignment, described the Web services approach to the Service Oriented Architecture concept. Also, described the Java APIs for programming Web services and demonstrated examples of their use by providing detailed step-by-step examples of how to program Web services in Java.

ASSIGNMENT NO. 6

Problem Statement :

Implement Bully and Ring algorithm for leader election.

Tools/Environment :

Java Programming Environment, JDK 1.8, Eclipse Neon(EE).

Theory :

Election Algorithm:

1. Many distributed algorithms require a process to act as a coordinator.

2. The coordinator can be any process that organizes actions of other processes.
3. A coordinator may fail.

4. How is a new coordinator chosen or elected?

Assumptions:

Each process has a unique number to distinguish them. Processes know each other's process numbers.

There are two types of Distributed Algorithms:

1. Bully Algorithm

2. Ring Algorithm

Bully Algorithm:

A . When a process, P, notices that the coordinator is no longer responding to requests, it initiates an election.

1. P sends an ELECTION message to all processes with higher numbers.

2. If no one responds, P wins the election and becomes a coordinator.

3. If one of the higher-ups answers, it takes over. P's job is done.

B. When a process gets an ELECTION message from one of its lower-numbered colleagues:

1. Receiver sends an OK message back to the sender to indicate that he is alive and will take over.

2. Eventually, all processes give up a part of one, and that one is the new coordinator.

3. The new coordinator announces its victory by sending all processes a CO-ORDINATOR message telling them that it is the new coordinator.

C . If a process that previously down came back:

1. It holds an election.

2. If it happens to be the highest process currently running, it will win the election and take over the coordinator's job.

"Biggest guy" always wins and hence the name bully algorithm.

Ring Algorithm:

Initiation:

1. When a process notices that the coordinator is not functioning:

2. Another process (initiator) initiates the election by sending an "ELECTION" message (containing its process number) Leader Election:

3. Initiator sends the message to its successor (if successor is down, sender skips over it and goes to the next member along the ring, or the one after that, until a running process is located).

4. At each step, the sender adds its own process number to the list in the message.

5. When the message gets back to the process that started it all: The message comes back to the initiator. In the queue, the process with the maximum ID Number wins. Initiator announces the winner by sending another message around the ring.

Designing the solution:

A . For Ring Algorithm

Initiation:

1. Consider the Process 4 understands that Process 7 is not responding.

2.Process 4 initiates the Election by sending an "ELECTION" message to its

successor (or next alive process) with its ID. Leader Election:

3.Messages come back to the initiator. Here the initiator is 4.

4. Initiator announces the winner by sending another message around the ring. Here the process with the highest process ID is 6. The initiator will announce that Process 6 is Coordinator.

B. For Bully Algorithm:

1. Creating Class for Process which includes
    i) State: Active / Inactive
    ii) Index: Stores index of process.
    iii) ID: Process ID
2. Import Scanner Class for getting input from Console
3. Getting input from the User for several Processes and store them into an object of classes.
4. Sort these objects based on process id.
5. Make the last process id as "inactive".
6. Ask for menu 1.Election 2.Exit
7. Ask for initializing the election process.
8. These inputs will be used by Ring Algorithm.

Compiling and Executing the solution:

1. Create Java Project in Eclipse
2. Create Package
3. Add a class in the package Ring.java.
4. Compile and Execute in Eclipse.

Conclusion:

Election algorithms are designed to choose a coordinator. We have two election algorithms for two different configurations of the distributed systems. The Bully algorithm applies to the system where every process can send a message to every other process in the system and The Ring algorithm applies to systems organized as a ring (logically or physically). In this algorithm, we assume that the link between the process is unidirectional and every process can message to the process on its right only.

ASSIGNMENT NO. 4

Problem Statement :

Implement Berkeley algorithm for clock synchronization.

Tools/Environment :

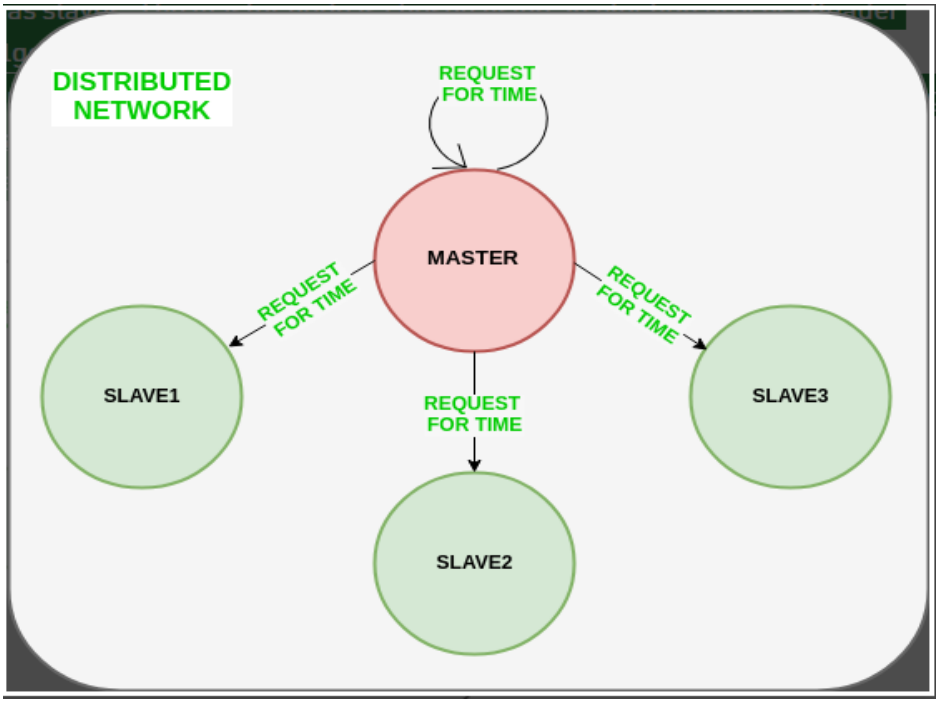
Ubuntu , Turbo C++

Theory :

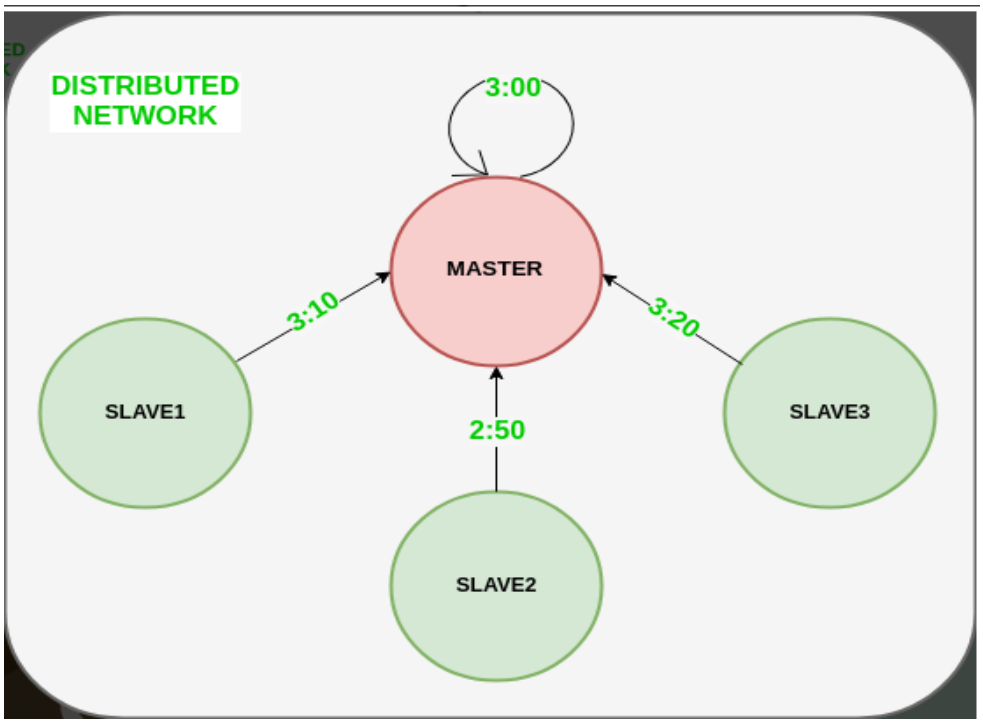
Berkeley's Algorithm is a clock synchronization technique used in distributed systems. The algorithm assumes that each machine node in the network either doesn't have an accurate time source or doesn't possess a UTC server.

Algorithm

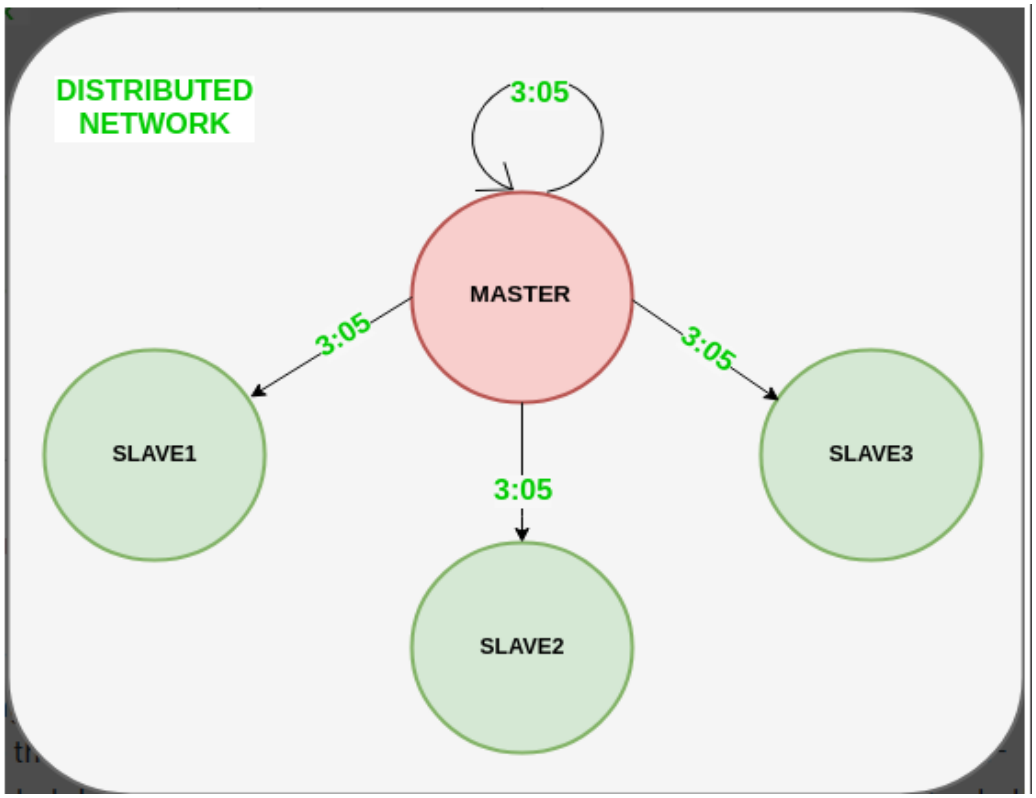
1) An individual node is chosen as the master node from a pool node in the network. This node is the main node in the network which acts as a master and the rest of the nodes act as slaves. The master node is chosen using an election process/leader election algorithm.
2) Master node periodically pings slaves nodes and fetches clock time at them using Cristian's algorithm.
The diagram below illustrates how the master sends requests to slave nodes.



The diagram below illustrates how slave nodes send back time given by their system clock.



3) Master node calculates the average time difference between all the clock times received and the clock time given by the master's system clock itself. This average time difference is added to the current time at the master's system clock and broadcasted over the network.



Features of Berkeley's Algorithm:

- **Centralized time coordinator:** Berkeley's Algorithm uses a centralized time coordinator, which is responsible for maintaining the global time and distributing it to all the client machines.
- **Clock adjustment:** The algorithm adjusts the clock of each client machine based on the difference between its local time and the time received from the time coordinator.
- **Average calculation:** The algorithm calculates the average time difference between the client machines and the time coordinator to reduce the effect of any clock drift.
- **Fault tolerance:** Berkeley's Algorithm is fault-tolerant, as it can handle failures in the network or the time coordinator by using backup time coordinators.
- **Accuracy: T**he algorithm provides accurate time synchronization across all the client machines, reducing the chances of errors due to time discrepancies.
- **Scalability:** The algorithm is scalable, as it can handle a large number of client machines, and the time coordinator can be easily replicated to provide high availability.
- **Security:** Berkeley's Algorithm provides security mechanisms such as authentication and encryption to protect the time information from unauthorized access or tampering.

Execution Steps:

Compile

Just make under dir "p1_berkeley_server_clients".

Server side

Run ./server under dir "p1_berkeley_server_clients".
In server.cpp I firstly setup normal socket and keep it listening.

Then there is a while loop which waiting for clients connections. When you open a new terminal window and run ./client it will catch connections from clients. At the bottom part of this while loop it asks you where you have enough clients, if yes this while loop will stop. Clients connection information will be stored into vectors client_sockets, client_ips and client_ports.
After confriming all clients have connected, then is the communication between serer and clients. The sever will send message to client asking for their lock clock value and sttore them into a vector clients_local_clocks. A for loop is used to iterate all client connections.
Then the server calculate the average value of all clock values, including itself, and how to adjust for each node. Then a for loop is used to send this adjustment offset to each client accordingly.

Then the server adjust itself's clock.

Client sides

Each time you run ./client under dir "p1_berkeley_server_clients" in a new opened terminal window, it creates a new client process.
In client.cpp it first connect to server whose ip and port is hard-coded. Then waiting for server's message.

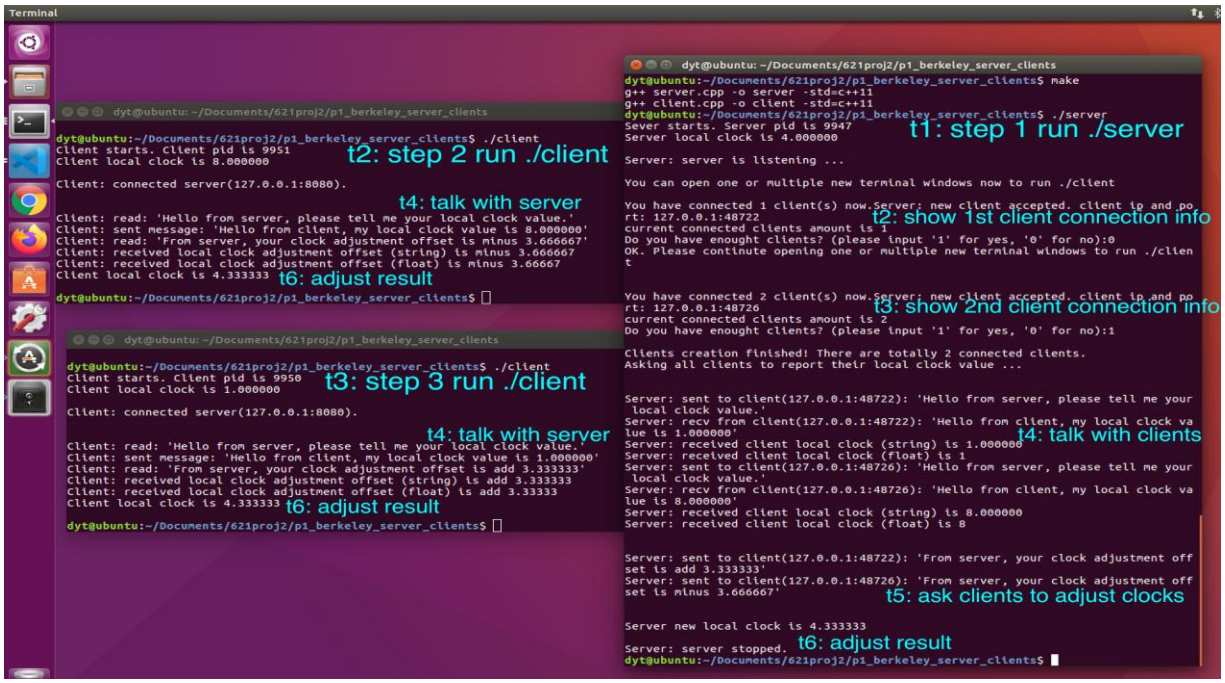
The first message it receives from server would be asking for its local clock value and the client will reply it. Then wait for new message from server.

The second message it receives from server would be how to asjust its clock and the client will do it. Then the client would have correct clock now.

At this moment, the server and all clients have clock synchronization.

The below screenshot shows how I ran it with 2 clients:

1. Run ./server in one terminal first.
2. Then run ./client in multiple ternimals.



Conclusion:

Thus we have studied Berkley's Algorithm.

ASSIGNMENT NO. 5

Problem Statement :

Implement token ring based mutual exclusion algorithm.

Tools/Environment :

Ubuntu , JDK

Theory :

Mutual exclusion is a concurrency control property which is introduced to prevent race conditions. It is the requirement that a process cannot enter its critical section while another concurrent process is currently present or executing in its critical section i.e only one process is allowed to execute the critical section at any given instance of time.

In Distributed systems, we neither have shared memory nor a common physical clock and there for we cannot solve mutual exclusion problem using shared variables. To eliminate the mutual exclusion problem in distributed system approach based on message passing is used.

Requirements of Mutual exclusion Algorithm:

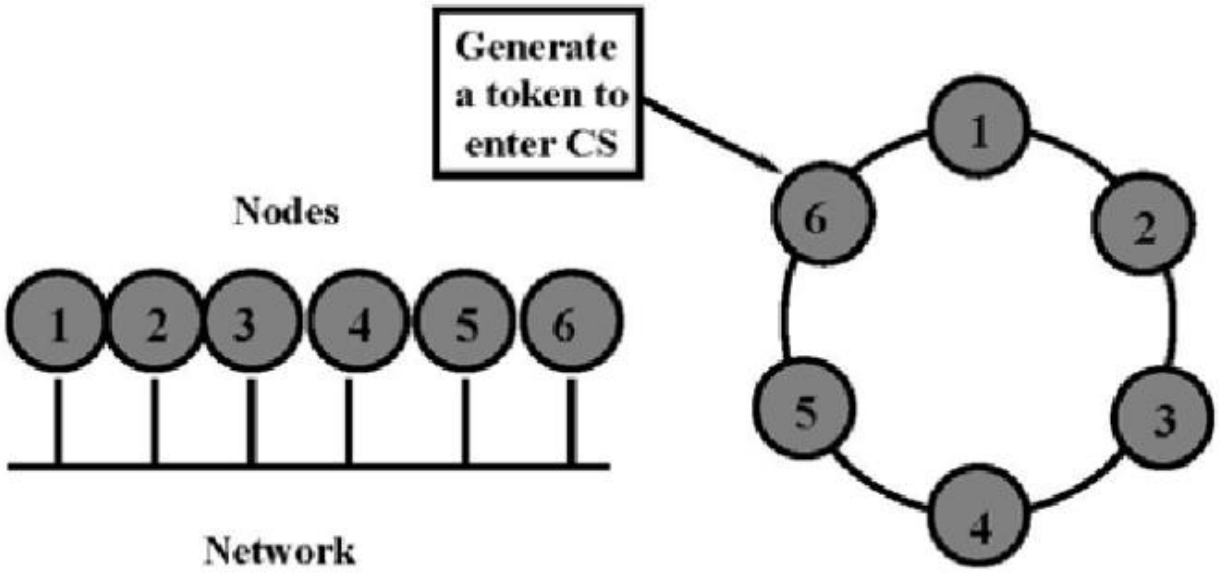
- **No Deadlock:**
  Two or more site should not endlessly wait for any message that will never arrive.
- **No Starvation:**
  Every site who wants to execute critical section should get an opportunity to execute it in finite time. Any site should not wait indefinitely to execute critical section while other site are repeatedly executing critical section
- **Fairness:**
  Each site should get a fair chance to execute critical section. Any request to execute critical section must be executed in the order they are made i.e Critical section execution requests should be executed in the order of their arrival in the system.
- **Fault Tolerance:**
  In case of failure, it should be able to recognize it by itself in order to continue functioning without any disruption.

Token Based Algorithm:

Token Ring algorithm achieves mutual exclusion in a distributed system by creating a bus network of processes. A logical ring is constructed with these processes and each process is assigned a position in the ring. Each process knows who is next in line after itself.

Algorithm :

- In this algorithm it is assumed that all the processes in the system are organized in a logical ring. The figure blow describes the structure.
- The ring positions may be allocated in numerical order of network addresses and is unidirectional in the sense that all messages are passed only in clockwise or anti-clockwise direction.
- When a process sends a request message to current coordinator and does not receive a reply within a fixed timeout, it assumes the coordinator has crashed. It then initializes the ring and process Pi is given a token.
- The token circulates around the ring. It is passed from process k to k+1 in point to point messages. When a process acquires the token from its neighbor it checks to see if it is attempting to enter a critical region. If so the process enters the region does all the execution and leaves the region. After it has exited it passes the token along the ring. It is not permitted to enter a second critical region using the same token.
- If a process is handed the token by its neighbor and is not interested in entering a critical region it just passes along. When no processes want to enter any critical regions the token just circulates at high speed around the ring.
- Only one process has the token at any instant so only one process can actually be in a critical region. Since the token circulates among the process in a well-defined order, starvation cannot occur.
- Once a process decides it wants to enter a critical region, at worst it will have to wait for every other process to enter and leave one critical region.
- The disadvantage is that if the token is lost it must be regenerated. But the detection of lost token is difficult. If the token is not received for a long time it might not be lost but is in use.



Conclusion:

Thus we have studied token ring based mutual exclusion algorithm.

Assignment No :1

Problem Statement :

Implement multi-threaded client/server Process communication using RMI.

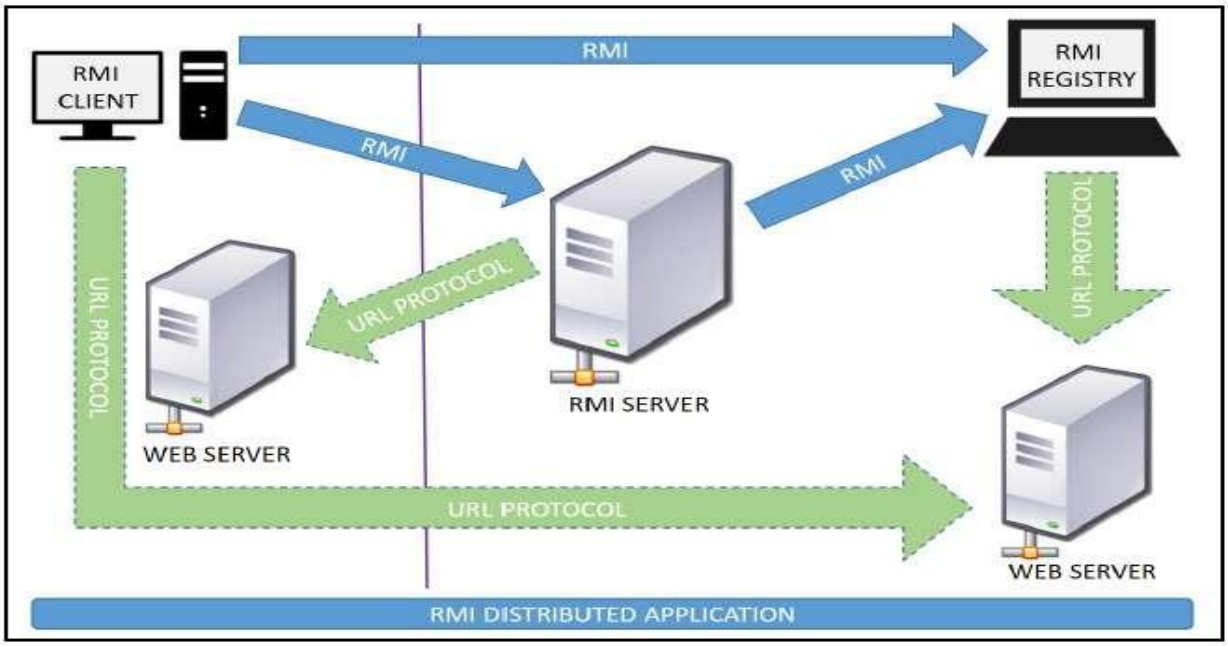
Tools/ Environment :

Java Programming Environment, jdk 1.8, rmiregistry

Theory :

RMI provides communication between java applications that are deployed on different servers and connected remotely using objects called **stub** and **skeleton**. This communication architecture makes a distributed application seem like a group of objects communicating across a remote connection. These objects are encapsulated by exposing an interface, which helps access the private state and behavior of an object through its methods.

The following diagram shows how RMI happens between the RMI client and RMI server with the help of the RMI registry:



RMI REGISTRY is a remote object registry, a Bootstrap naming service, that is used by

RMI SERVER on the same host to bind remote objects to names. Clients on local and remote hosts then look up the remote objects and make remote method invocations.

Key terminologies of RMI:

Remote object: This is an object in a specific JVM whose methods are exposed so they could be invoked by another program deployed on a different JVM.

Remote interface: This is a Java interface that defines the methods that exist in a remote

object. A remote object can implement more than one remote interface to adopt multiple remote interface behaviors.

RMI: This is a way of invoking a remote object's methods with the help of a remote interface. It can be carried with a syntax that is similar to the local method invocation.

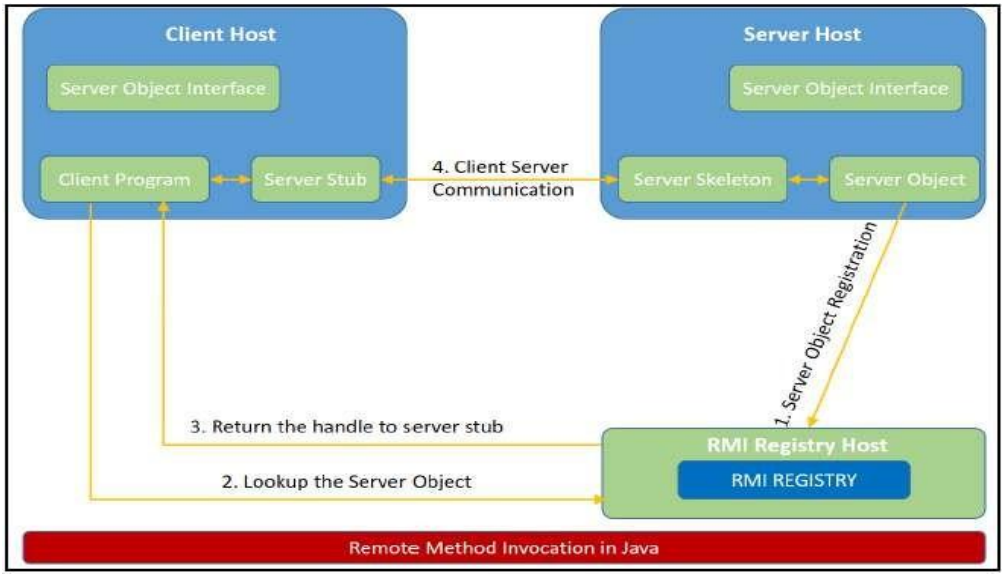
Stub: This is a Java object that acts as an entry point for the client object to route any outgoing requests. It exists on the client JVM and represents the handle to the remote object.
If any object invokes a method on the stub object, the stub establishes RMI by following these steps:

1. It initiates a connection to the remote machine JVM.
2. It marshals (write and transmit) the parameters passed to it via the remote JVM.
3. It waits for a response from the remote object and unmarshals (read) the returned value or exception, then it responds to the caller with that value or exception.

Skeleton: This is an object that behaves like a gateway on the server side. It acts as a remote object with which the client objects interact through the stub. This means that any requests coming from the remote client are routed through it. If the skeleton receives a request, it establishes RMI through these steps:

1. It reads the parameter sent to the remote method.
2. It invokes the actual remote object method.
3. It marshals (writes and transmits) the result back to the caller(stub).

The following diagram demonstrates RMI communication with stub and skeleton involved:



Designing The Solution :

The essential steps that need to be followed to develop a distributed application with RMI are as follows:

1. Design and implement a component that should not only be involved in the distributed application, but also the local components.
2. Ensure that the components that participate in the RMI calls are accessible across networks.
3. Establish a network connection between applications that need to interact using the RMI.

1. Remote interface definition: The purpose of defining a remote interface is to declare the methods that should be available for invocation by a remote client.
Programming the interface instead of programming the component implementation is an essential design principle adopted by all modern Java frameworks, including Spring. In the same pattern, the definition of a remote interface takes importance in RMI design as well.

2. **Remote object implementation**: Java allows a class to implement more than one interface at a time. This helps remote objects implement one or more remote interfaces. The remote object class may have to implement other local interfaces and methods that it is responsible for. Avoid adding complexity to this scenario, in terms of how the arguments or return parameter values of such component methods should be written.

3. **Remote client implementation**: Client objects that interact with remote server objects can be written once the remote interfaces are carefully defined even after the remote objects are deployed.

Let's design a project that can sit on a server. After that different client projects interact with this project to pass the parameters and get the computation on the remote object execute and return the result to the client components.

Implementing The Solution :

Consider building an application to perform diverse mathematical operations.

The server receives a request from a client, processes it, and returns a result. In this example, the request specifies two numbers. The server adds these together and returns the sum.

1. **Creating remote interface, implement remote interface, server-side and client-side program and Compile thecode.**

This application uses four source files. The first file, **AddServerIntf.java**, defines the remote interface that is provided by the server. It contains one method that accepts two **double** arguments and returns their sum. All remote interfaces must extend the **Remote**interface, which is part of **java.rmi**. **Remote** defines no members. Its purpose is simply to indicate that an interface uses remote methods. All remote methods can throw a **RemoteException**.

The second source file, **AddServerImpl.java**, implements the remote interface. The implementation of the **add()** method is straightforward. All remote objects must extend **UnicastRemoteObject**, which provides functionality that is needed to make objects available from remote machines.

The third source file, **AddServer.java**, contains the main program for the server machine. Its primary function is **to update the RMI registry on that machine**. This is done by using the **rebind()**method of the **Naming**class (found in **java.rmi**). That method associates a name with an object reference. The first argument to the **rebind()** method is a string that names the server as "AddServer". Its second argument is a reference to an instance of **AddServerImpl**.

The fourth source file, **AddClient.java**, implements the client side of this distributed

application. **AddClient.java** requires three command-line arguments. The first is the IP address or name of the server machine. The second and third arguments are the two numbers that are to be summed.

The application begins by forming a string that follows the URL syntax. This URL uses the **rmi**protocol. The string includes the IP address or name of the server and the string "AddServer". The program then invokes the **lookup( )** method of the **Naming** class. This method accepts one argument, the **rmi**URL, and returns a reference to an object of type **AddServerIntf**. All remote method invocations can then be directed to this object.
The program continues by displaying its arguments and then invokes the remote **add()**method. The sum is returned from this method and is then printed.
Use **javac**to compile the four source files that are created.

2. Generate aStub

Before using client and server, the necessary stub must be generated. In the context of RMI,a *stub*isaJavaobjectthatresidesontheclientmachine.Itsfunctionistopresentthesame

interfaces as the remote server. Remote method calls initiated by the client are actually directed to the stub. The stub works with the other parts of the RMI system to formulate a request that is sent to the remote machine.

All of this information must be sent to the remote machine. That is, an object passed as an argument to a remote method call must be serialized and sent to the remote machine. If a response must be returned to the client, the process works in reverse. **The serialization and deserialization facilities are also used if objects are returned to a client.**
To generate a stub the command is RMIcompiler is invoked as follows:

rmicAddServerImpl.

This command generates the file **AddServerImpl_Stub.class**.

3. Install Files on the Client and ServerMachines

Copy **AddClient.class**, **AddServerImpl_Stub.class**, **AddServerIntf.class** to a directory on the client machine.
Copy **AddServerIntf.class**, **AddServerImpl.class**, **AddServerImpl_ Stub.class**, and **AddServer.class**to a directory on the server machine.

4. Start the RMI Registry on the ServerMachine

Java provides a program called **rmiregistry**,which executes on the server machine. It maps names to object references. Start the RMI Registry from the command line, as shown here:

startrmiregistry

5. Start theServer

The server code is started from the command line, as shown here:
javaAddServer

The **AddServer**code instantiates **AddServerImpl**and registers that object with the name "AddServer".

6. Start theClient

The **AddClient**software requires three arguments: the name or IP address of the server machine and the two numbers that are to be summed together. You may invoke it from the command line by using one of the two formats shown here:

javaAddClient 192.168.13.14 7 8

Conclusion :

Remote Method Invocation (RMI) allows you to build Java applications that are distributed among several machines. Remote Method Invocation (RMI) allows a Java object that executes on one machine to invoke a method of a Java object that executes on another machine. This is an important feature, because it allows you to build distributed applications.

Assignment No :2

Problem Statement :

Develop any distributed application using CORBA to demonstrate object brokering. (Calculator or String operations).

Tools/ Environment :

Java Programming Environment, JDK 1.8

Theory :

Common Object Request Broker Architecture(CORBA):

CORBA is an acronym for Common Object Request Broker Architecture. It is an open source, vendor-independent architecture and infrastructure developed by the **Object Management Group** (**OMG**) to integrate enterprise applications across a distributed network. CORBA specifications provide guidelines for such integration applications, based on the way they want to interact, irrespective of the technology; hence, all kinds of technologies can implement these standards using their own technical implementations.

When two applications/systems in a distributed environment interact with each other, there are quite a few unknowns between those applications/systems, including the technology they are developed in (such as Java/ PHP/ .NET), the base operating system they are running on (such as Windows/Linux), or system configuration (such as memory allocation). **They communicate mostly with the help of each other's network address or through a naming service.** Due to this, these applications end up with quite a few issues in integration, including content (message) mapping mismatches.

An application developed based on CORBA standards with standard **Internet Inter-ORB Protocol** (**IIOP**), irrespective of the vendor that develops it, should be able to smoothly integrate and operate with another application developed based on CORBA standards through the same or different vendor.

Except legacy applications, most of the applications follow common standards when it comes to object modeling, for example. All applications related to, say, "HR&Benefits" maintain an object model with details of the organization, employees with demographic information, benefits, payroll, and deductions. They are only different in the way they handle the details, based on the country and region they are operating for. For each object type, similar to the HR&Benefits systems, we can define an interface using the **Interface Definition Language** (**OMG IDL**).

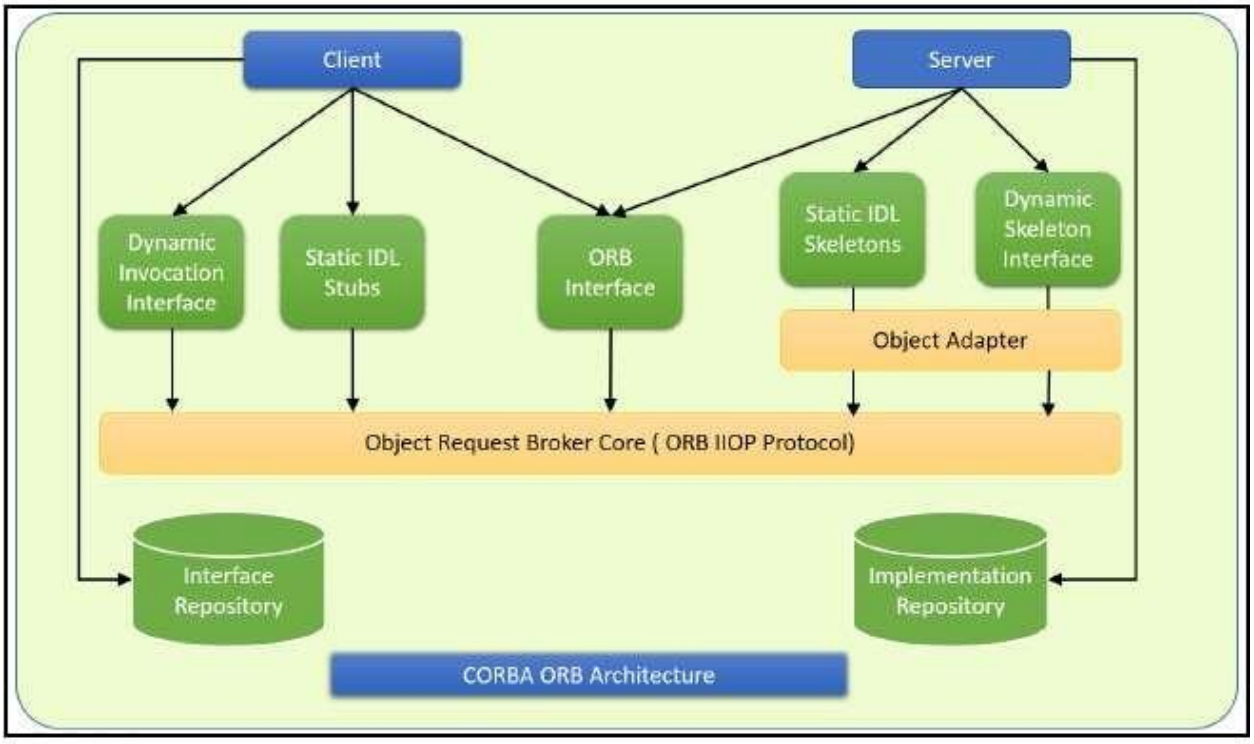
The contract between these applications is defined in terms of an interface for the server objects that the clients can call. This IDL interface is used by each client to indicate when they should call any particular method to marshal (read and send the arguments).

The target object is going to use the same interface definition when it receives the request from the client to unmarshal (read the arguments) in order to execute the method that was requested by the client operation. Again, during response handling, the interface definition is helpful to marshal (send from the server) and unmarshal (receive and read the response) arguments on the

client side once received.

The IDL interface is a design concept that works with multiple programming languages including C, C++, Java, Ruby, Python, and IDLscript. This is close to writing a program to an interface, a concept we have been discussing that most recent programming languages and frameworks, such as Spring. The interface has to be defined clearly for each object. The systems encapsulate the actual implementation along with their respective data handling and processing, and only the methods are available to the rest of the world through the interface. Hence, the clients are forced to develop their invocation logic for the IDL interface exposed by the application they want to connect to with the method parameters (input and output) advised by the interface operation.

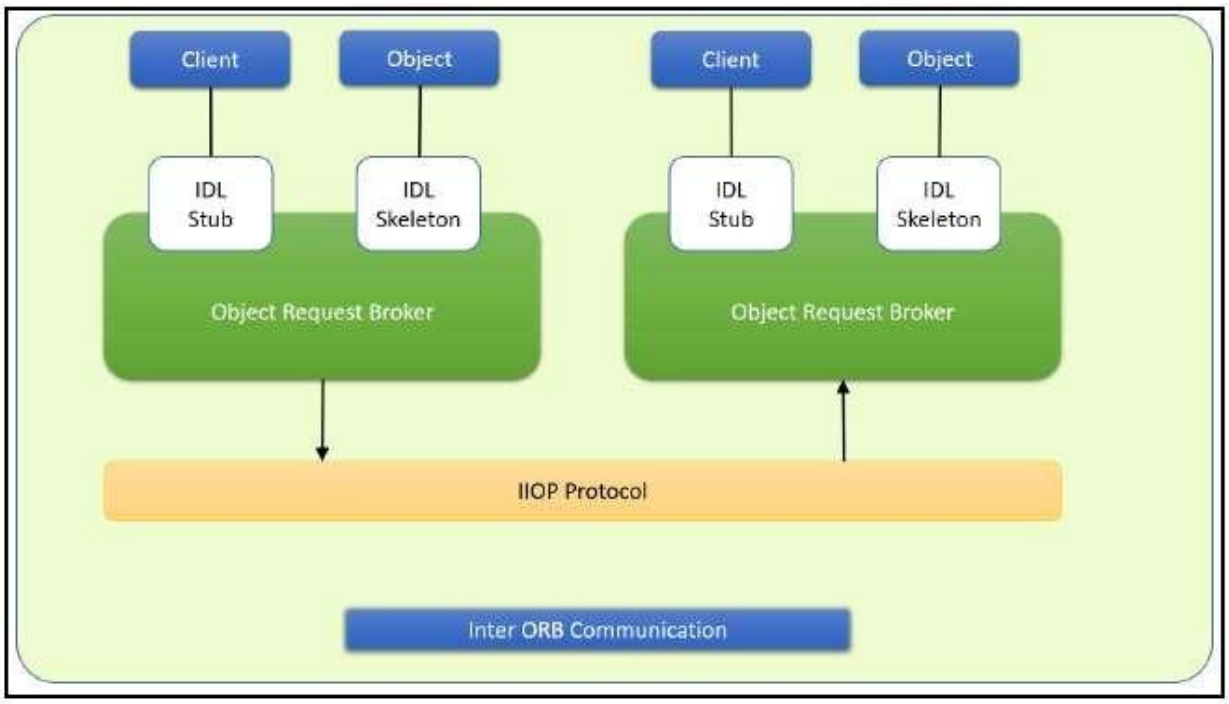
The following diagram shows a single-process ORB CORBA architecture with the IDL configured as client stubs with object skeletons, The objects are written (on the right) and a client for it (on the left), as represented in the diagram. The client and server use stubs and skeletons as proxies, respectively. The IDL interface follows a strict definition, and even though the client and server are implemented in different technologies, they should integrate smoothly with the interface definition strictlyimplemented.



In CORBA, each object instance acquires an object reference for itself with the electronic token identifier. Client invocations are going to use these object references that have the ability to figure out which ORB instance they are supposed to interact with. The stub and skeleton represent the client and server, respectively, to their counterparts. They help establish this communication through ORB and pass the arguments to the right method and its instance during the invocation.

Inter-ORB communication

The following diagram shows how remote invocation works for inter-ORB communication. It shows that the clients that interacted have created **IDL Stub** and **IDL Skeleton** based on **Object Request Broker** and communicated through **IIOP Protocol**.



To invoke the remote object instance, the client can get its object reference using a naming service. Replacing the object reference with the remote object reference, the client can make the invocation of the remote method with the same syntax as the local object method invocation. ORB keeps the responsibility of recognizing the remote object reference based on the client object invocation through a naming service and routes it accordingly.

Java Support for CORBA

CORBA complements the Java™ platform by providing a distributed object framework, services to support that framework, and interoperability with other languages. The Java platform complements CORBA by providing a portable, highly productive implementation environment, and a very robust platform. By combining the Java platform with CORBA and other key enterprise technologies, the Java Platform is the ultimate platform for distributed technology solutions.

CORBA standards provide the proven, interoperable infrastructure to the Java platform. IIOP (Internet Inter-ORB Protocol) manages the communication between the object components that power the system. The Java platform provides a portable object infrastructure that works on every major operating system. CORBA provides the network transparency, Java provides the implementation transparency. **An *Object Request Broker (ORB)* is part of the**

Java Platform. The ORB is a runtime component that can be used for distributed computing using IIOP communication. Java IDL is a Java API for interoperability and integration with CORBA. JavaIDLincludedbothaJava-basedORB,whichsupportedIIOP,andthe**IDL-to-Java compiler**, for generating client-side stubs and server-side code skeletons. J2SE v.1.4 includes an **Object Request Broker Daemon (ORBD), which is used to enable clients to transparently locate and invoke persistent objects on servers in the CORBA environment.**

When using the **IDL programming model,** the interface is everything! It defines the points of entry that can be called from a remote process, such as the types of arguments the called procedure will accept, or the value/output parameter of information returned. Using IDL, the programmer can make the entry points and data types that pass between communicating processes act like a standard language.

CORBA is a language-neutral system in which the argument values or return values are limited to what can be represented in the involved implementation languages. In CORBA, object orientation is limited only to objects that can be passed by reference (the object code itself cannot be passed from machine-to-machine) or are predefined in the overall framework. Passed and returned types must be those declared in theinterface.

With RMI, the interface and the implementation language are described in the same language, so you don't have to worry about mapping from one to the other. Language-level objects (the code itself) can be passed from one process to the next. Values can be returned by their actual type, not the declared type. Or, you can compile the interfaces to generate IIOP stubs and skeletons which allow your objects to be accessible from other CORBA-compliant languages.

The IDL Programming Model:

The IDL programming model, known as Java™ IDL, consists of both the Java CORBA ORB and the idljcompiler that maps the IDL to Java bindings that use the Java CORBA ORB, as well as a set of APIs, which can be explored by selecting the org.omg prefix from the Package section of the APIindex.

Java IDL adds CORBA (Common Object Request Broker Architecture) capability to the Java platform, providing standards-based interoperability and connectivity. Runtime components include a Java ORB for distributed computing using IIOP communication.

To use the IDL programming model, define remote interfaces using OMG Interface Definition Language (IDL), then compile the interfaces using idljcompiler. When you run theidljcompiler over your interface definition file, it generates the Java version of the interface, as well as the class code files for the stubs and skeletons that enable applications to hook into theORB.

Portable Object Adapter (POA) : An *object adapter* is the mechanism that connects a request using an object reference with the proper code to service that request. The Portable Object Adapter, or POA, is a particular type of object adapter that is defined by the CORBA specification. The POA is designed to meet the following goals:

- Allow programmers to construct object implementations that are portable between different ORBproducts.
- Provide support for objects with persistentidentities.

Designing The Solution :

Here the design of how to create a complete CORBA (Common Object Request Broker Architecture) application using IDL (Interface Definition Language) to define interfaces and Java IDL compiler to generate stubs and skeletons. You can also create CORBA application by defining the interfaces in the Java programming language.

The server-side implementation generated by the idljcompiler is the *Portable Servant Inheritance Model*, also known as the POA(Portable Object Adapter) model. This document presents a sample application created using the default behavior of the idljcompiler, which uses a POA server-side model.

1. Creating CORBA Objects using JavaIDL:

In order to distribute a Java object over the network using CORBA, one has to define it's own CORBA-enabled interface and it implementation. This involves doing the following:

- Writing an interface in the CORBA Interface Definition Language
- Generating a Java base interface, plus a Java stub and skeleton class, using an IDL-to-Java compiler
- Writing a server-side implementation of the Java

interface in Java Interfaces in IDL are declared

much like interfaces in Java.

Modules

Modules are declared in IDL using the module keyword, followed by a name for the module and an opening brace that starts the module scope. Everything defined within the scope of this module (interfaces, constants, other modules) falls within the module and is referenced in other IDL modules using the syntax *modulename*::x.e.g.

/
/

I
D
L

m
o
d
u
l
e

j
e
n
{
```
   modulecorba {
      interfaceNeatExample ...
   };
};
```

Interfaces

The declaration of an interface includes an interface header and an interface body. The header specifies the name of the interface and the interfaces it inherits from (if any). Here is an IDL interface header:

interface PrintServer : Server { ...

This header starts the declaration of an interface called *PrintServer* that inherits all the methods and data members from the *Server* interface.

Data members and methods

The interface body declares all the data members (or attributes) and methods of an interface. Data members are declared using the attribute keyword. At a minimum, the declaration includes a name and a type.

read only attribute string myString;

The method can be declared by specifying its name, return type, and parameters, at a minimum.

stringparseString(in string buffer);

This declares a method called *parseString()* that accepts a single string argument and returns a string value.

A complete IDL example

Now let's tie all these basic elements together. Here's a complete IDL example that declares a module within another module, which itself contains several interfaces:

```
module OS {
   module
      servi
      ces  {
      interf
      ace
      Serve
      r {
         readonly    attribute    string
         serverName;    booleaninit(in
         string sName);
      };

      interface Printable {
         boolean print(in string header);
      };

      interfacePrintServer          :
         Server                     {
         booleanprintThis(in
         Printable p);
      };
   };
};
```

The first interface, Server, has a single read-only string attribute and an init() method that accepts a string and returns a boolean. The Printable interface has a single print()method that accepts a string header. Finally, the PrintServer interface extends the Server interface and adds a printThis() method that accepts a Printable object and returns a boolean. In all cases, we've declared the method arguments as input-only (i.e., pass-by-value), using the in keyword.

2. Turning IDL IntoJava

Once the remote interfaces in IDL are described, you need to generate Java classes that act as a starting point for implementing those remote interfaces

in Java using an IDL-to-Java compiler. Every standard IDL-to-Java compiler generates the following 3 Java classes from an IDL interface:

- A Java interface with the same name as the IDL interface. This can act as the basis for a Java implementation of the interface (but you have to write it, since IDL doesn't provide any details about method implementations).
- A *helper* class whose name is the name of the IDL interface with "Helper" appended to it (e.g., ServerHelper). The primary purpose of this class is to provide a staticnarrow() method that can safely cast CORBA Object references to the Java interface type. The helper class also provides other useful static methods, such as read() and write() methods that allow you to read and write an object of the corresponding type using I/O streams.
- A *holder* class whose name is the name of the IDL interface with "Holder" appended to it (e.g., ServerHolder). This class is used when objects with this interface are used as out or inout arguments in remote CORBA methods. Instead of being passed directly into the remote method, the object is wrapped with its holder before being passed. When a remote method has parameters that are declared as outor inout, the method has to be able to update the argument it is passed and return the updated value. The only way to guarantee this, even for primitive Java datatypes, is to force outand inout arguments to be wrapped in Java holder classes, which are filled with the output value of the argument when the method returns.

The idltojtool generate 2 other classes:

- **A client *stub* class,** called *_interface-name*Stub, that acts as a client-side implementation of the interface and knows how to convert method requests into ORB requests that are forwarded to the actual remote object. The stub class for an interface named Server is called_ServerStub.
- **A server *skeleton* class,** called *_interface-name*ImplBase, that is a base class for a server- side implementation of the interface. The base class can accept requests for the object from the ORB and channel return values back through the ORB to the remote client. The skeleton class for an interface named Serveris called _ServerImplBase.

So, in addition to generating a Java mapping of the IDL interface and some helper classes for the Java interface, the *idltoj*compiler also creates subclasses that act as an interface between a CORBA client and the ORB and between the server-side implementation and theORB.

This creates the five Java classes: a Java version of the interface, a helper class, a holder class, a client stub, and a server skeleton.

3. Writing the Implementation

The IDL interface is written and generated the Java interface and support classes for it,

including the client stub and the server skeleton. Now, concrete server-side implementations of all of the methods on the interface needs to becreated.

Implementing The Solution :

Here, we are demonstrating the "Hello World" Example. **To create this example, create a directory named hello/ where you develop sample applications and create the files in this directory.**

1. Defining the Interface(Hello.idl)

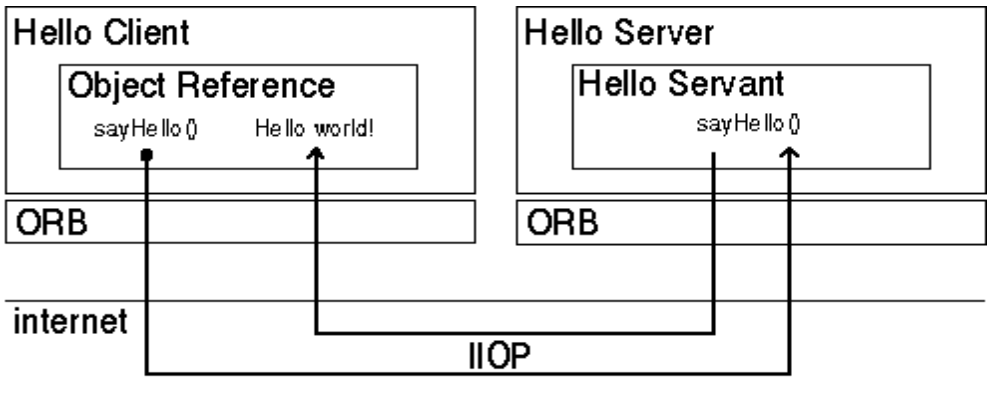
The first step to creating a CORBA application is to specify all of your objects and their interfaces using the OMG's Interface Definition Language (IDL).To complete the application, you simply provide the server **(HelloServer.java)** and client **(HelloClient.java)** implementations.

2. Implementing the Server(HelloServer.java)

The example server consists of two classes, the servant and the server. The servant, HelloImpl, is the implementation of the Hello IDL interface; each Helloinstance is implemented by a HelloImplinstance. The servant is a subclass of HelloPOA, which is generated by the idljcompiler from the example IDL. The servant contains one method for each IDL operation, in this example, the sayHello() and shutdown() methods. Servant methods are just like ordinary Java methods; the extra code to deal with the ORB, with marshaling arguments and results, and so on, is provided by the skeleton.

The HelloServerclass has the server's main()method, which:

- Creates and initializes an ORBinstance
- Gets a reference to the root POA and activates thePOAManager
- Creates a servant instance (the implementation of one CORBA Hello object) and tells the ORB aboutit
- Gets a CORBA object reference for a naming context in which to register the new CORBA object
- Gets the root namingcontext
- Registers the new object in the naming context under the name"Hello"
- Waits for invocations of the new object from theclient.



3. Implementing the Client Application (HelloClient.java)

The example application client that follows:

- Creates and initializes an ORB
- Obtains a reference to the root naming context
- Looks up "Hello" in the naming context and receives a reference to that CORBA object
- Invokestheobject'ssayHello()andshutdown()operationsandprintstheresult.

Building and Executing the solution :

The Hello World program lets you learn and experiment with all the tasks required to develop almost any CORBA program that uses static invocation, which uses a client stub for the invocation and a server skeleton for the service being invoked and is used when the interface of the object is known at compile time.

This example requires a naming service, which is a CORBA service that allows **CORBA objects** to be named by means of binding a name to an object reference. The **name binding** may be stored in the naming service, and a client may supply the name to obtain the desired object reference. The two options for Naming Services with Java include **orbd**, a daemon process containing a Bootstrap Service, a Transient NamingService,

To run this client-server application on the development machine:

1. Change to the directory that contains the fileHello.idl.
2. Run the IDL-to-Java compiler, idlj, on the IDL file to create stubs and skeletons. This step assumes that you have included the path to the java/bin directory in your path.

   idlj-fall Hello.idl

   You must use the -fall option with the idlj compiler to generate both client and server- side bindings. This command line will generate the default server-side bindings, which assumes the POA Inheritance server-side model.

   The files generated by the idlj compiler for Hello.idl, with the -fall command line option, are:

   - HelloPOA.java:
     This abstract class is the stream-based server skeleton, providing basic CORBA functionality for the server. It extends org.omg.PortableServer.Servant, and implements the InvokeHandlerinterface and the HelloOperationsinterface. The server class HelloImplextends HelloPOA.

   - _HelloStub.java:
     This class is the client stub, providing CORBA functionality for the client. It extends org.omg.CORBA.portable.ObjectImpl and implements the Hello.javainterface.

- Hello.java:
  This interface contains the Java version of IDL interface written. The Hello.java interface extends org.omg.CORBA.Object, providing standard CORBA object functionality. It also extends the HelloOperations interface and org.omg.CORBA.portable.IDLEntity.

- HelloHelper.java
  This class provides auxiliary functionality, notably the narrow() method required to cast CORBA object references to their proper types. **The Helper class is responsible for reading and writing the data type to CORBA streams, and inserting and extracting the data type from AnyS.** The Holder class delegates to the methods in the Helper class for reading and writing.

- HelloHolder.java
  This final class holds a public instance member of type Hello. Whenever the IDL type is an out or an in out parameter, the Holder class is used. It provides operations for org.omg.CORBA.portable.OutputStream and org.omg.CORBA.portable.InputStream arguments, which CORBA allows, but which do not map easily to Java's semantics. The Holder class delegates to the methods in the Helper class for reading and writing. It implementsorg.omg.CORBA.portable.Streamable.

- HelloOperations.java

  This interface contains the methods sayHello() and shutdown(). The IDL-to-Java mapping puts all of the operations defined on the IDL interface into this file, which is shared by both the stubs and skeletons.

3. Compile the .java files, including the stubs and skeletons (which are in the directory directoryHelloApp). This step assumes the java/bindirectory is included in your path.

   javac *.java HelloApp/*.java

4. Startorbd.

   To start orbdfrom a UNIX command shell, enter:

   orbd -ORBInitialPort 1050&

   Note that 1050 is the port on which you want the name server to run. The -ORBInitialPortargument is a required command-line argument.

5. Start theHelloServer:

   To start the HelloServerfrom a UNIX command shell, enter:

javaHelloServer -ORBInitialPort 1050 -ORBInitialHostlocalhost&

You will see HelloServerready and waiting... when the server is started.

6. Run the clientapplication:

javaHelloClient -ORBInitialPort 1050 -ORBInitialHostlocalhost

When the client is running, you will see a response such as the following on your terminal: Obtained a handle on server object: IOR: (binarycode) Hello World! HelloServerexiting...

After completion kill the name server (orbd).

Conclusion :

CORBA provides the network transparency, Java provides the implementation transparency. CORBA complements the Java™ platform by providing a distributed object framework, services to support that framework, and interoperability with other languages. The Java platform complements CORBA by providing a portable, highly productive implementation environment. The combination of Java and CORBA allows you to build more scalable and more capable applications than can be built using the JDK alone.