KTH ROYAL INSTITUTE
OF TECHNOLOGY

Remote Invocation

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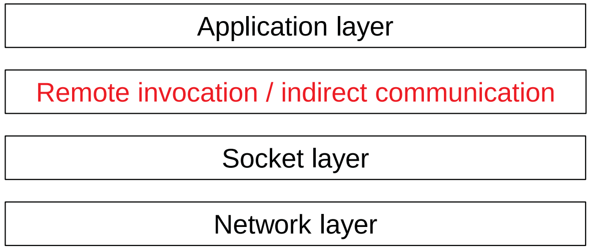
Middleware



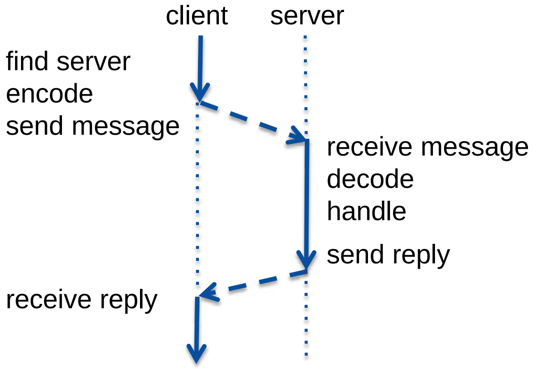
Application layer

Remote invocation / indirect communication

Socket layer

Network layer

Request / Reply



client server

find server
encode
send message

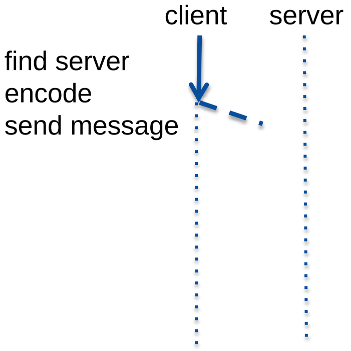
receive message
decode
handle

send reply

receive reply

- identify and locate the server
- encode/decode the message
- send reply to the right client
- attach reply to request

Lost request

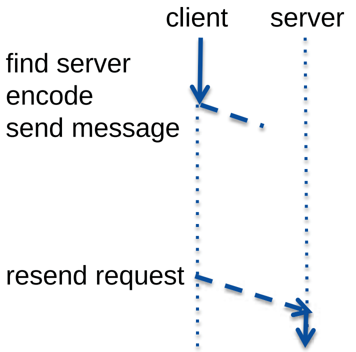


client server

find server
encode
send message

What do we do if request is lost?

Resend request



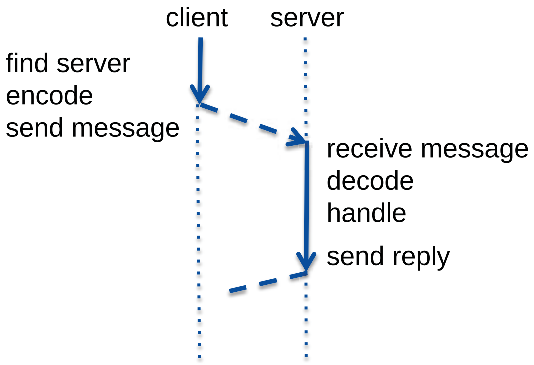
client
server

find server
encode
send message

resend request

- need to detect that message is potentially lost
- wait for a timeout (how long) or error from underlying layer
- resend the request
- simple, problem solved

Lost reply



client
server

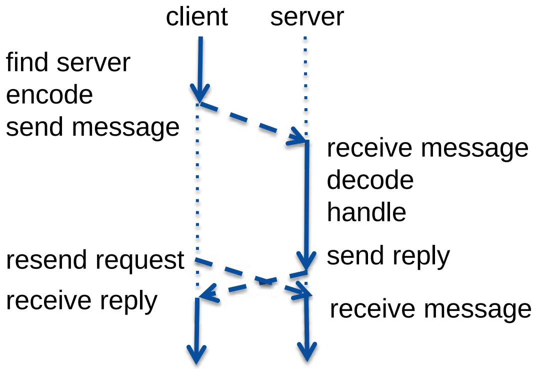
find server
encode
send message

receive message
decode
handle

send reply

- client will wait for timeout and re-send request
- not a problem

Problem



client
server

find server
encode
send message

receive message
decode
handle

resend request
receive reply

send reply

receive message

- a problem
- server might need a history of all previous request
- *might need*

Idempotent operations

- add 100 euros to my account
- what is the status of my account
- Sweden scored yet another goal!
- The standing is now 2-1!

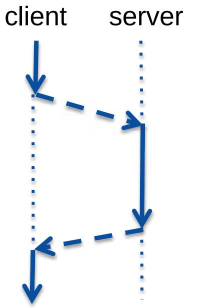
History

If operations are not idempotent, the server must make sure that the same request is not executed twice.

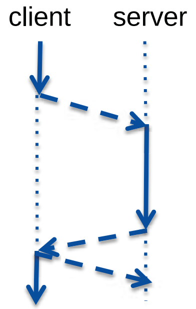
Keep a history of all request and the replies. If a request is resent the same reply can be sent without re-execution.

For how long do you keep the history?

Request-Reply-Acknowledge



Request-Reply (RR)



Request-Reply-Acknowledge (RRA)

At-most-once or At-least-once

How about this:

If an operation succeeds, then..

at-most-once: the request has been executed once.

> *Implemented using a history or simply not re-sending requests.*

at-least-once: the request has been executed at least once.

> *No need for a history, simply resend requests until a reply is received.*

At most or At least

How about errors:

Even if we do resend messages we will have to give up at some time.

If an operation fails/is lost, then..

at-most-once:

at-least-once:

At most or At least

Pros and cons:

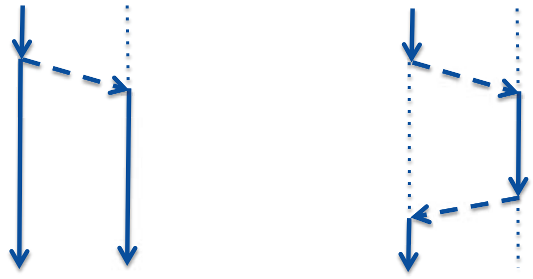
- *at-most-once without re-sending requests:*
  simple to implement, not fault-tolerant
- *at-most-once with history:*
  expensive to implement, fault-tolerant
- *at-least-once:*
  simple to implement, fault-tolerant

Can you live with at-least-once semantics?

UDP or TCP

Should we implement a request-reply protocol over UDP or TCP?

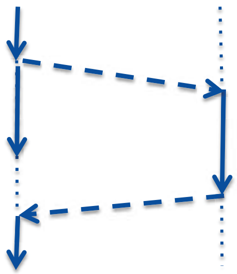
Synchronous or Asynchronous



Asynchronous

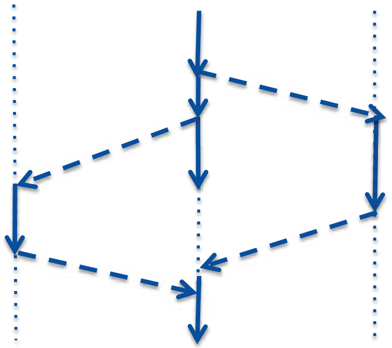
Synchronous

RR over Asynchronous



- send request
- continue to execute
- suspend if not arrived
- read reply

Hide the latency



HTTP

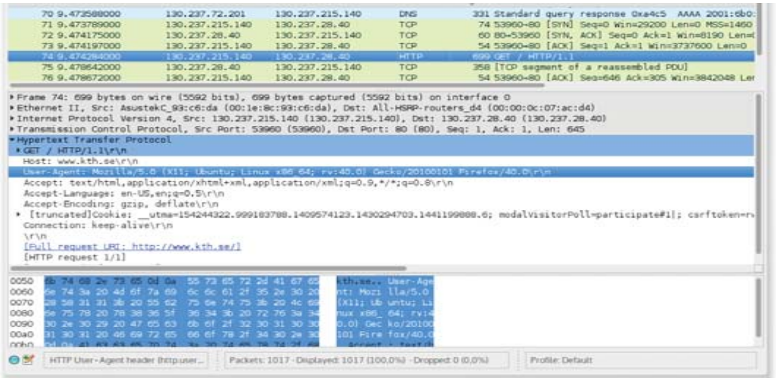
A request reply protocol, described in RFC 2616.

```
Request = Request-Line *(header CRLF) CRLF [ message-body ]

Request-Line = Method SP Request-URI SP HTTP-Version CRLF

    GET /index.html HTTP/1.1\r\n foo 42 \r\n\r\nHello
```

HTTP methods

- **GET**: request a resource, *should be idempotent*
- **HEAD**: request only header information
- **POST**: upload information to a resource, included in body, status of server could change
- **PUT**: add or replace a resource, idempotent
- **DELETE**: add or replace content, idempotent

Wireshark



```
70 9.473588000   130.237.72.201    130.237.215.140   DNS    331 Standard query response 0xa4c5  AAAA 2001:6b0:
71 9.473789000   130.237.215.140   130.237.28.40     TCP     74 53960→80 [SYN] Seq=0 Win=29200 Len=0 MSS=1460
72 9.474175000   130.237.28.40     130.237.215.140   TCP     60 80→53960 [SYN, ACK] Seq=0 Ack=1 Win=8190 Len=
73 9.474197000   130.237.215.140   130.237.28.40     TCP     54 53960→80 [ACK] Seq=1 Ack=1 Win=3737600 Len=0
74 9.474284000   130.237.215.140   130.237.28.40     HTTP   699 GET / HTTP/1.1
75 9.478642000   130.237.28.40     130.237.215.140   TCP    358 [TCP segment of a reassembled PDU]
76 9.478672000   130.237.215.140   130.237.28.40     TCP     54 53960→80 [ACK] Seq=646 Ack=305 Win=3842048 Len

▸ Frame 74: 699 bytes on wire (5592 bits), 699 bytes captured (5592 bits) on interface 0
▸ Ethernet II, Src: AsustekC_93:c6:da (00:1e:8c:93:c6:da), Dst: All-HSRP-routers_d4 (00:00:0c:07:ac:d4)
▸ Internet Protocol Version 4, Src: 130.237.215.140 (130.237.215.140), Dst: 130.237.28.40 (130.237.28.40)
▸ Transmission Control Protocol, Src Port: 53960 (53960), Dst Port: 80 (80), Seq: 1, Ack: 1, Len: 645
▾ Hypertext Transfer Protocol
  ▸ GET / HTTP/1.1\r\n
    Host: www.kth.se\r\n
    User-Agent: Mozilla/5.0 (X11; Ubuntu; Linux x86_64; rv:40.0) Gecko/20100101 Firefox/40.0\r\n
    Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8\r\n
    Accept-Language: en-US,en;q=0.5\r\n
    Accept-Encoding: gzip, deflate\r\n
  ▸ [truncated]Cookie: __utma=154244322.999183788.1409574123.1430294703.1441199888.6; modalVisitorPoll=participate#1|; csrftoken=r
    Connection: keep-alive\r\n
    \r\n
    [Full request URI: http://www.kth.se/]
    [HTTP request 1/1]

0050  6b 74 68 2e 73 65 0d 0a  55 73 65 72 2d 41 67 65   kth.se.. User-Age
0060  6e 74 3a 20 4d 6f 7a 69  6c 6c 61 2f 35 2e 30 20   nt: Mozi lla/5.0 
0070  28 58 31 31 3b 20 55 62  75 6e 74 75 3b 20 4c 69   (X11; Ub untu; Li
0080  6e 75 78 20 78 38 36 5f  36 34 3b 20 72 76 3a 34   nux x86_ 64; rv:4
0090  30 2e 30 29 20 47 65 63  6b 6f 2f 32 30 31 30 30   0.0) Gec ko/20100
00a0  31 30 31 20 46 69 72 65  66 6f 78 2f 34 30 2e 30   101 Fire fox/40.0
00b0  0d 0a 41 63 63 65 70 74  3a 20 74 65 78 74 2f 68   ..Accept : text/h

HTTP User-Agent header (http.user...   Packets: 1017 · Displayed: 1017 (100.0%) · Dropped: 0 (0.0%)   Profile: Default
```

HTTP GET

```
GET / HTTP/1.1
Host: www.kth.se
User-Agent: Mozilla/5.0 (X11; Ubuntu; Linux x86_64; rv:40.0) Gecko/20100101
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
Accept-Language: en-US,en;q=0.5
Accept.Encoding: gzip, deflate
Cookie: ......
Connection: keep-alive
```

HTTP Response

```
HTTP/1.1 200 OK
Date: Tue, 08 Sep 2015 10:37:49 GMT
Server: Apache/2.2.15 (Red Hat)
X-UA-Compatible: IE=edge
Set-Cookie: JSESSIONID=CDC76A3;Path=/; Secure; HttpOnly
Content-Language: sv-SE
Content-Length: 59507
Connection: close
Content-Type: text/html;charset=UTF-8
<!DOCTYPE html>
<html lang="sv">
<title>KTH | Valkommen till KTH</title>
```

The web

On the web the resource is often a HTML document that is presented in a browser.

HTTP could be used as a general-purpose request-reply protocol.

REST and SOAP

Request-reply protocols for Web-services:

- **REST (Representational State Transfer)**
  - content described in XML, JSON, . . .
  - light weight,
- **SOAP (Simple Object Access Protocol)**
  - over HTTP, SMTP . . .
  - content described in SOAP/XML
  - standardized, heavy weight

HTTP over TCP

HTTP over TCP - a good idea?

Masking a request-reply

Could we use a regular program construct to hide the fact that we do a request-reply?

Masking a request-reply

Could we use a regular program construct to hide the fact that we do a request-reply?

- **RPC**: Remote Procedure Call
- **RMI**: Remote Method Invocation

Motivation for RPC and RMI

Message passing is convenient for consumers-producers (filters) and P2P, but it is somewhat low level for client-server applications

- Client/server interactions are based on a request/response protocol;
- Client requests are typically mapped to procedures on server;
- A client waits for a response from the server.

Need for more convenient (easier to use) communication mechanisms for developing client/server applications

Motivation for RPC and RMI

Remote Procedure Call (RPC) and rendezvous

– Procedure interface; message passing implementation

Remote Method Invocation (RMI)

– RMI is an object-oriented analog of RPC

RPC, rendezvous and RMI are implemented on top of message passing.

Procedure calls

What is a procedure call:

- find the procedure
- give the procedure access to arguments
- pass control to the procedure
- collect the reply if any
- continue execution

How do we turn this into a tool for distributed programming?

Operational semantics

```
int x, n;
n = 5;
proc(n);
x = n;
```

```
int x, arr[3];
arr[0] = 5;
proc(arr);
x = arr[0];
```

Call by value/reference

Call by value

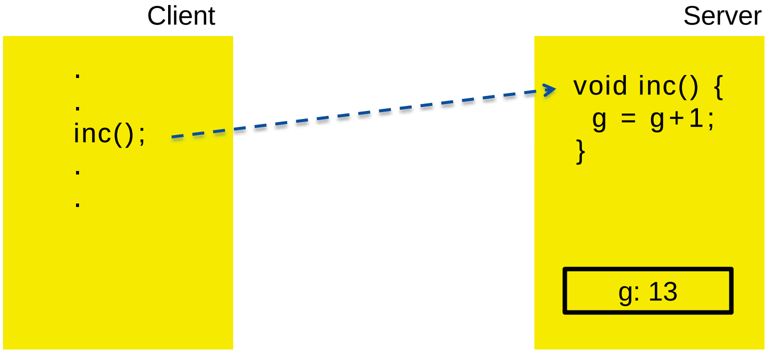
– A procedure is given a copy of the datum

Call by reference

– A procedure is given a reference to the datum

What if the datum is a reference and we pass a copy of the datum?
Why is this important?

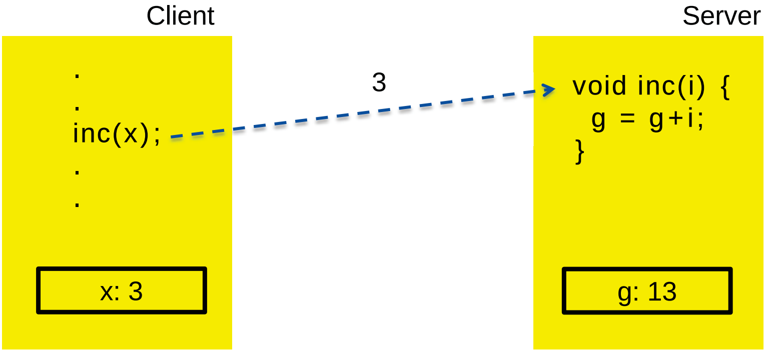
RPC: Remote Procedure Call



```
.
.
inc();
.
.
```

```
void inc() {
  g = g+1;
}
```

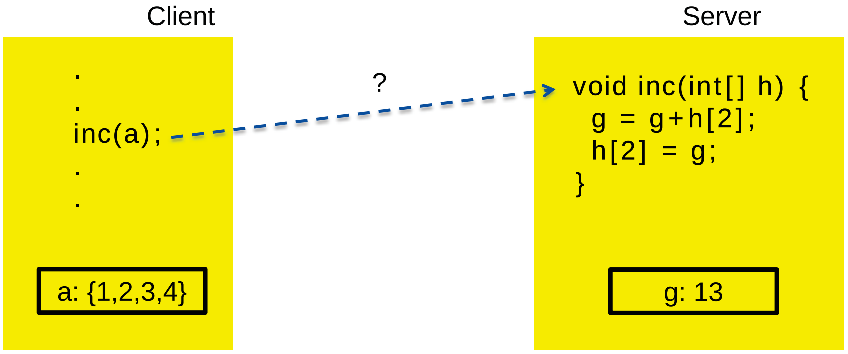
RPC: Remote Procedure Call



```
.
.
inc(x);
.
.
```

```
void inc(i) {
  g = g+i;
}
```

RPC: Remote Procedure Call



```
.
.
inc(a);
.
.
```

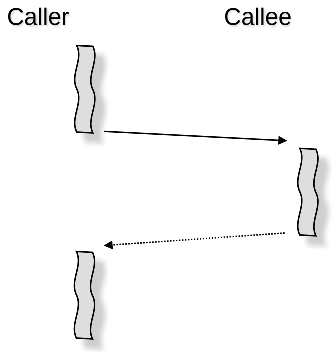
```
void inc(int[] h) {
  g = g+h[2];
  h[2] = g;
}
```

RPC: Remote Procedure Call

RPC is a mechanism that allows a program running on one computer (VM) to cause a procedure to be executed on another computer (VM) without the programmer needing to explicitly code for this.

Two processes involved:

- **Caller (RPC client)** is a **calling process** that initiates an RPC to a server.
- **Callee (RPC server)** is a **called process** that accepts the call.

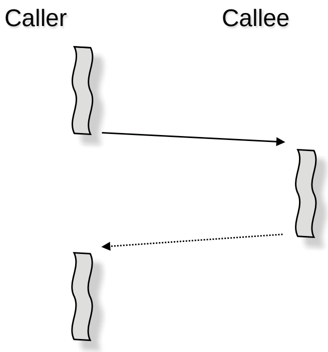


RPC: Remote Procedure Call (cont'd)

Each RPC is executed in a **separate process (thread)** on the server side

An RPC is a synchronous operation.

- The caller is suspended until the results of the remote procedure are returned.
- Like a regular or local procedure call.
- Guess why?



Identifying a Remote Procedure

Each RPC procedure is uniquely identified by

- – A program number
  - identifies a group of related remote procedures
- – A version number
- – A procedure number

An RPC call message has three unsigned fields:

- – Remote program number
- – Remote program version number
- – Remote procedure number

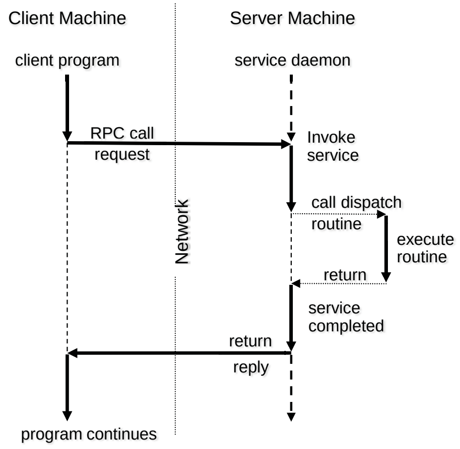
The three fields uniquely identify the procedure to be called.

Executing RPC

On each RPC the server starts a ***new process*** to execute the call.

- The new process terminates when the procedure returns and results are sent to the caller.
- Calls from the same caller and calls from different callers are serviced by ***different concurrent processes*** on server.

Concurrent invocations might interfere with each other when accessing shared objects – might need ***synchronization***



Open Network Computing (ONC) RPC (SunRPC)

- targeting intranet, file servers etc
- at-least-once call semantics
- procedures described in Interface Definition Language (IDL)
- XDR (eXternal Data Representation) specifies message structure
- used UDP as transport protocol (TCP also available)

Java RMI (Remote Method Invocation)

- similar to RPC but:
  - we now invoke methods of remote objects
  - at-most-once semantics
- Objects can be passed as arguments, how should this be done?
  - by value
  - by reference

Java RMI

We can do either:

A *remote object* is passed as a reference (*by reference*) i.e. it remains as at the original place where it was created.

A *serializable object* is passed as a copy (*by value*) i.e. the object is duplicated.

Finding the procedure/object

How do we locate a remote procedure/object/process?

Network address that specifies the location or..

a known “binder” process that keeps track of registered resources.

Remote Method Invocation (RMI)

Remote method invocation (RMI) is a mechanism to invoke a method on remote object, i.e. object in another computer or virtual machine.

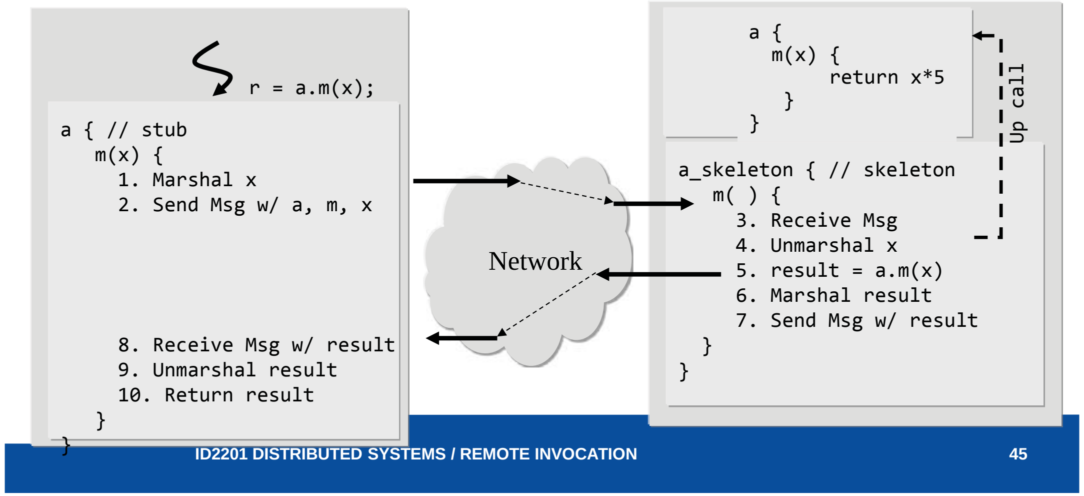
RMI is the object-oriented analog of RPC in an distributed OO environment, e.g. OMG CORBA, Java RMI, .NET

- RPC allows calling procedures over a network
- RMI invokes objects’ methods over a network

Location transparency: invoke a method on a stub like on a local object

Location awareness: the stub makes remote call across a network and returns a results via stack

Remote Method Invocation



```
r = a.m(x);
```

```
a { // stub
   m(x) {
     1. Marshal x
     2. Send Msg w/ a, m, x



     8. Receive Msg w/ result
     9. Unmarshal result
     10. Return result
   }
}
```

```
a {
   m(x) {
        return x*5
   }
}
```

```
a_skeleton { // skeleton
   m( ) {
     3. Receive Msg
     4. Unmarshal x
     5. result = a.m(x)
     6. Marshal result
     7. Send Msg w/ result
   }
}
```

Locating Objects

How does a caller get a reference to a remote object, i.e. stub?

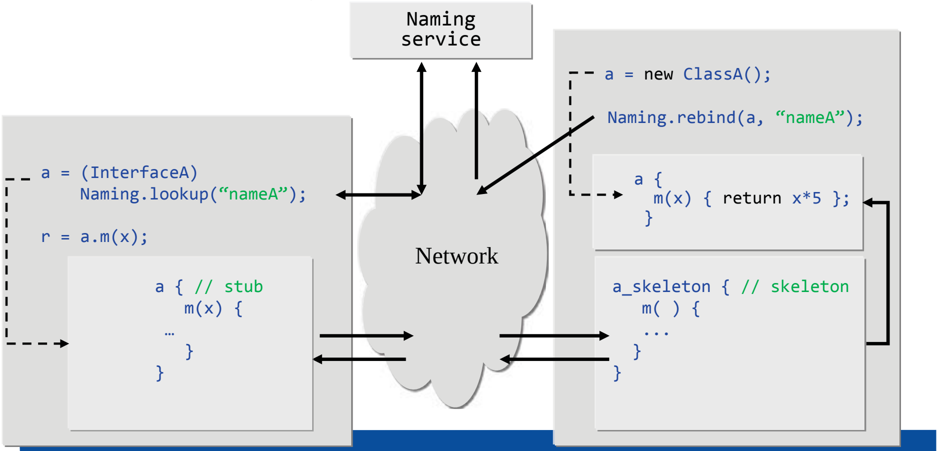
One approach is to use a ***Naming Service***:

- Associate a unique name with an object.
- Bind the name to the object at the Naming Service.
  - The record typically includes name, class name, object reference (i.e. location information) and other information to create a stub.
- The client looks up the object by name in the Naming Service.

The primary reference problem: How to locate the Naming Service?

- Configuration problem: URL of the naming service

Use of Naming Service



```
a = (InterfaceA)
    Naming.lookup("nameA");

r = a.m(x);
```

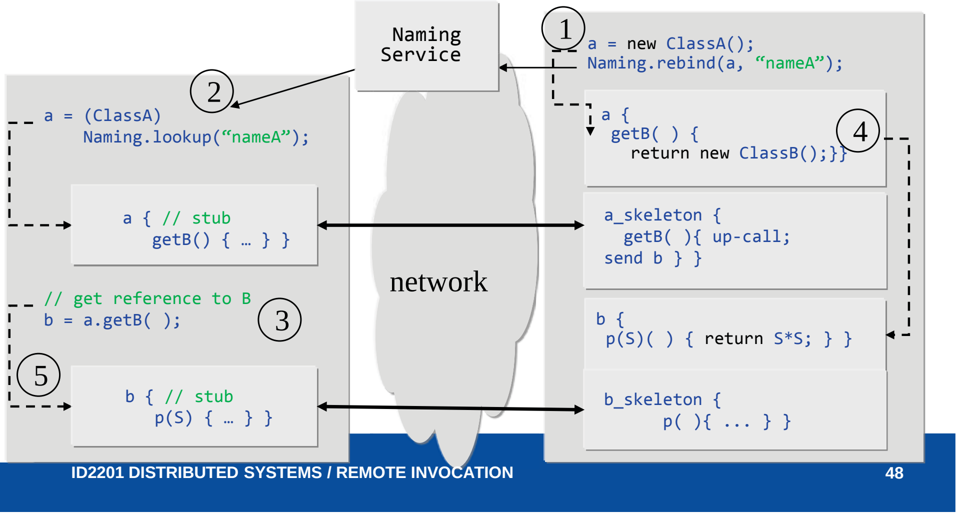
```
a { // stub
   m(x) {
  …
   }
}
```

```
a = new ClassA();

Naming.rebind(a, "nameA");
```

```
a {
  m(x) { return x*5 };
 }
```

```
a_skeleton { // skeleton
   m( ) {
   ...
  }
}
```

Remote Reference in Return



```
a = (ClassA)
    Naming.lookup("nameA");
```

```
a { // stub
   getB() { … } }
```

```
// get reference to B
b = a.getB( );
```

```
b { // stub
   p(S) { … } }
```

```
a = new ClassA();
Naming.rebind(a, "nameA");
```

```
a {
 getB( ) {
   return new ClassB();}}
```

```
a_skeleton {
  getB( ){ up-call;
send b } }
```

```
b {
 p(S)( ) { return S*S; } }
```

```
b_skeleton {
      p( ){ ... } }
```

Remote invocation design decisions

- failure handling: maybe / at-most-once / at-least-once
- call-by-value / call-by-reference
- message specification and encoding
- specification of resource
- procedure binder – naming service

Examples

- SunRPC: call-by-value, at-least-once, IDL, XDR, binder
- JavaRMI: call-by-value/reference, at-most-once, interface, JRMP (Java Remote Method Protocol), rmiregistry
- Erlang: message passing, maybe, no, ETF (External Term Format), local registry only
- CORBA (Common Object Request Broker Architecture): call-by-reference, IDL, ORB (Object Request Broker), tnameserv
- Web Services: WSDL (Web Services Description Language), UDDI (Universal Description, Discovery, and Integration)

Java RMI (Remote Method Invocation)

Java RMI is a mechanism that allows a thread in one JVM to invoke a method on a object located in another JVM.

- Provides ***Java native ORB (Object Request Broker)***

The Java RMI facility allows applications or applets running on different JVMs, to interact with each other by invoking remote methods:

- Remote reference (stub) is treated as local object.
- Method invocation on the reference causes the method to be executed on the remote JVM.
- Serialized arguments and return values are passed over network connections.
- Uses ***Object streams*** to pass objects “by value”.

RMI Classes and Interfaces

`java.rmi.Remote`

- Interface that indicates interfaces whose methods may be invoked from a non-local JVM -- remote interfaces.

`java.rmi.Naming`

- The RMI Naming Service client that is used to bind a name to an object and to lookup an object by name.

`java.rmi.RemoteException`

- The common superclass for a number of communication-related RMI exceptions.

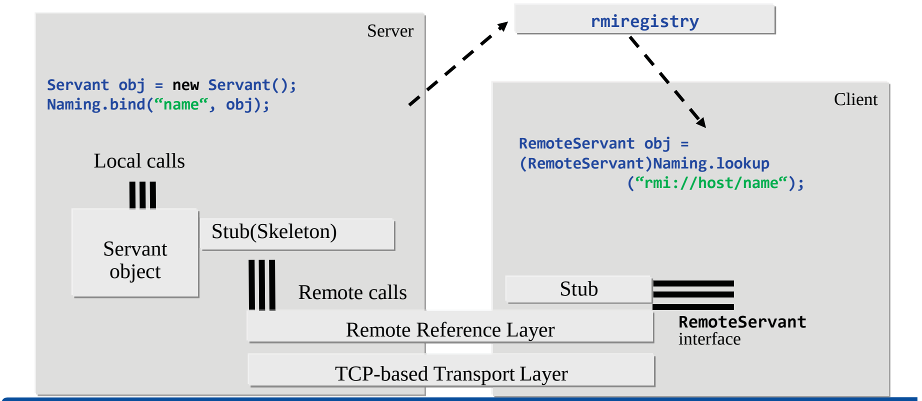
`java.rmi.server.UnicastRemoteObject`

- A class that indicates a non-replicated remote object.

Developing and Executing a Distributed Application with Java RMI

1. Define a remote interface(s) that extends `java.rmi.Remote`.
2. Develop a class (a.k.a. servant class) that implements the interface.
3. Develop a server class that provides a container for servants, i.e. creates the servants and registers them at the Naming Service.
4. Develop a client class that gets a reference to a remote object(s) and calls its remote methods.
5. Compile all classes and interfaces using `javac`.
6. Start the Naming service `rmiregistry`
7. Start the server on a server host, and run the client on a client host.

Architecture of a Client-Server Application with Java RMI



```
Servant obj = new Servant();
Naming.bind(“name“, obj);
```

```
RemoteServant obj =
(RemoteServant)Naming.lookup
        (“rmi://host/name“);
```

Summary

Implementations of remote invocations: procedures, methods, messages to processes,
have fundamental problems that needs to be solved.

Try to see similarities between different implementations.

When they differ, is it fundamentally different or just implementation details.