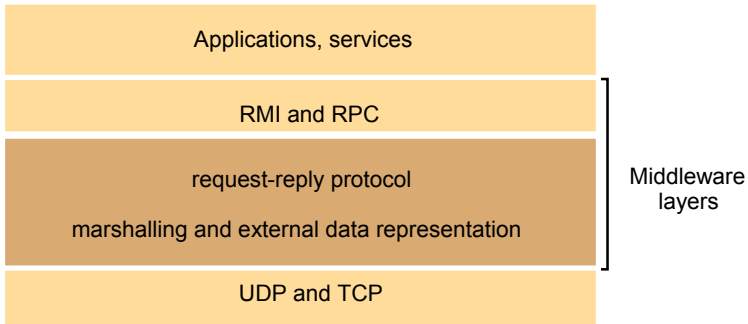
Communication in Distributed Systems: RPC/RMI

Motivation

- Sockets API ≡ send & recv calls ≡ I/O
- Remote Procedure Calls (RPC)
  - Goal: to provide a procedural interface for distributed (i.e., remote) services
  - To make distributed nature of service transparent to the programmer
    - No longer considered a good thing
- Remote Method Invocation (RMI)
  - RPC + Object Orientation
  - Allows objects living in one process to invoke methods of an object living in another process

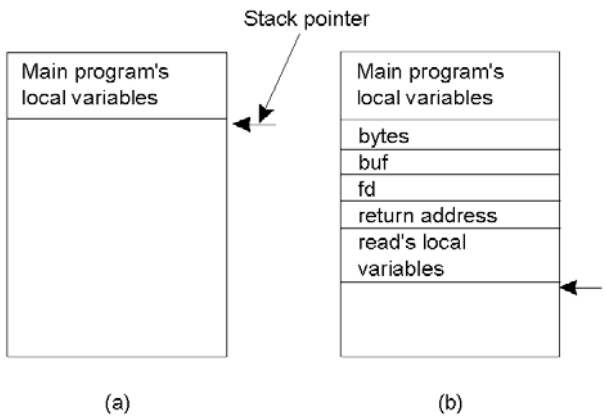
Middleware layers



Conventional Procedure Call

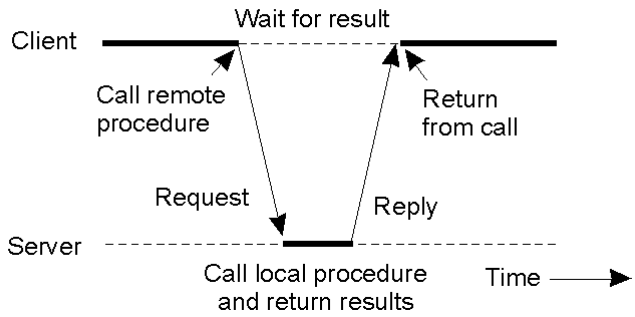
a) Parameter passing in a local procedure call: the stack before the call to read(fd,buf,bytes)

b) The stack while the called procedure is active



Remote Procedure Call

- Principle of RPC between a client and server program.



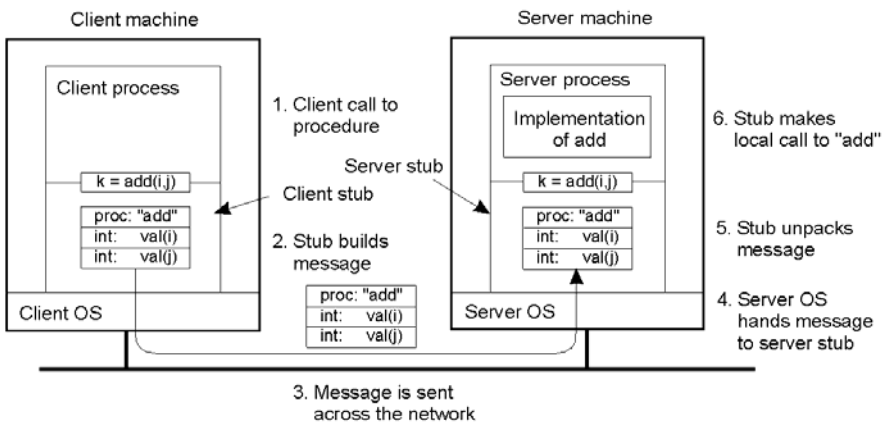
Remote Procedure Calls

- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems.
- **Stubs** – client-side proxy for the actual procedure on the server.
- The client-side stub locates the server and *marshalls* the parameters.
- The server-side stub receives this message, unpacks the marshalled parameters, and peforms the procedure on the server.

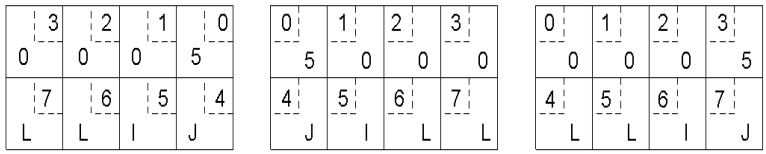
Steps of a Remote Procedure Call

1. Client procedure calls client stub in normal way
2. Client stub builds message, calls local OS
3. Client's OS sends message to remote OS
4. Remote OS gives message to server stub
5. Server stub unpacks parameters, calls server
6. Server does work, returns result to the stub
7. Server stub packs it in message, calls local OS
8. Server's OS sends message to client's OS
9. Client's OS gives message to client stub
10. Stub unpacks result, returns to client

Passing Value Parameters (1)



Passing Value Parameters (2)



(a) (b) (c)

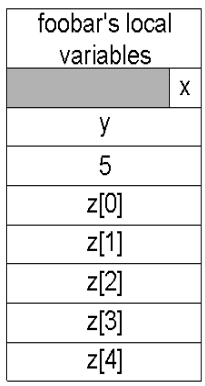
a) Original message on the Pentium
b) The message after receipt on the SPARC
c) The message after being inverted. The little numbers in boxes indicate the address of each byte

Parameter Specification and Stub Generation

a) A procedure
b) The corresponding message.

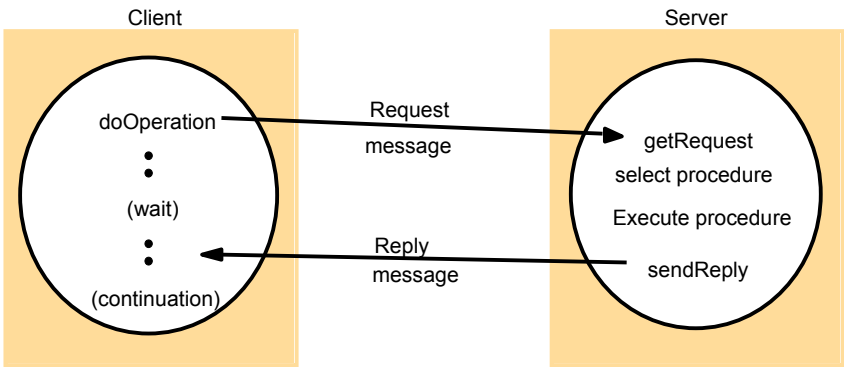
```
foobar( char x; float y; int z[5] )
{
   ....
}
```

(a)



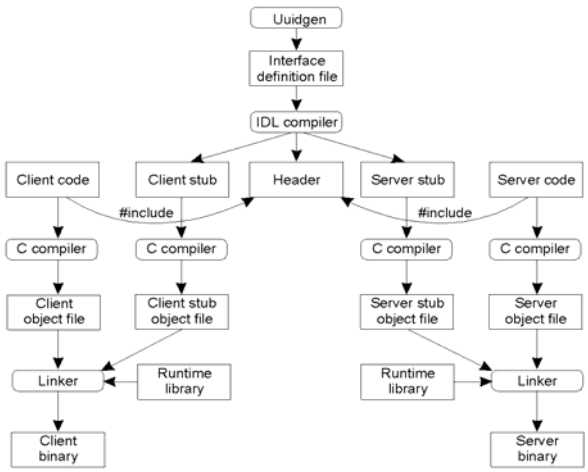
(b)

Request-reply communication



Writing a Client and a Server

The steps in writing a client and a server in DCE RPC (SUN RPC is similar)



Files interface in Sun XDR

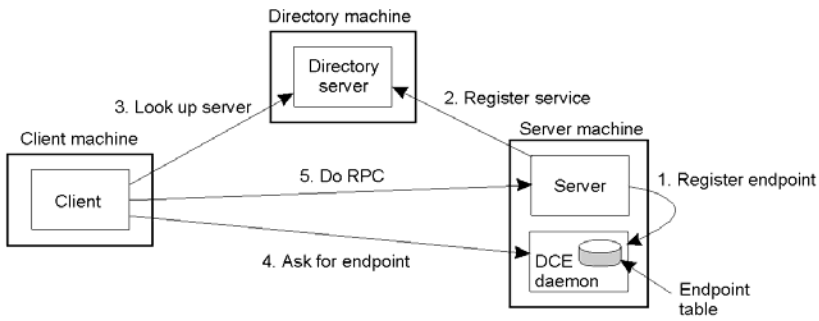
```
const MAX = 1000;
typedef int FileIdentifier;
typedef int FilePointer;
typedef int Length;
struct Data {
    int length;
    char buffer[MAX];
};
struct writeargs {
    FileIdentifier f;
    FilePointer position;
    Data data;
};
```

```
struct readargs {
    FileIdentifier f;
    FilePointer position;
    Length length;
};

program FILEREADWRITE {
  version VERSION {
    void WRITE(writeargs)=1;      1
    Data READ(readargs)=2;        2
  }=2;
} = 9999;
```

See additional slides on client and server programs

Binding a Client to a Server



NOTE: In SunRPC, you only have to register the service (not both service and endpoint). Each host runs its own binder process called portmapper

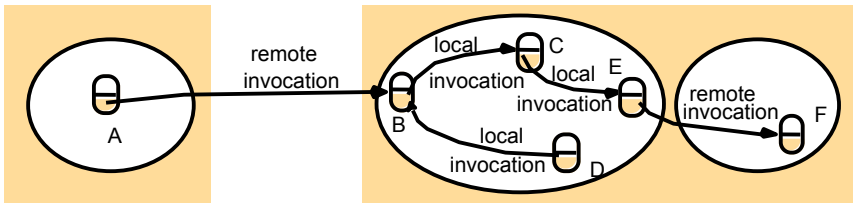
RMI

- RMI = RPC + Object-orientation
  - Java RMI
  - CORBA
    - Middleware that is language-independent
  - Microsoft DCOM/COM+
  - SOAP
    - RMI on top of HTTP

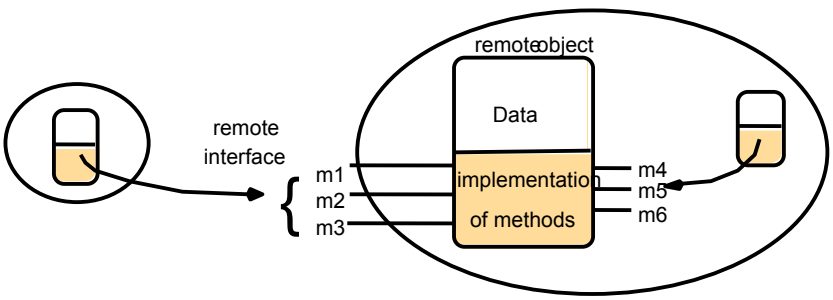
Interfaces in distributed systems

- Programs organized as a set of modules that communicate with one another via procedure calls/method invocations
- Explicit interfaces defined for each module in order to control interactions between modules
- In distributed systems, modules can be in different processes
- A remote interface specifies the methods of an object that are available for invocation by objects in other processes defining the types of the input and output arguments of each of them

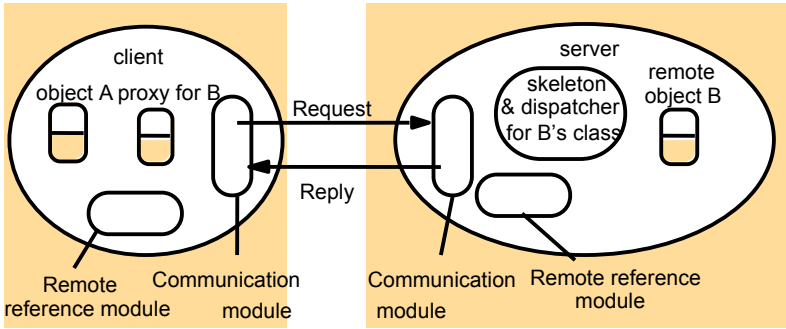
Remote and local method invocations



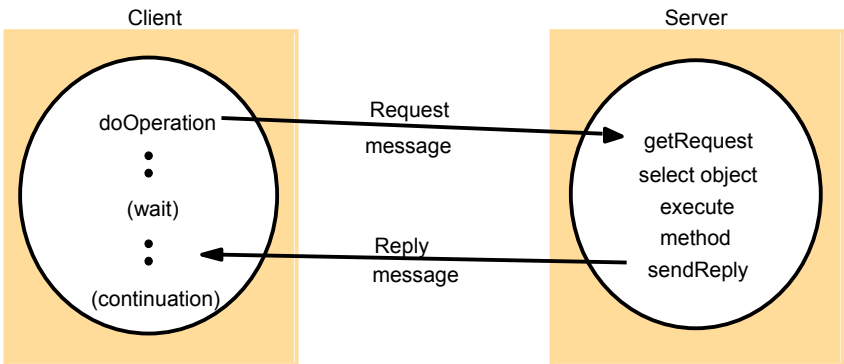
A remote object and its remote interface



The role of proxy and skeleton in remote method invocation



Request-reply communication for RPC/RMI



Operations of the request-reply protocol

public byte[] doOperation (RemoteObjectRef o, int methodId, byte[] arguments)
sends a request message to the remote object and returns the reply.
The arguments specify the remote object, the method to be invoked and the arguments of that method.

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.

Request-reply message structure

messageType	*int (0=Request, 1= Reply)*
requestId	*int*
objectReference	*RemoteObjectRef*
methodId	*int or Method*
arguments	*array of bytes*

Request-Reply protocol

- Issues in marshalling of parameters and results
  - Input, output, Inout parameters
  - Data representation
  - Passing pointers? (e.g., call by reference in C)
- Distributed object references
- Handling failures in request-reply protocol
  - Partial failure
    - Client, Server, Network

CORBA CDR message

index in sequence of bytes	4 bytes	*notes on representation*
0–3	5	*length of string*
4–7	"Smit"	*'Smith'*
8–11	"h___"	
12–15	6	*length of string*
16–19	"Lond"	*'London'*
20-23	"on__"	
24–27	1934	*unsigned long*

The flattened form represents a *Person* struct with value: {'Smith', 'London', 1934}

Java serialization

Serialized values				*Explanation*
Person	8-byte version number		h0	*class name, version number*
3	int year	java.lang.String name:	java.lang.String place:	*number, type and name of instance variables*
1934	5 Smith	6 London	h1	*values of instance variables*

The true serialized form contains additional type markers; h0 and h1 are handles

RMI Programming

- RMI software
  - Generated by IDL compiler
  - Proxy
    - Behaves like remote object to clients (invoker)
    - Marshals arguments, forwards message to remote object, unmarshals results, returns results to client
  - Skeleton
    - Server side stub;
    - Unmarshals arguments, invokes method, marshals results and sends to sending proxy's method
  - Dispatcher
    - Receives the request message from communication module, passes on the message to the appropriate method in the skeleton
- Server and Client programs

RMI Programming

- Binder
  - Client programs need a means of obtaining a remote object reference
  - Binder is a service that maintains a mapping from textual names to remote object references
  - Servers need to register the services they are exporting with the binder
  - Java RMIregistry, CORBA Naming service
- Server threads
  - Several choices: thread per object, thread per invocation
  - Remote method invocations must allow for concurrent execution

RPC/RMI systems

- RPC systems
  - SUN RPC
  - DCE RPC
- RMI systems
  - CORBA
  - DCOM
  - Java RMI
  - SOAP (Simple Object Access Protocol)
    - HTTP is request-reply protocol
    - XML for data representation

Java RMI

- Features
  - Integrated with Java language + libraries
    - Security, write once run anywhere, multithreaded
    - Object orientation
  - Can pass "behavior"
    - Mobile code
    - Not possible in CORBA, traditional RPC systems
  - Distributed Garbage Collection
  - *Remoteness of objects **intentionally** not transparent*

Remote Interfaces, Objects, and Methods

- Objects become remote by implementing a remote interface
  - A remote interface extends the interface java.rmi.Remote
  - Each method of the interface declares java.rmi.RemoteException in its `throws` clause in addition to any application-specific clauses

Creating distributed applications using RMI

1. Define the remote interfaces
2. Implement the remote objects
3. Implement the client (can be done anytime after remote interfaces have been defined)
4. Register the remote object in the name server registry
5. Generate the stub and client using *rmic*
6. Start the registry
7. Start the server
8. Run the client

Java Remote interfaces *Shape* and *ShapeList*

```
import java.rmi.*;
import java.util.Vector;
public interface Shape extends Remote {
    int getVersion() throws RemoteException;
    GraphicalObject  getAllState() throws RemoteException;          1
}
public interface ShapeList extends Remote {
    Shape newShape(GraphicalObject g) throws RemoteException; 2
    Vector allShapes() throws RemoteException;
    int getVersion() throws RemoteException;
}
```

The *Naming* class of Java RMIregistry

void rebind (String name, Remote obj)
This method is used by a server to register the identifier of a remote object by name, as shown in Figure 15.13, line 3.

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, as shown in Figure 15.15 line 1. A remote object reference is returned.

String [] list()
This method returns an array of Strings containing the names bound in the registry.

Java class *ShapeListServer* with *main* method

```
import java.rmi.*;
public class ShapeListServer{
    public static void main(String args[]){
        System.setSecurityManager(new RMISecurityManager());
        try{
            ShapeList aShapeList = new ShapeListServant();          1
                Naming.rebind("Shape List", aShapeList );           2
            System.out.println("ShapeList server ready");
            }catch(Exception e) {
            System.out.println("ShapeList server main " + e.getMessage());}
    }
}
```

Java class *ShapeListServant* implements interface *ShapeList*

```
import java.rmi.*;
import java.rmi.server.UnicastRemoteObject;
import java.util.Vector;
public class ShapeListServant extends UnicastRemoteObject implements ShapeList {
     private Vector theList;          // contains the list of Shapes          1
     private int version;
    public ShapeListServant()throws RemoteException{...}
    public Shape newShape(GraphicalObject g) throws RemoteException {        2
        version++;
            Shape s = new ShapeServant( g, version);                          3
            theList.addElement(s);
            return s;
    }
    public  Vector allShapes()throws RemoteException{...}
    public int getVersion() throws RemoteException { ... }
}
```


Java client of *ShapeList*

```
import java.rmi.*;
import java.rmi.server.*;
import java.util.Vector;
public class ShapeListClient{
   public static void main(String args[]){
     System.setSecurityManager(new RMISecurityManager());
     ShapeList aShapeList = null;
     try{
          aShapeList  = (ShapeList) Naming.lookup("//bruno.ShapeList") ;      1
          Vector sList = aShapeList.allShapes();                              2
     } catch(RemoteException e) {System.out.println(e.getMessage());
     }catch(Exception e) {System.out.println("Client: " + e.getMessage());}
   }
}
```