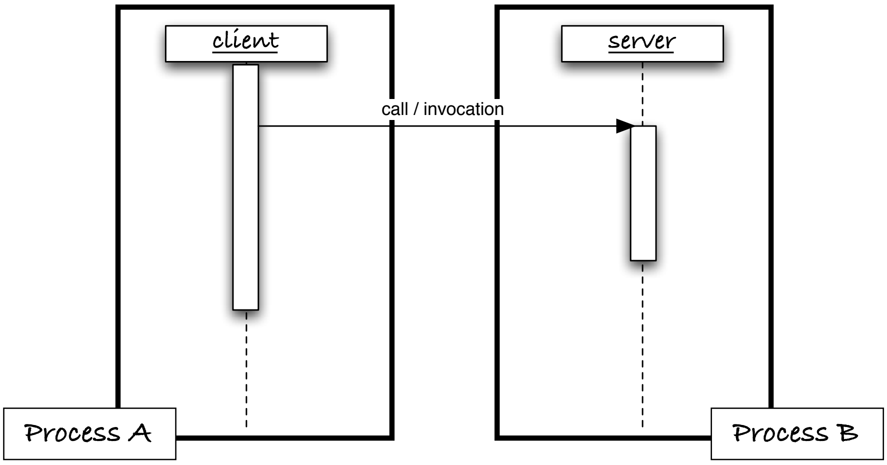
Remote Method Invocation

Benoît Garbinato
distributed object programming lab

Fundamental idea (1)

- □ Rely on the same programming paradigm for distributed applications as for centralized applications
  - □ In procedural languages, we will rely on the notion of Remote Procedure Call (RPC)
  - □ In object-oriented language, we will rely on the notion of Remote Method Invocation (RMI)

Fundamental idea (2)



A remote method (procedure) is transparently invoked (called) across the network, as if it was local

RPC: some history

1979 Bill Joy introduces the "Berkeley Enhancements", mainly interprocess communication (IPC) facilities. The modern network Unix is born (BSD).

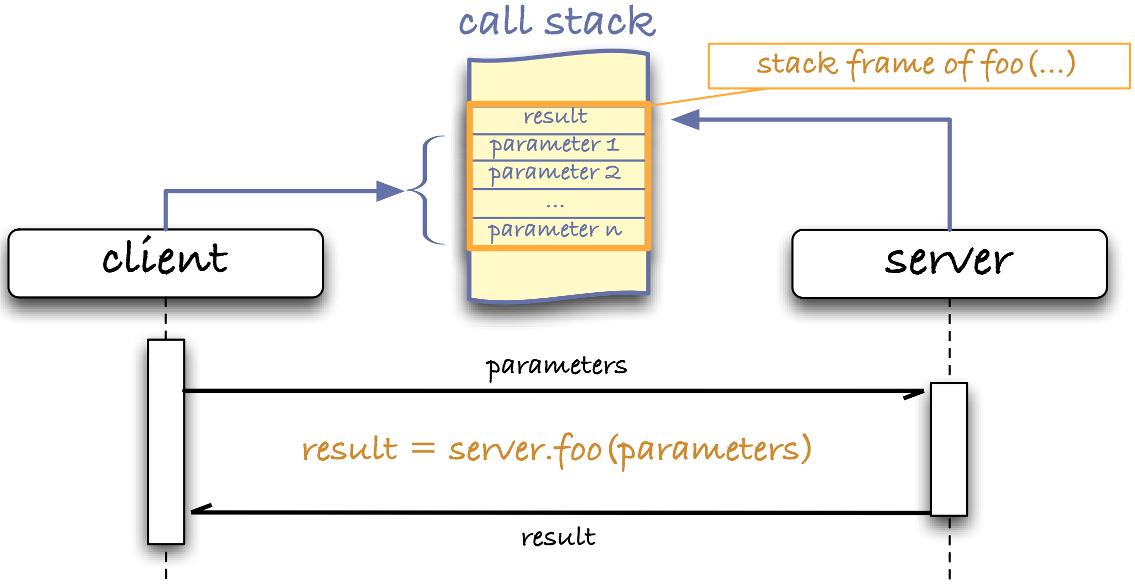
mid 80's Sun Microsystems uses BSD Unix as operating system for their workstations. They extends it with RPC, on top of which they build NFS and NIS (later on NIS+).

1988 The Open Software Foundation (OSF) is formed to develop a portable open system platform, known as the Distributed Computing Environment (DCE). The latter proposes DCE RPC as basic communication mechanism.

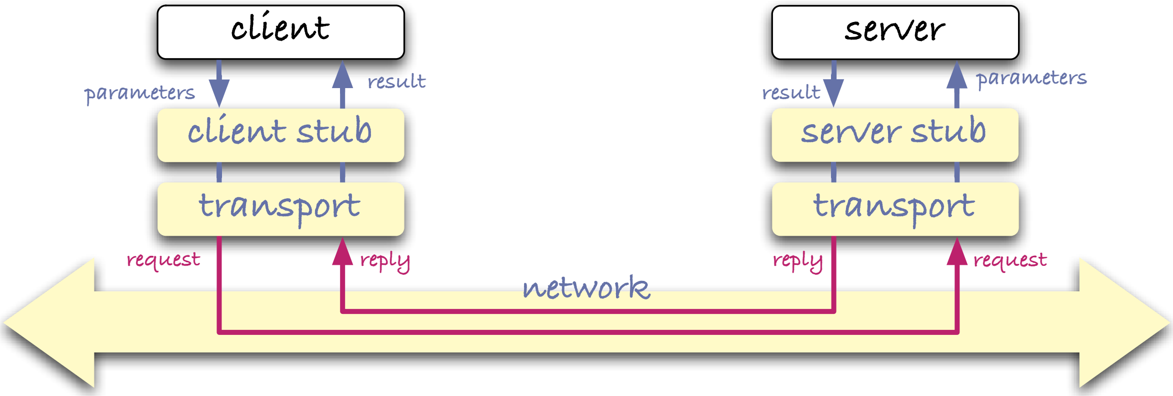
mid 90's The Object Management Group (OMG) follows the same approach to devise the Common Object Request Broker Architecture (CORBA) for object-based middleware. At the same time, Sun greatly simplifies & extends the RMI paradigm its Java & Jini platforms.

Today Everybody talks about Web Services as the next "big thing", but it is merely a web-flavored version of the RPC/RMI paradigm, using HTTP & XML.

A local method invocation

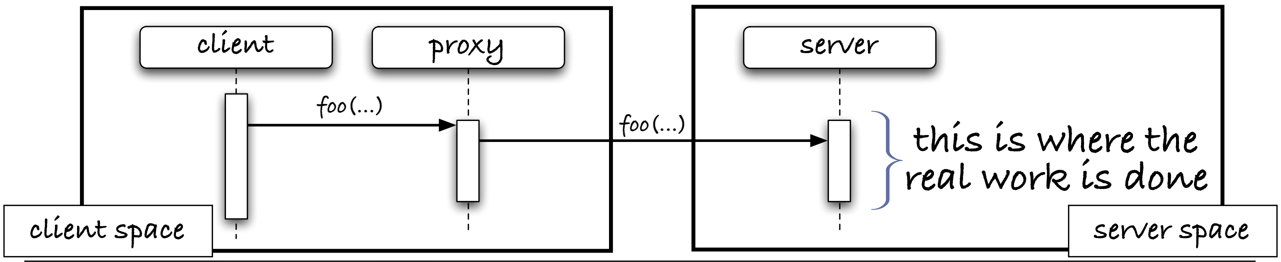


A remote method invocation



The notion of proxy

- □ A proxy is the representative of a server object in the address space of the client
- □ A proxy implements the same interface as the server (but not in the same way)



this is where the real work is done

Java RMI

- □ In Java, Remote method invocation is integrated in the standard class library, via packages such as java.rmi, java.rmi.server, etc.
- □ In addition , Sun's Java Development Kit (JDK) includes a set of tools for supporting RMI, e.g., rmic, rmiregistry, etc.
- □ We can distinguish three distinct times when building rmi-based applications, namely development, deployment and execution.

Execution time

1. The server object registers its name & proxy in the naming service (rmi registry)
2. The client object obtains a proxy of the server object via that naming service
3. The client object can then invoke the server proxy, which will then forward the invocation to the server object

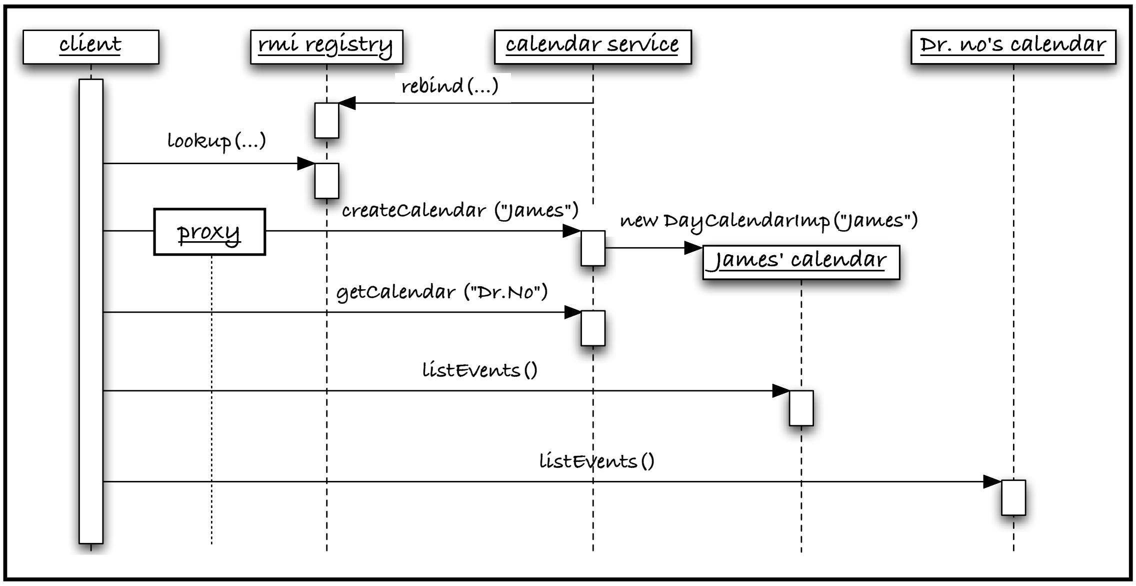
Server side: create & bind

```
public class CalendarApp  {
    ...
     public static void main(String[] args) throws Exception {
         String theName= "Calendar";
         CalendarServer theServer= new CalendarServer();

         Naming.rebind(theName, theServer);
         System.out.println("Calendar service is running!");
     }
}
```

Client side: lookup & use

```
public class CalendarClient  {
   ...
    public static void main(String[] args) throws Exception {
        String calServName= "//www.acme.com/Calendar";
        CalendarService calServ=
                (CalendarService) Naming.lookup(calServName);

        calServ.createCalendar("James");
        Collection allCals= calServ.getCalendars();
        DayCalendar dno= calServ.getCalendar("Dr. No");
        String[] elist= dno.listEvents();
    }
}
```

Calendar Application



Development time

1. Define the interface of the remote service
2. Implement the client and server classes in a decoupled way, thanks to the interface
3. Use javac to compile all above sources
4. Use the rmic compiler to create the proxy of the remote class for you

Typical remote interfaces

```
import java.util.*;
import java.rmi.*;

public interface CalendarService extends Remote {
    public DayCalendar createCalendar(String name) throws RemoteException, CalendarException;
    public DayCalendar getCalendar(String name) throws RemoteException, CalendarException;
    public ArrayList getCalendars() throws RemoteException;
    public boolean exists(String name) throws RemoteException;
}
```

```
import java.util.*;
import java.rmi.*;

public interface DayCalendar extends Remote {
    public boolean isFree(Date date) throws RemoteException;
    public DayEvent plan(DayEvent event) throws RemoteException, CalendarException;
    public String[] listEvents() throws RemoteException;
    public String getName() throws RemoteException;
}
```

A typical remote class

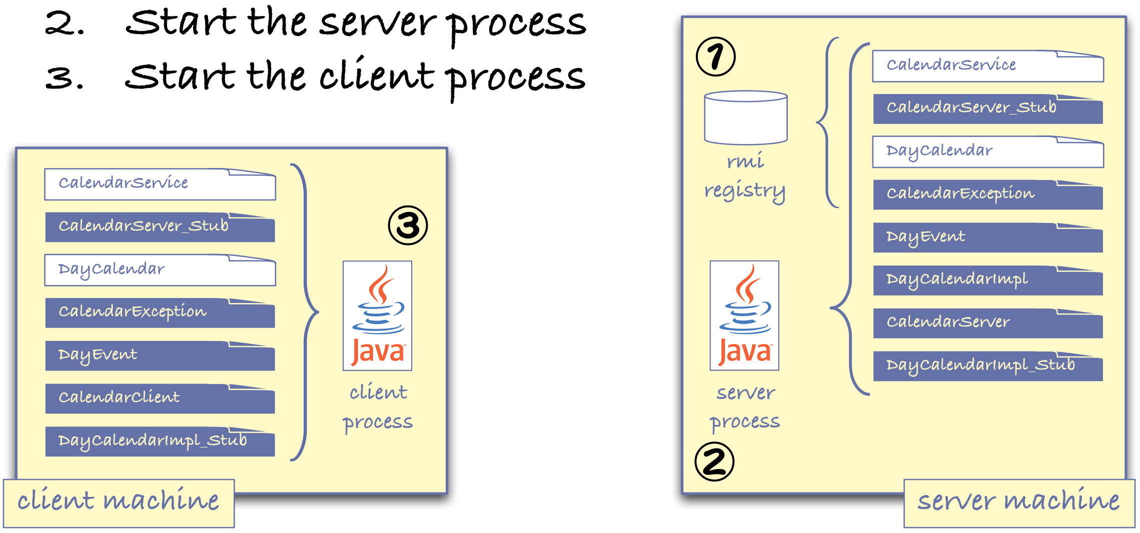
```
public class CalendarServer extends UnicastRemoteObject implements CalendarService  {
    private Hashtable calendars;

    public CalendarServer() throws RemoteException {
        calendars= new Hashtable();
    }
    public DayCalendar createCalendar(String name) throws RemoteException, CalendarException {
        if (calendars.containsKey(name)) throw new CalendarException(name + "\" already exists.");
        DayCalendar newCal= new DayCalendarImpl(name);
        calendars.put(name, newCal);
        return newCal;
    }
    public DayCalendar getCalendar(String name) throws RemoteException, CalendarException {
        if (!calendars.containsKey(name)) throw new CalendarException(name + "\" does not exist.");
        return ((DayCalendar) calendars.get(name));
    }
    public ArrayList getCalendars() throws RemoteException {
        return new ArrayList(calendars.values());
    }
    public boolean exists(String name) throws RemoteException {
        return calendars.containsKey(name);
    }
}
```

Argument passing rules

1. An argument or a return value can be a primitive type, a local serializable object (i.e, implementing java.io.Serializable), or a remote object.
2. A primitive type value is passed by copy.
3. A local object is also passed by copy, using standard object serialization.
4. A remote object is passed by reference, i.e., its proxy is passed rather than the object itself.

Deployment time

1. Start the rmi registry
2. Start the server process
3. Start the client process



Checkup

- □ On the server we have:

```
CalendarServer theServer= new CalendarServer();
```

  whereas on the client we have:

```
CalendarService calServ=
        (CalendarService) Naming.lookup(calServName);
```

  why this difference?

- □ Where are calendars located?
- □ How does the client get access to calendars?
- □ How do we communicate with the rmi registry ?

RMI callbacks (1)

- A remote object does not need to be registered in the naming service to be remotely accessible, e.g., DayCalendarImpl.

- The client can also make an object remotely accessible to the server, allowing the latter to asynchronously call back the client, e.g., to notify the client that a new event was scheduled on some calendar.

RMI callbacks (2)

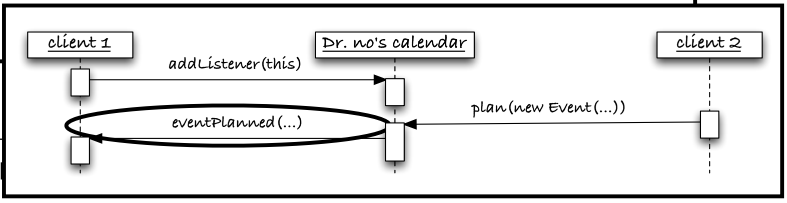
```
public interface CalendarListener extends Remote {
    public void eventPlanned(DayEvent e) throws RemoteException;
}
```

```
public interface DayCalendar extends Remote {
    public boolean isFree(Date date) throws RemoteException;
    public DayEvent plan(DayEvent event) throws RemoteException, CalendarException;
    public String[] listEvents() throws RemoteException;
    public String getName() throws RemoteException;
    public void addListener(CalendarListener l) throws RemoteException;
}
```

```
public class CalendarClient extends UnicastRemoteObject implements CalendarListener  {
    ...
    public static void main(String[] args) throws Exception {
        String calServName= "//www.acme.com/Calendar";
        CalendarService calServ= (CalendarService) Naming.lookup(calServName);
        DayCalendar dno= calServ.getCalendar("Dr. No");
        CalendarListener calist= new CalendarClient();
        dno.addListener(calist);
        dno.plan(new DayEvent(new Date(), "Conquer the world"));
    }
    public void eventPlanned(DayEvent e) throws RemoteException {
        System.out.println("--> New event planned: " + e);
    }
}
```

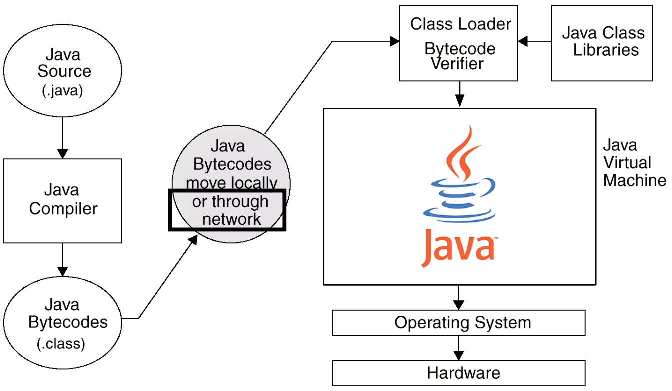
RMI callbacks (3)

```
public class DayCalendarImpl extends UnicastRemoteObject implements DayCalendar {
    private TreeSet eventSet;
    private ArrayList listeners;
    ...

    public void addListener(CalendarListener l) throws RemoteException {
        listeners.add(l);
    }
    private void notifyListeners(DayEvent e) {
        Iterator iter= listeners.iterator();
        while ( iter.hasNext() )
            try {
                ((CalendarListener) iter.next()).eventPlanned(e);
            } catch (RemoteException re) { System.err.println("Notification failed"); };
    }
    public DayEvent plan(DayEvent event) throws RemoteException, CalendarException {
        if (eventSet.contains(event)) throw new CalendarException("The date is not free");
        eventSet.add(event);
        notifyListeners(event);
        return event;
    }
    ...
}
```



Dynamic code download (1)

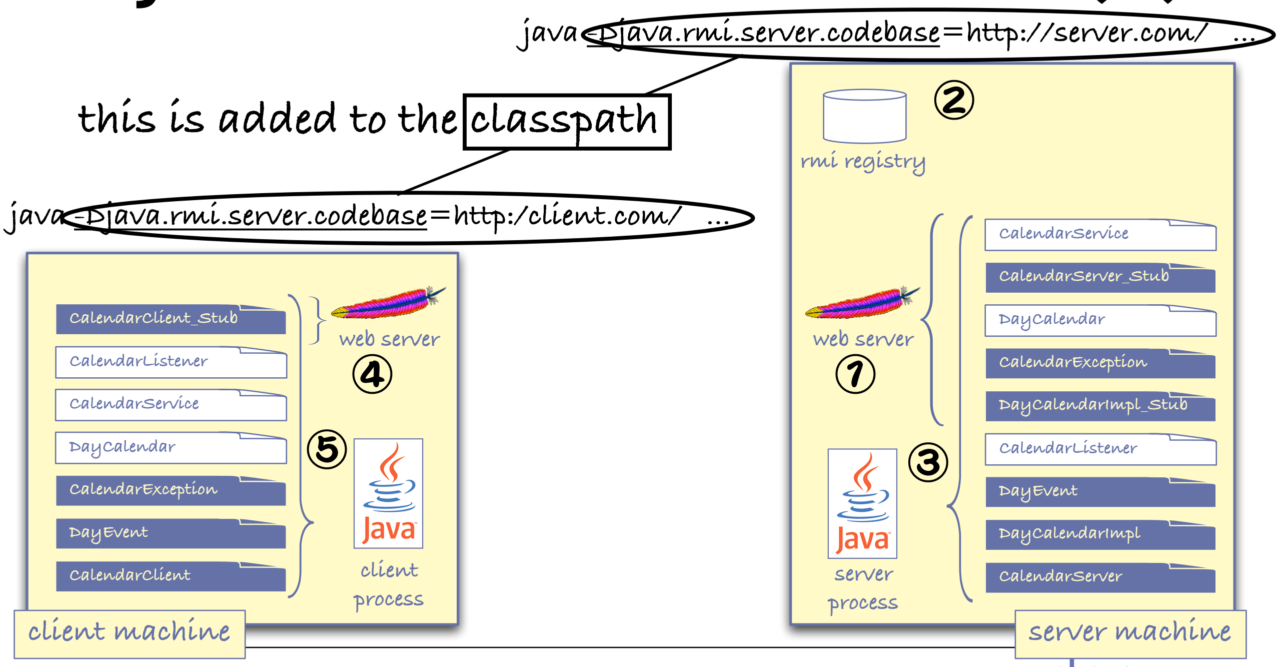
- ☐ The Java platform allows for the dynamic download of classes from any URL (Uniform Resource Locator)



Dynamic code download (2)

- The proxy is located on the client but it conceptually belongs to the server
- Because we have a Java Virtual Machine on both the server and the client, it is possible to have the proxy class move from the server to the client at runtime (dynamic code download)
- Dynamic code download can be used not only for proxies but for any Java class

Dynamic code download (3)



Security viewpoint

- From a security viewpoint, downloading classes is a critical action (i.e., potentially dangerous)
- For this reason, when code download is activated (via the java.rmi.server.codebase property), the Java Virtual Machine requires a security manager to be installed
- The security policy enforced by the security manager can be expressed declaratively in a security policy file

Security manager & policy

Source code:

```
if (System.getSecurityManager() == null)
    System.setSecurityManager(new RMISecurityManager());
```

Command line:

```
java -Djava.security.policy=my.policy  ...
```

Policy files:
(my.policy)

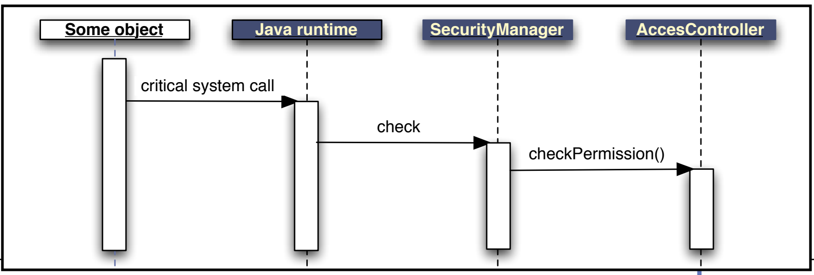
client

```
grant {
   permission java.net.SocketPermission "server.com:1024-65535", "connect,accept";
   permission java.net.SocketPermission "server.com:80", "connect,accept";
};
```

server

```
grant {
   permission java.net.SocketPermission "*:1024-65535", "connect,accept";
   permission java.net.SocketPermission "*:80", "connect,accept";
};
```

Runtime:



Distributed Garbage Collection

- □ The Java platform transparently extends garbage collection to distributed objects. This extension is known as Distributed Garbage Collection (DGC).
- □ A remote object is collected when there no longer exists any remote or local references to it
- □ Any object referenced by the naming service (rmi registry) is not collected

Unreferenced *vs.* finalized

- □ By implementing the Unreferenced interface, a remote object can ask to be notified when there no longer exists any remote references to it
- □ In the unreferenced() method, the remote object is given the opportunity to release some resources, e.g., the remote reference on a another remote object

```
public class DayCalendarImpl extends UnicastRemoteObject implements DayCalendar, Unreferenced {
    ...
    public void unreferenced() {
        System.out.println("-> Oups, I am no longer remotely referenced!");
    }
    protected void finalize() throws Throwable {
        System.out.print("This time, I am really about to be garbage collected...”);
        System.out.print("so bye bye cruel world!");
    }
}
```

called by the distributed garbage collector

called by the local garbage collector

Limitations of DGC

- □ An implementation of DGC should ensure
  - □ Safety, which implies not collecting too early
  - □ Liveness, which implies eventually collecting
- □ Due to its inherent decentralized nature, the implementation of DGC is based on reference counting, which poses several issues:
  - □ It does not deal properly with circular references
  - □ It does not deal properly with asynchronous systems
- □ Partial solution: the notion of lease

The notion of *lease*

- □ A lease is a remote reference with a validity limited in time
- □ In Java, remotes references are actually leases
- □ If the client does not renew its lease before the associated timeout expires, the reference counter on the server side is decremented
- □ Leases are automatically managed for you, i.e., the renewal is automatic as long as the client is alive and the remote reference exists