Distributed Systems - Middlewares

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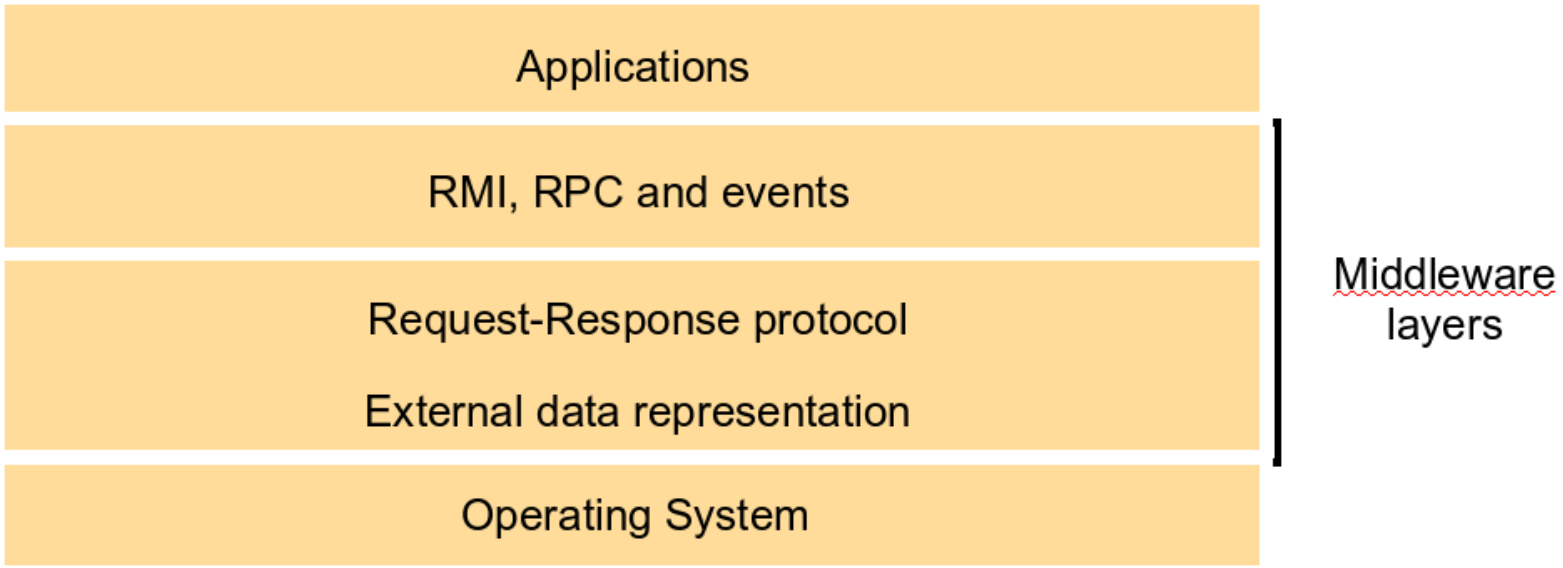
1. Middlewares
2. Remote Method Invocation
   - Java RMI
   - Corba
3. Remote Procedure Call
   - Sun RPC

Middlewares

- Abstraction layer for inter-process communication (IPC)
- Offer programming models that hide underlying details
- Handles data and call marshalling
- Provides call semantics

Middlewares



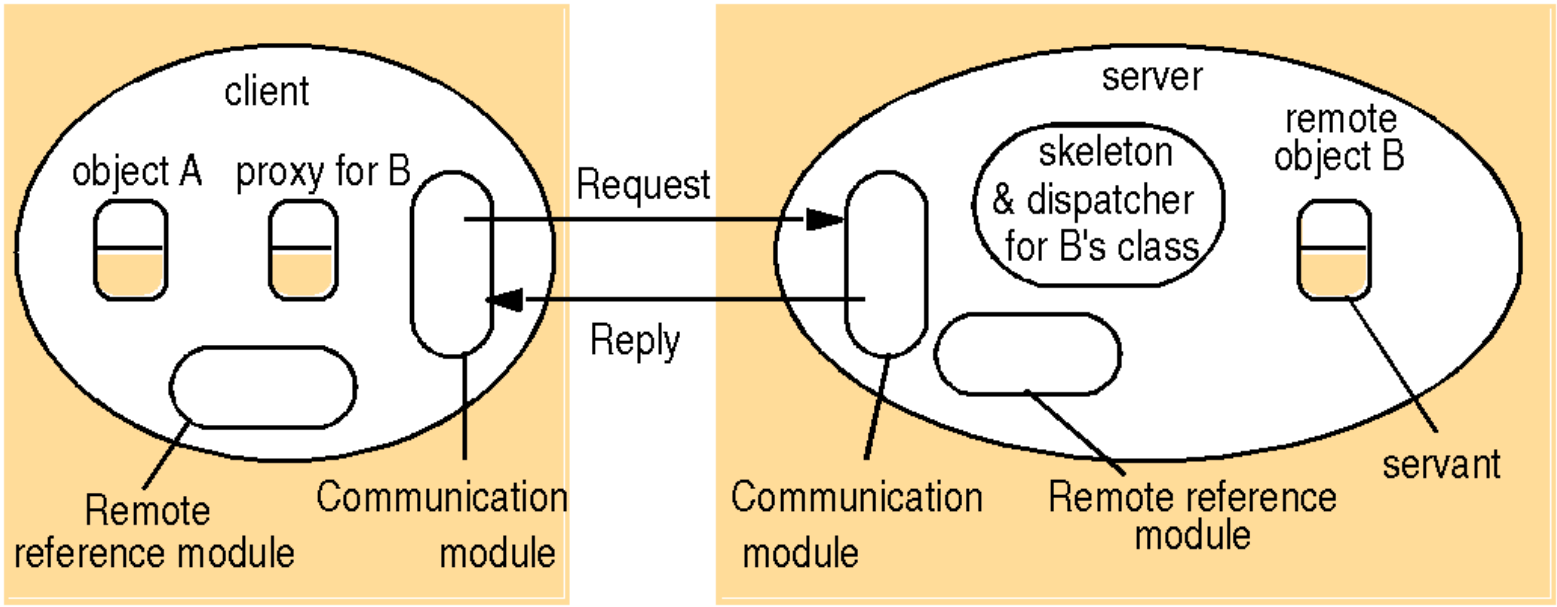
Middleware Example: Globus

- Middleware and development toolkit for Grid computing
- Provides a web service-based programming model
- Abstracts details of underlying systems
  (user systems, batch queues, monitoring programs, system heterogeneity issues, load balancing systems etc)
- Web services provide language and platform neutral access to system functionality
- Security models mapped between systems

Remote Method Invocation (RMI)

- Extends the object oriented model to the *distributed object model*
- Objects are referenced using remote object references
- Objects publish *remote interfaces* which are used to invoke service methods
- Call semantics for distributed objects differ from those of local objects
- Distributed garbage collection techniques employed for memory management (e.g., reference counting)

RMI Anatomy


client
object A
proxy for B
Request
Reply
Remote reference module
Communication module
server
skeleton & dispatcher for B's class
remote object B
Communication module
Remote reference module
servant

Java RMI

- Java Remote Method Invocation

  `http://java.sun.com/javase/6/docs/platform/rmi/spec/rmiTOC.html`
- Distributed object model
  - runs in separate processes (possibly) on separate hosts
- Facilitates object calls between JVMs
  - marshalling transparent to programmers
- Integrated part of Java (J2SE)
- Language dependent (100% pure Java)

Java RMI Overview

- Server publishes remote object references in *RMIRegistry*
  - naming service maps names to remote object references
- Clients acquire remote object references via
  - name resolutions (RMIRegistry)
  - return values of remote method calls
- Clients use remote objects as regular Java objects
  - parameter semantics differ
- Classes can be dynamically downloaded by RMI
  - receive object of unknown class (automatic download)
  - allows dynamic introduction of new classes

Remote Objects

- Java objects that implement a remote interface
  - interface extends *java.rmi.Remote*
  - declares remote methods
  - methods in the remote interface throw *RemoteException*
- Clients perform remote method invocations via the remote interface (using only the methods in the remote interface)
- Clients must handle RemoteExceptions
- Parameter passing
  - local and remote objects may be passed as parameters / return values
  - all objects must implement *java.io.Serializable*
  - primitive types / local objects *passed by value*
  - remote objects *passed by reference*

Using Java RMI

1. Define a remote interface
2. Implement the remote interface
3. Write a client program
4. Compile
   - generate client stubs (`rmic <servant class>`)
   - server and client classes
5. Make classes available over the network

Implementing a Java RMI Client

- Acquire an initial remote object reference
  - `Naming.lookup(String name)`
  - gives a *Remote* reference
- Handle RemoteException
- Regular Java code

Implementing a Java RMI Server

- Inherit UnicastRemoteObject
- Implement Remote interface(s)
- Install a security manager
- Publish remote object(s) in RMIRegistry (bootstrapping)
  - `Naming.rebind(String name, Remote object)`

Security

- Security Manager
  - protects local system resources from downloaded code
  - determines access rights
- RMISecurityManager (default)
- Alternative: policy file specifying rights
- Network traffic can be encrypted (using, e.g., SSL)

Example: Policy Files

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

grant {
  permission java.net.SocketPermission "*:1024-65536", "connect,accept";
  permission java.net.SocketPermission "*:80", "connect";
}
```

Threading Issues

- From the RMI specification:
  A method dispatched by the RMI runtime to a remote object implementation may or may not execute in a separate thread. The RMI runtime makes no guarantees with respect to mapping remote object invocations to threads. Since remote method invocation on the same remote object may execute concurrently, **a remote object implementation needs to make sure its implementation is thread-safe**.
- Always protect concurrent data access
  (regardless of middleware)

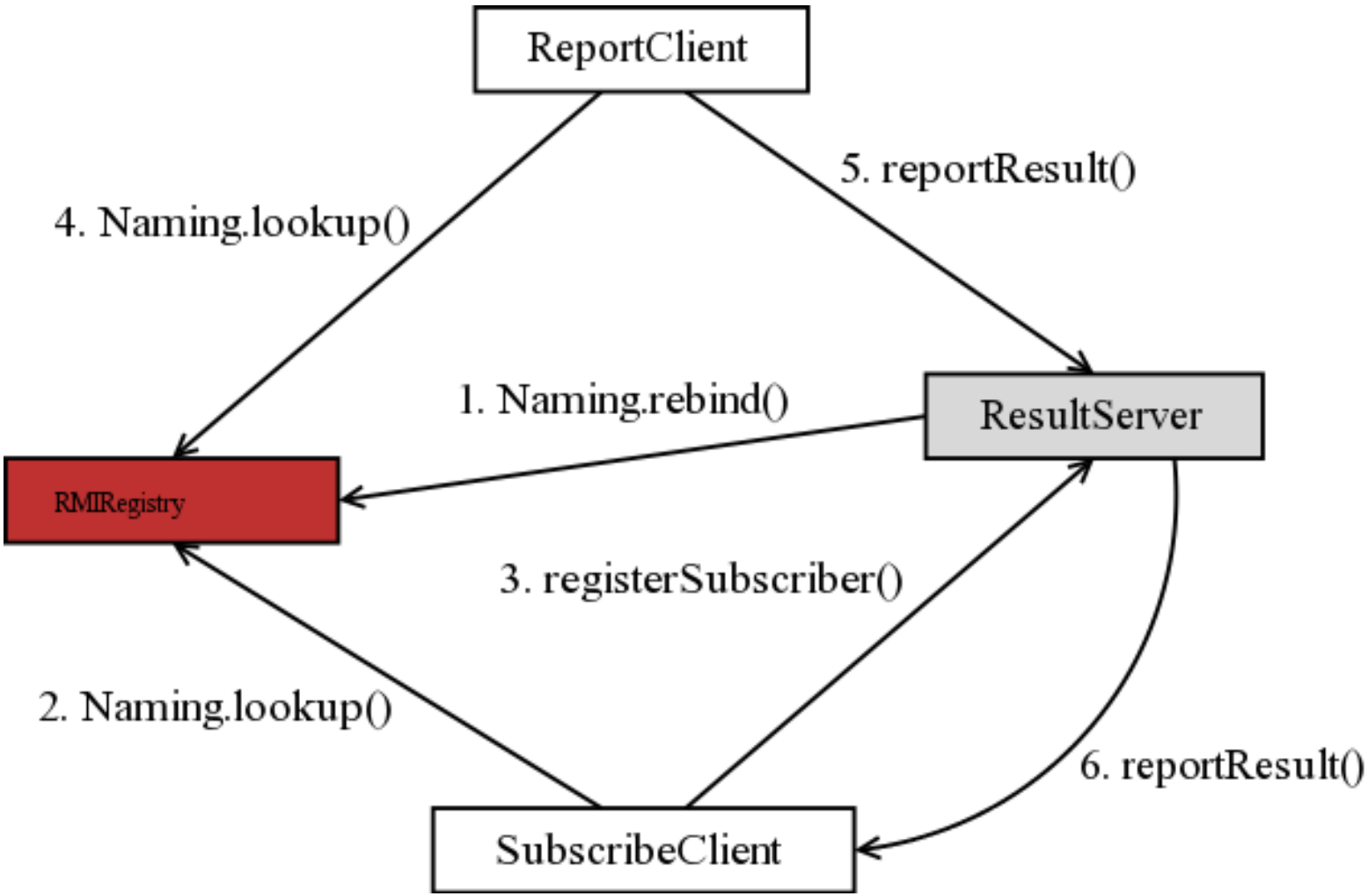
Example: Result Service

- Result service, offering sport results to interested users using a publish-subscribe pattern
  - sport results are reported to a service
  - users can subscribe to results for specific games
  - When a game result update is submitted, the result service sends updates to subscribers
- Callback-based updates
  - avoids resource drains due to polling issues
  - client provides server with callback references for updates
  - server also acts as a client (and vice versa)

Example Architecture

- Remote interfaces
  - *ResultService*: handles subscriptions and results
  - *ResultSubscriber*: callback, receives updates
- Server classes
  - *ResultServiceImpl*: implements ResultService
  - *ResultServer*: instantiates and registers the service
  - *Result*: contains game result information
  - *ResultSubscriberImpl*: implements ResultSubscriber
- Client classes
  - *ReportClient*: reports results to a ResultService
  - *SubscribeClient*: creates game result subscriptions

Example Component Interactions



Example: Remote Interfaces

```
public interface ResultService extends Remote
{
  public void reportResult (Result result)
    throws RemoteException;
  public void registerSubscriber (ResultSubscriber subscriber, String match)
    throws RemoteException;
  public void deregisterSubscriber (ResultSubscriber subscriber, String match)
    throws RemoteException;
}

public interface ResultSubscriber extends Remote
{
  public void reportResult(Result result)
    throws RemoteException;
}
```

Example: Result

```
public class Result
  implements Serializable
{
  protected String match = null;
  protected String result = null;
  public Result(String match, String result)
  {
    this.match = match;
    this.result = result;
  }

  public String getMatch()
  {
    return this.match;
  }

  public String getResult()
  {
    return this.result;
  }
}
```

Example: ResultServiceImpl 1/3

```
public class ResultServiceImpl extends UnicastRemoteObject
  implements ResultService
{
  protected Hashtable<String, List<ResultSubscriber>> subscriberMap;

  public synchronized void registerSubscriber(ResultSubscriber subscriber,
                                              String match)
    throws RemoteException
  {
    List<ResultSubscriber> matchSubscribers = subscriberMap.get(match);
    if (matchSubscribers == null)
    {
      matchSubscribers = new ArrayList<ResultSubscriber>();
      subscriberMap.put(match, matchSubscribers);
    }
    matchSubscribers.add(subscriber);
  }
```

Example: ResultServiceImpl 2/3

```
public synchronized void deregisterSubscriber (ResultSubscriber subscriber,
                                               String match)
  throws RemoteException
{
  List<ResultSubscriber> matchSubscribers = subscriberMap.get(match);
  if (matchSubscribers != null)
  {
    matchSubscribers.remove(subscriber);
  }
}

public void reportResult(Result result)
  throws RemoteException
{
  notifySubscribers(result);
}
```

Example: ResultServiceImpl 3/3

```
  private synchronized void notifySubscribers(Result result)
  {
    List<ResultSubscriber> matchSubscribers =
      subscriberMap.get(result.getMatch());
    if (matchSubscribers == null)
    {
      return;
    }
    Iterator<ResultSubscriber> subscriberIter = matchSubscribers.iterator();
    while (subscriberIter.hasNext())
    {
      ResultSubscriber subscriber = subscriberIter.next();
      try
      {
        subscriber.reportResult(result);
      }
      catch (RemoteException e)
      {
        subscriberIter.remove();
      }
    }
  }
}
```

Example: ResultServer

```
ResultService resultService = new ResultServiceImpl();
Naming.rebind("//localhost/result",resultService);
```

Example: ResultSubscriberImpl

```
public class ResultSubscriberImpl extends UnicastRemoteObject
  implements ResultSubscriber
{
  public void reportResult(Result result)
    throws RemoteException
  {
    System.out.println("Result update: " + result.getMatch() + "\t" +
                       result.getResult());
  }
}
```

Example: SubscribeClient

```
ResultSubscriber subscriber = new ResultSubscriberImpl();
ResultService service = (ResultService)Naming.lookup("//localhost/result");
service.registerSubscriber(subscriber,"SWE-FIN");
System.out.println("Waiting for score reports ...");
System.in.read();
service.deregisterSubscriber(subscriber,"SWE-FIN");
...
```

Example: ReportClient

```
Result result = new Result("SWE-FIN","1-0");
ResultService service = (ResultService)Naming.lookup("//localhost/result");
...
```

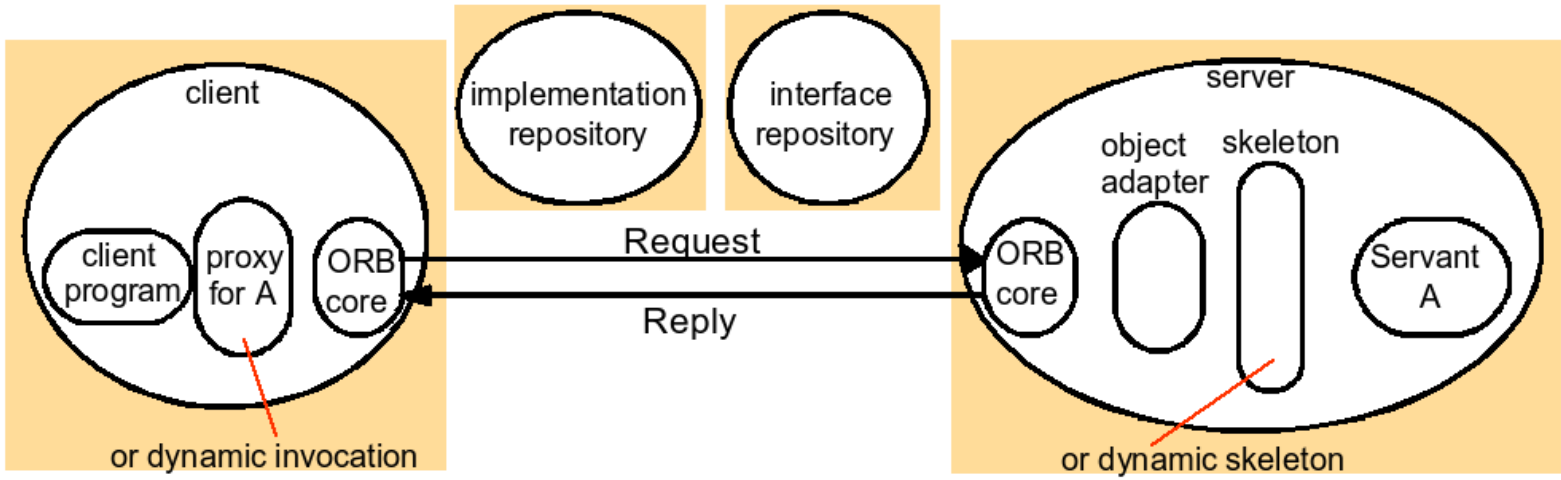
Using Java RMI

- Generate stubs and compile
- Start RMIRegistry
  - `rmiregistry <port>`
- Register objects
  - `Naming.rebind("//<host>:<port>/object");`
- Specify code base (class loading paths)
  - `-Djava.rmi.codebase=<class URLs>`
- Specify security policy
  - `-Djava.security.policy=<policy file>`

Corba

- Standardized framework for RMI
- Language dependent
  - multiple CORBA-implementations exists (multiple languages and OS)
- CORBA objects have interfaces and remote object references but can be implemented in non-OO languages (e.g., C)
  - marshalling more complicated
  - IDLs can not define classes
  - cannot send object instances
  - can send primitive types, aggregated types and remote objects references

Corba


client
client program
proxy for A
ORB core
or dynamic invocation
implementation repository
interface repository
Request
Reply
server
object adapter
skeleton
ORB core
Servant A
or dynamic skeleton

Corba

- Interface Definition Language (IDL)
  -interface definitions
- Common Data Representation (CDR)
  - external data representations
- Interoperable Object References (IOR)
  - remote object references
- General Inter-ORB Protocol (GIOP)
  - communication protocol

Corba

- Object adapter
  - acts as a data marshalling bridge
  - acts as a dispatcher (via skeletons) to servant instances
- Interface repository
  - used for dynamic (non-proxy) call ("interface reflection")
- Implementation repository
  - locates and activates registered servers

Result Service CORBA IDL

Compiled using an IDL-compiler to generate client proxies, server skeletons, classes and types for the IDL types.

```
struct Result
{
  string match;
  string score;
};

interface ResultSubscriber
{
  void reportResult(in Result score);
};

interface ResultService
{
  void reportResult(in Result score);
  void registerSubscriber(in ResultSubscriber subscriber, in string match);
  void deregisterSubscriber(in ResultSubscriber subscriber, in string match);
};
```

Example: Corba Servants

```
public class ResultServiceServant extends ResultServicePOA
{
  ... // see Java RMI ResultServiceImpl
}

public class ResultSubscriberServant extends ResultSubscriberPOA
{
  ... // see Java RMI ResultSubscriberImpl
}
```

Example: Corba ResultService

```
// Initialize ORB
ORB orb = ORB.init(args, null);

// The servant object must be registered with a POA.
// Obtain a reference to the root POA.
POA rootPOA = POAHelper.narrow(orb.resolve_initial_references("RootPOA"));

// Create our servant object, register it with the POA and activate it.
ResultServiceServant servant = new ResultServiceServant();
rootPOA.activate_object(servant);

// Print the IOR of our servant
System.out.println("Servant IOR: [" +
                   orb.object_to_string(servant._this_object()) +
                   "]");

// Activate the POA, enabling it to serve client requests.
rootPOA.the_POAManager().activate();

// Wait for client invocations
orb.run();
```

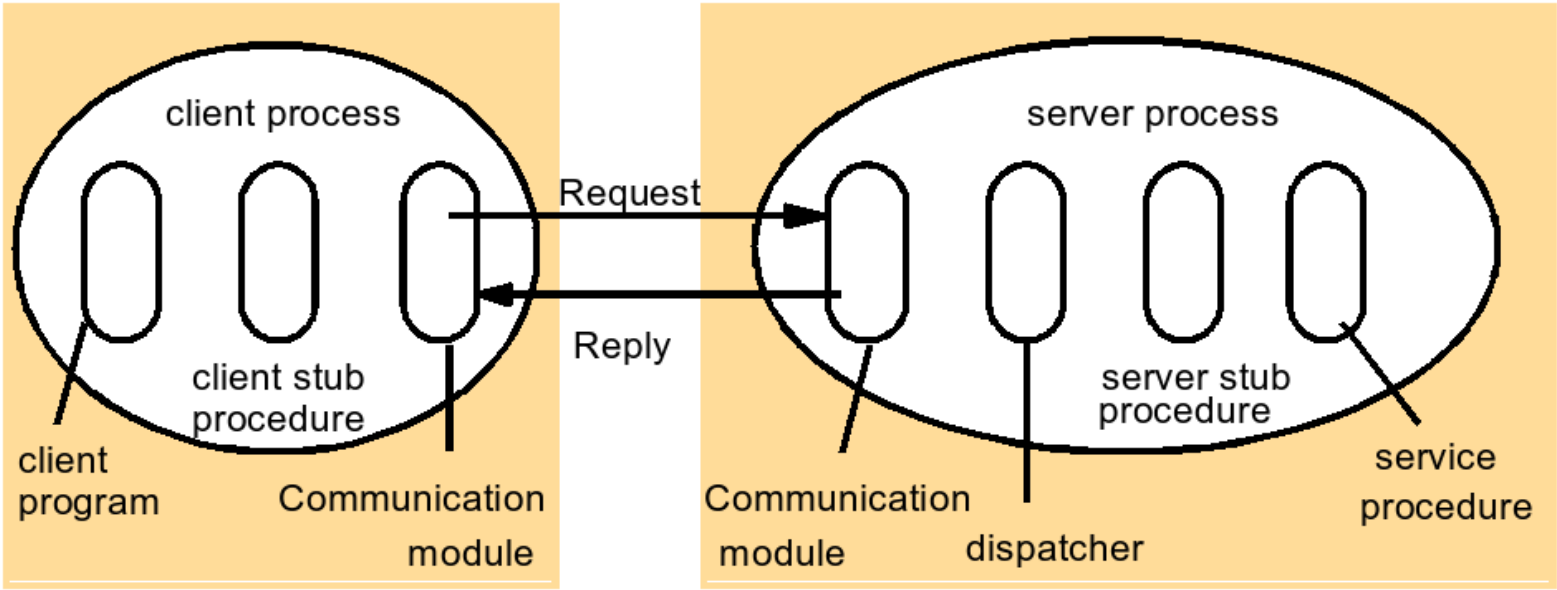
Example: Corba ResultClient

```
String resultServiceIOR = args[0];
Result result = new Result();
result.match = args[1];
result.score = args[2];

// Initialize the ORB
ORB orb = ORB.init(args, null);

// Get remote object reference from IOR
org.omg.CORBA.Object objRef = orb.string_to_object(resultServiceIOR);

// Downcast CORBA object to its appropriate type
ResultService resultService = ResultServiceHelper.narrow(objRef);

// Remote method invocation
resultService.reportResult(result);
```

Remote Procedure Call (RPC)

- Inter-process communication over networks
- Allows processes to call procedures in other processes
- Fore-runner to RMI (introduced in RFC 707 anno 1976)
- Served as basis for the communication model in the *Distributed Component Object Model (DCOM)*

Remote Procedure Call (RPC)



Sun RPC

- Created for client-server communication abstraction in the Sun Network File System (NFS)
- Alternative name: Open Network Computing (ONC) RPC
- The most common library for RPC, see
  - Brown. *Unix Distributed Programming*. Prentice Hall
  - RFC 1831
  - man rpc
- Supported by most UNIX operating systems
- Multiple language ties
  - C, Perl, Java, etc

External Data Representation (XDR)

- Sun XDR
  - originally a standard that defined external data representations for primitive and aggregated types in NFS
  - uses implicit typing (protocol context determines type)
  - extended to an IDL
- Sun RPC interface
  - program number + version number used as interface id
  - procedure declarations with associated types
  - procedure signature + number used as procedure id
  - single input and return parameters

rpcgen

- `rpcgen` - interface compiler that generates
  - client stubs
  - server main, stubs and dispatcher
  - XDR marshalling routines
  - header files for (declared) types

Binding Service

- *Port mapper*
  - runs locally on all hosts
  - maps services to ports
- Services register with port mapper, specifying
  - program number
  - version
  - port
- Clients resolve server port using (program number + version) tuples

Example: fileserver.x

```
const MAX_BLOCK_SIZE = 1000;

struct Block
{
  int length;
  char buffer[MAX_BLOCK_SIZE];
};

struct readargs
{
  string name<>;
  int block_offset;
  int block_length;
};

program FILESERVER
{
  version VERSION
  {
    Block READBLOCK(readargs)=1;
  } = 1;
} = 9999;
```

Example: readblock.c

```
Block *readblock_1 (readargs *args)
{
  static Block block;
  int fd = open(args->name,O_RDONLY);
  lseek(fd, args->block_offset,SEEK_SET);
  block.length = read(fd, block.buffer,args->block_length);
  return &block;
}
```

Example: fileclient.c

```
main (int argc, char ** argv)
{
  CLIENT *clientHandle;
  char *serverName;
  char *filePath;
  readargs readArgs;
  Block *data;
  serverName = argv[1];
  readArgs.name = argv[2];
  readArgs.block_offset = atoi(argv[3]);
  readArgs.block_length = atoi(argv[4]);
  /* creates socket and a client handle */
  clientHandle = clnt_create(serverName,FILESERVER,VERSION,"udp");
  /* call remote procedure */
  data = readblock_1(&readArgs, clientHandle);
  data->buffer[data->length] = '\0';
  printf("Read block:\n%s\n",data->buffer);
  clnt_destroy(clientHandle); /* closes socket */
}
```

Summary

	Java RMI	CORBA	Sun RPC
Multilingual	No	Yes	Yes
External Data Representation	Object Serialization	CDR	Sun XDR
Data format	Binary	Binary	Binary
IDL	Java Interfaces	CORBA IDL	Sub XDR
Type Support	Objects	Primitive & Aggregated	Primitive & Aggregated
Distributed Garbage Collection	Yes	No	N/A
Binder	RMIRegistry	CORBA Naming Service	Port Mapper
Bootstrapping	Registry Look-Ups	IOR / Registry Look-Ups	Registry Look-Ups
Call Semantics	At-most-once	At-most-once / Maybe	At-most-once

Next Time

- SOA and Web Services