KTH ROYAL INSTITUTE
OF TECHNOLOGY

Remote Invocation

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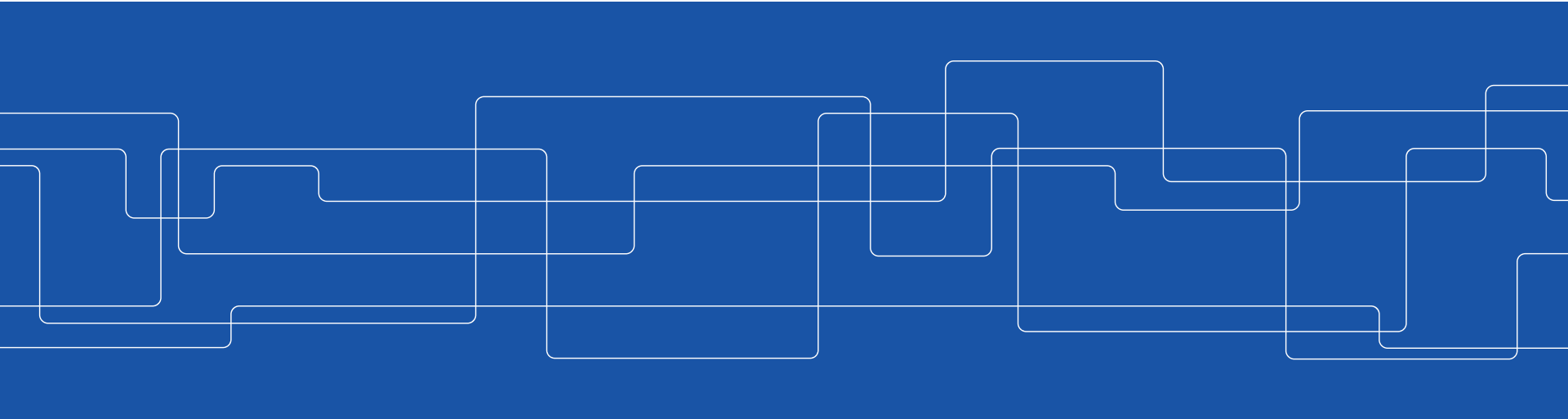
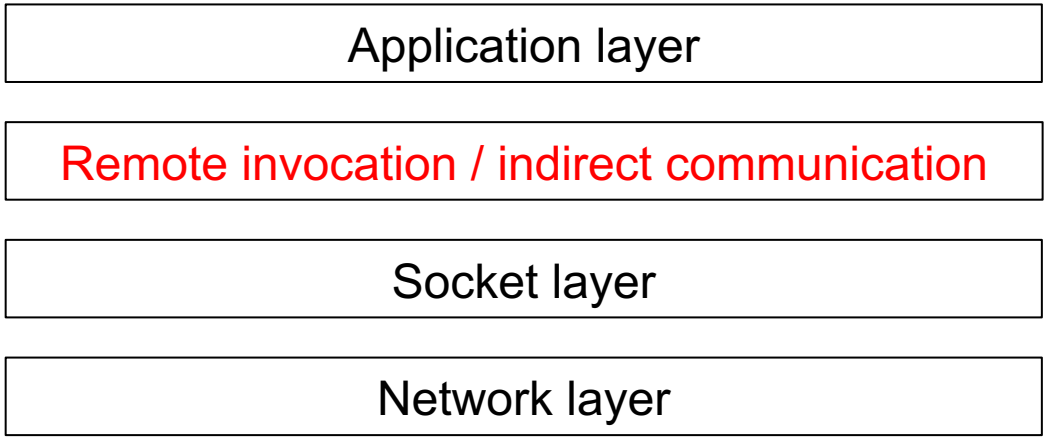
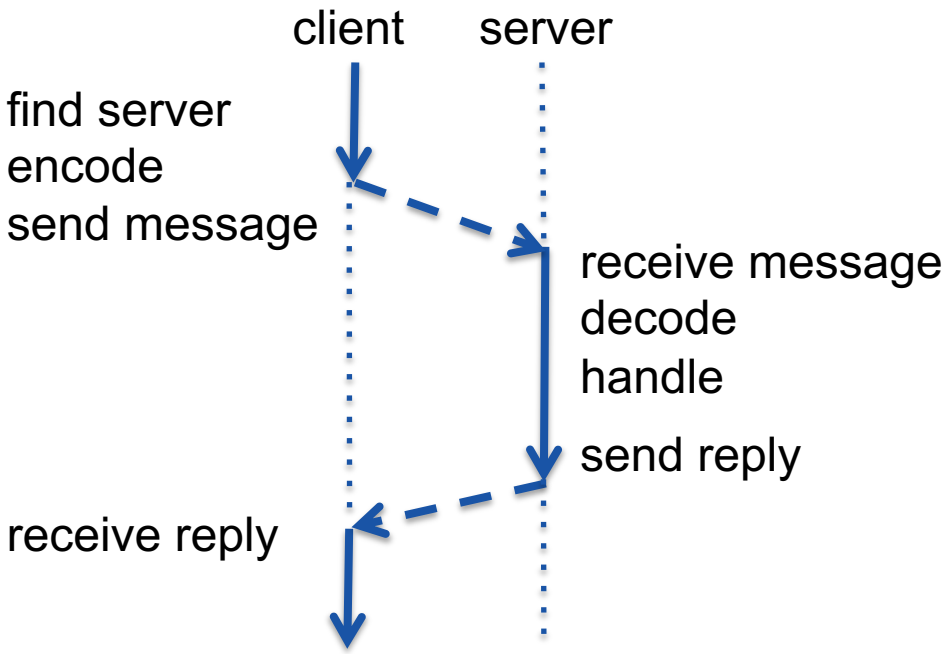


Middleware

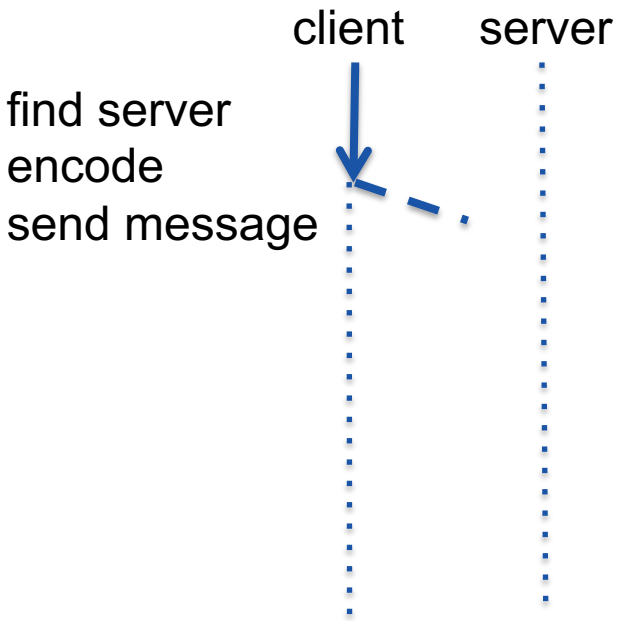

Application layer
Remote invocation / indirect communication
Socket layer
Network layer

Request / Reply



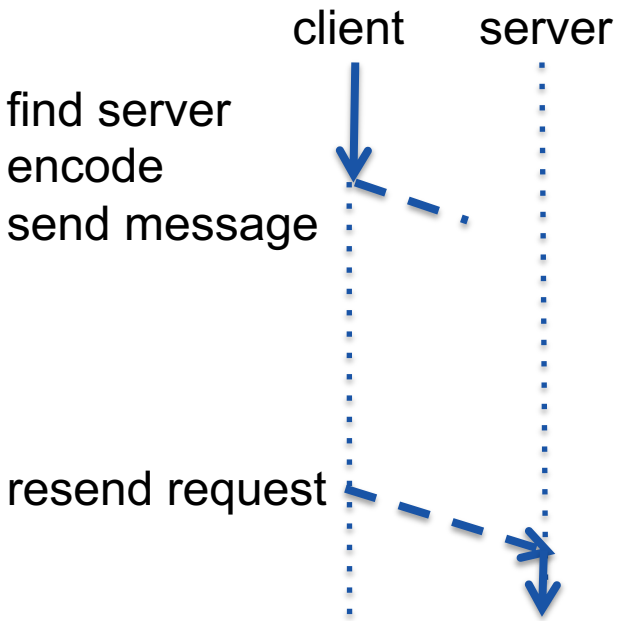
- identify and locate the server
- encode/decode the message
- send a reply to the right client
- attach a reply to the request

Lost request



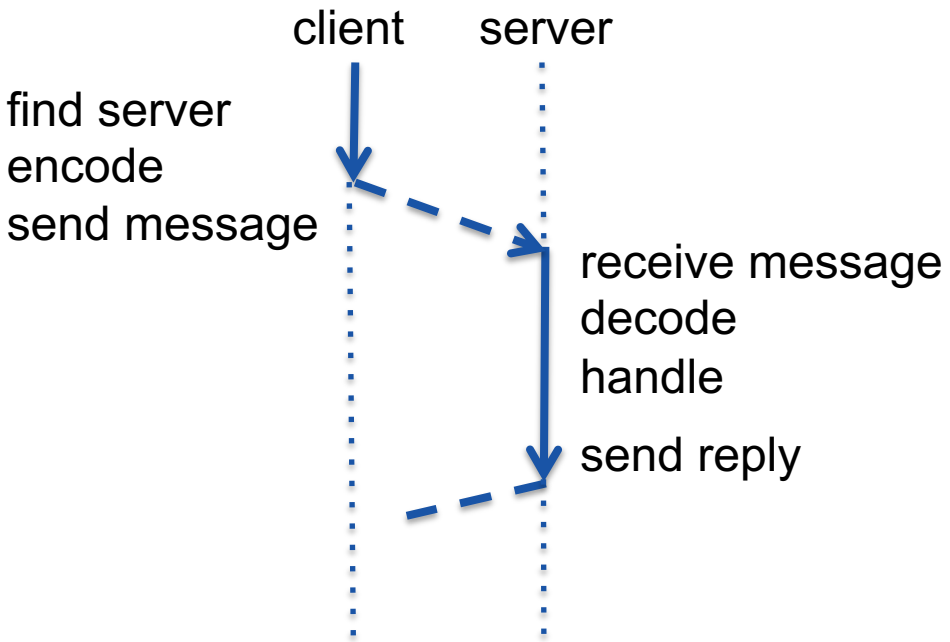
What do we do if the request is lost?

Resend request



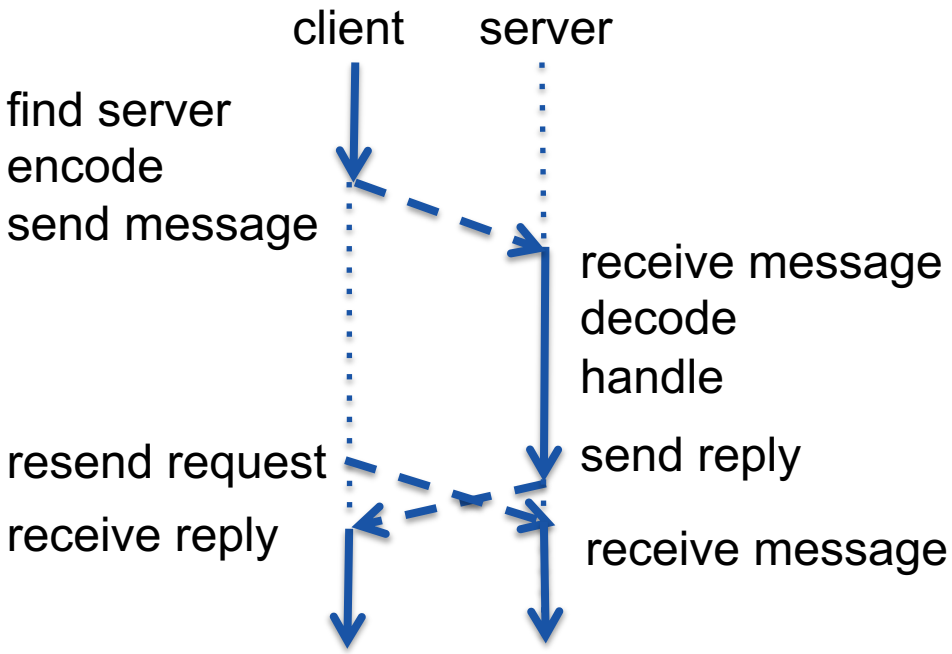
- need to detect that message is potentially lost
- wait for a timeout (how long) or error from the underlying layer
- resend the request
- simple, problem solved

Lost reply



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

Problem



- a problem
- the 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!

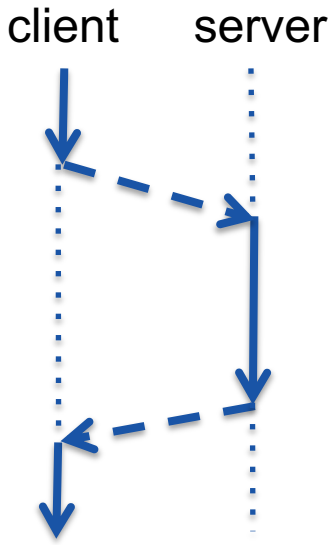
History

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

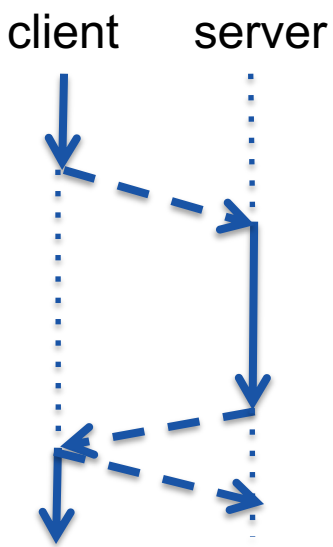
Keep a history of all requests and replies. The same reply can be sent without re-executing if a request is resent.

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 resending 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:

- the request might have been executed at most once

at-least-once:

- the request might have been executed at least once

At most or At least

Pros and cons:

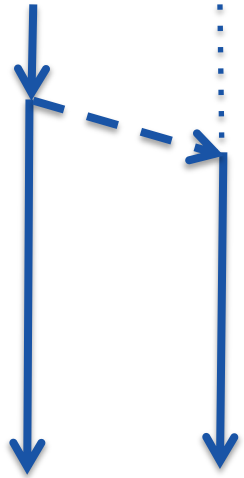
- *At-most-once without re-sending requests:*
  Simple to implement, not fault-tolerant
- *At-most-once with history:*
  Expensive to implement, fault-tolerant
- *At-least-once:*
  Simple to implement, fault-tolerant

Can you live with at-least-once semantics?

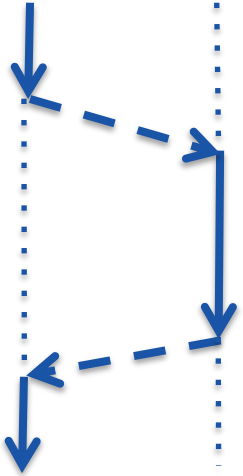
UDP or TCP

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

Synchronous or Asynchronous

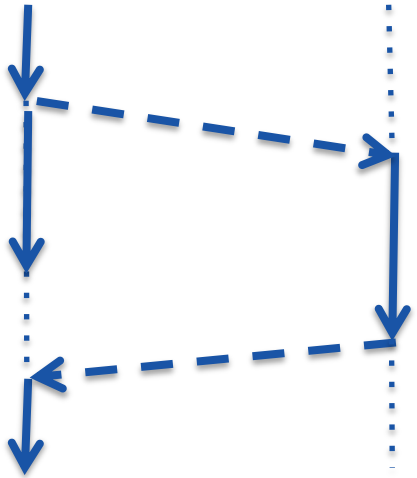


Asynchronous



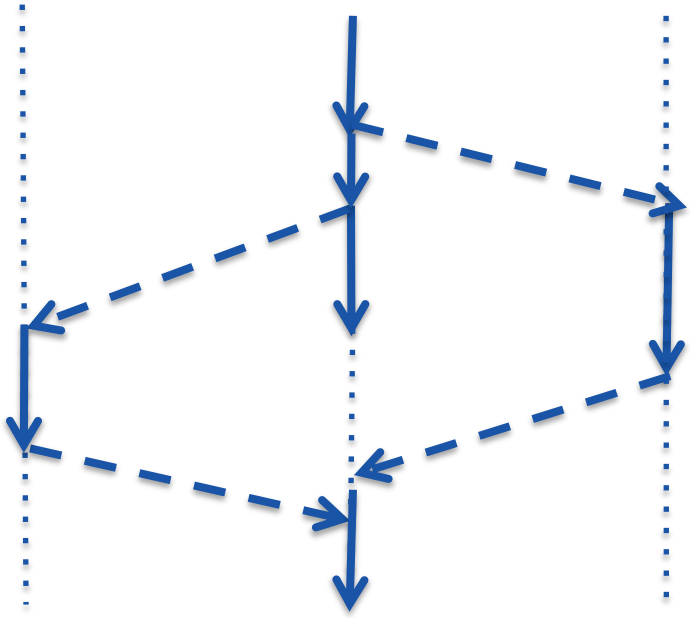
Synchronous

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]

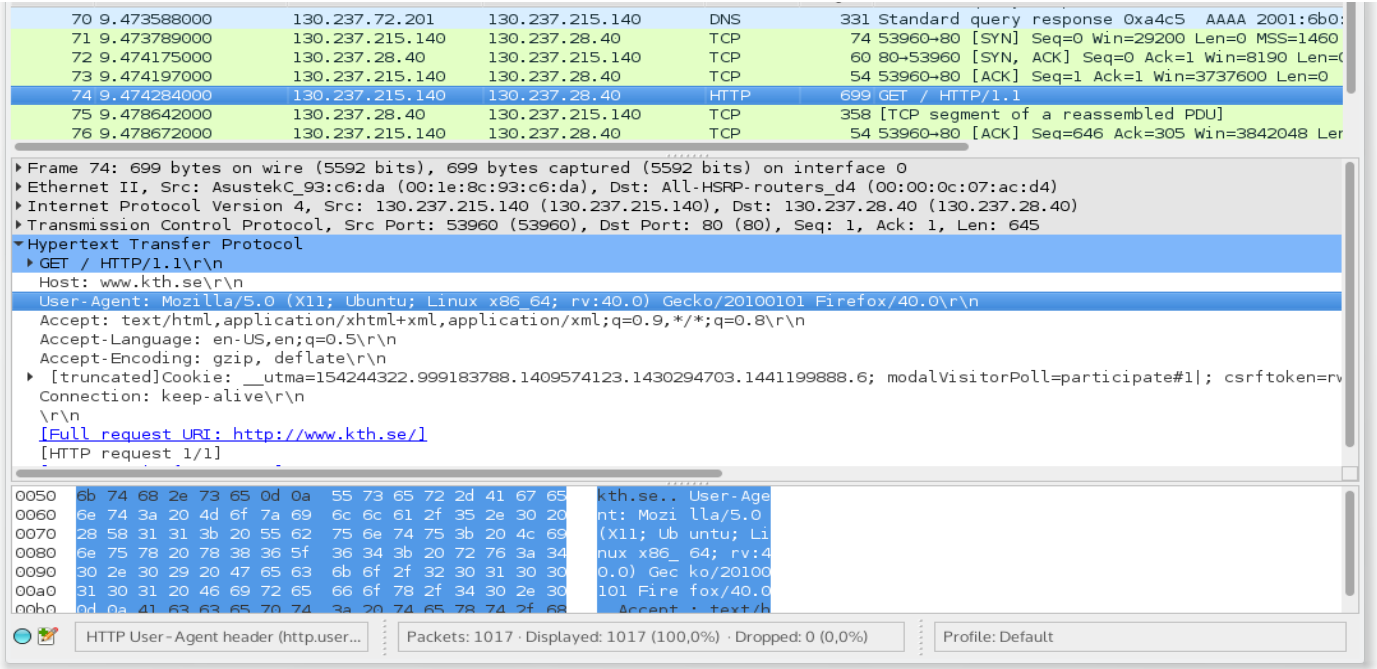
Request-Line = Method SP Request-URI SP HTTP-Version CRLF

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 the body, status of the 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=0
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=rv
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
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 an 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, . . .
  - lightweight,
- **SOAP (Simple Object Access Protocol)**
  - over HTTP, SMTP . . .
  - content described in SOAP/XML
  - standardized, heavyweight

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 the 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.

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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

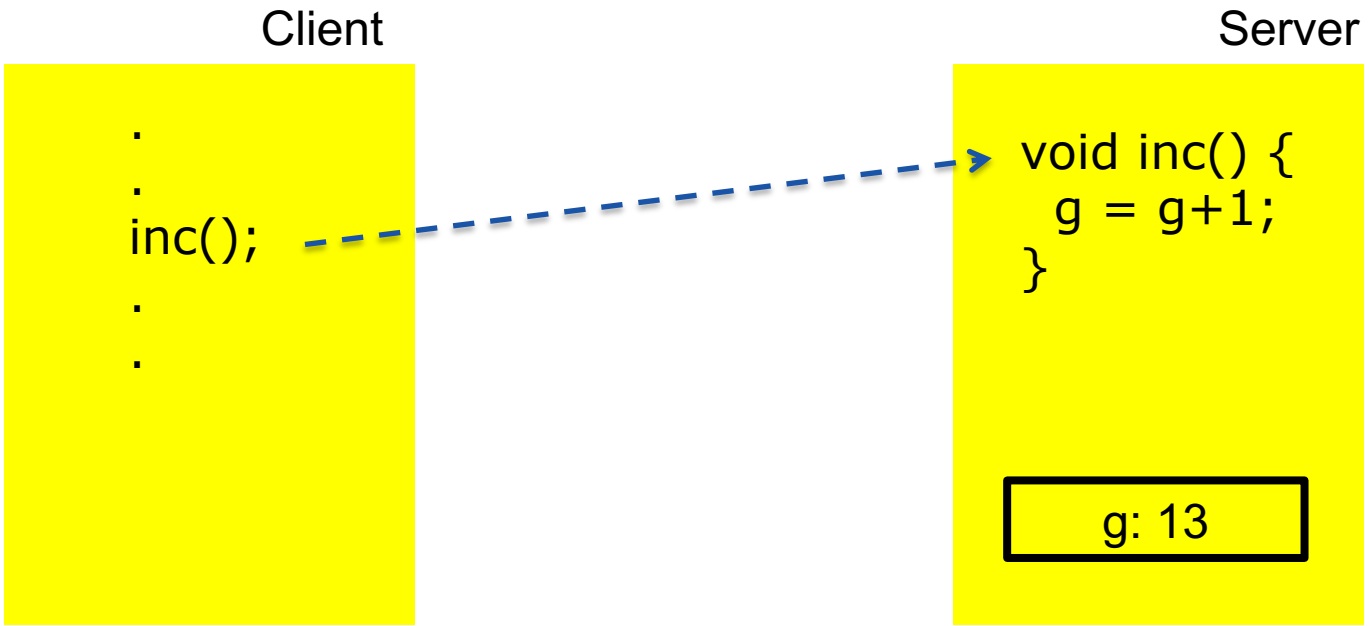
- A procedure is given a copy of the datum

Call by reference

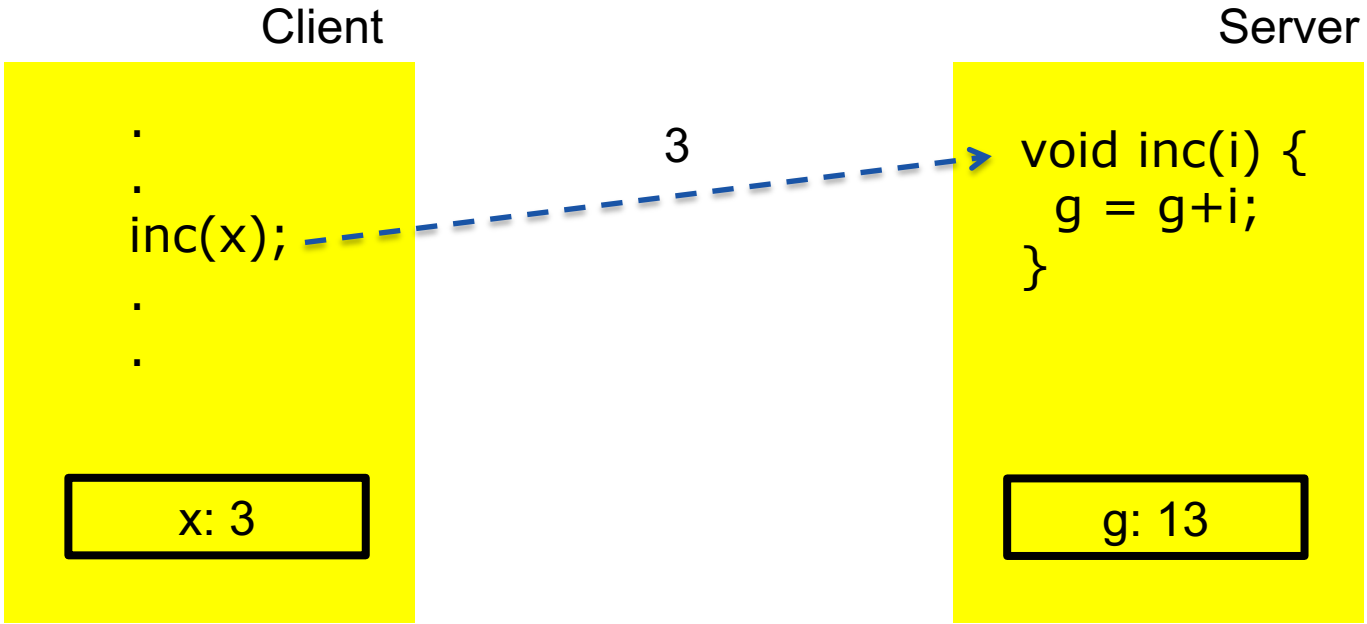
- A procedure is given a reference to the datum

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

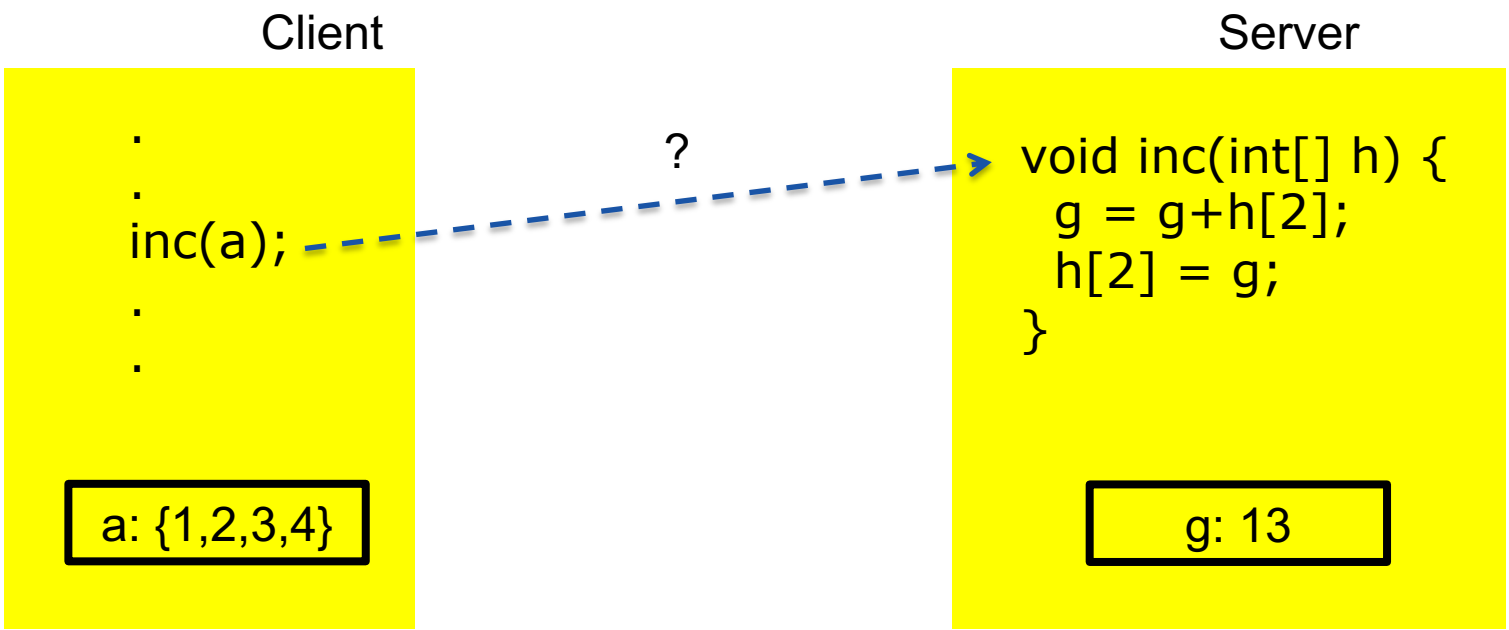
RPC: Remote Procedure Call



RPC: Remote Procedure Call



RPC: Remote Procedure Call

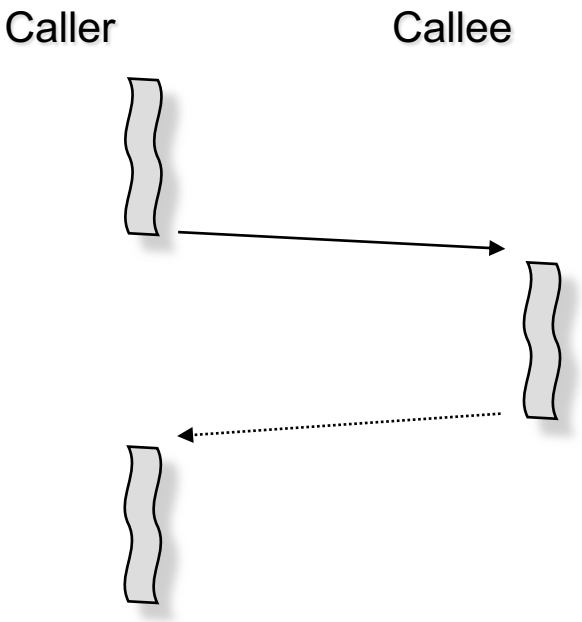


RPC: Remote Procedure Call

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 code for this explicitly.

Two processes are 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.

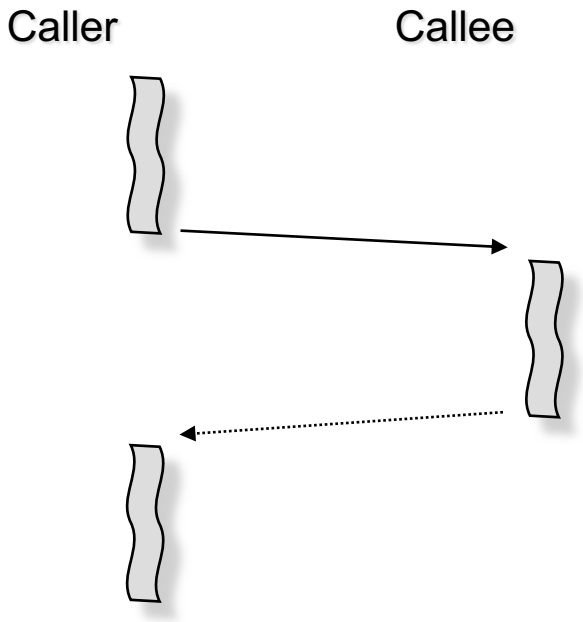


RPC: Remote Procedure Call (cont'd)

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

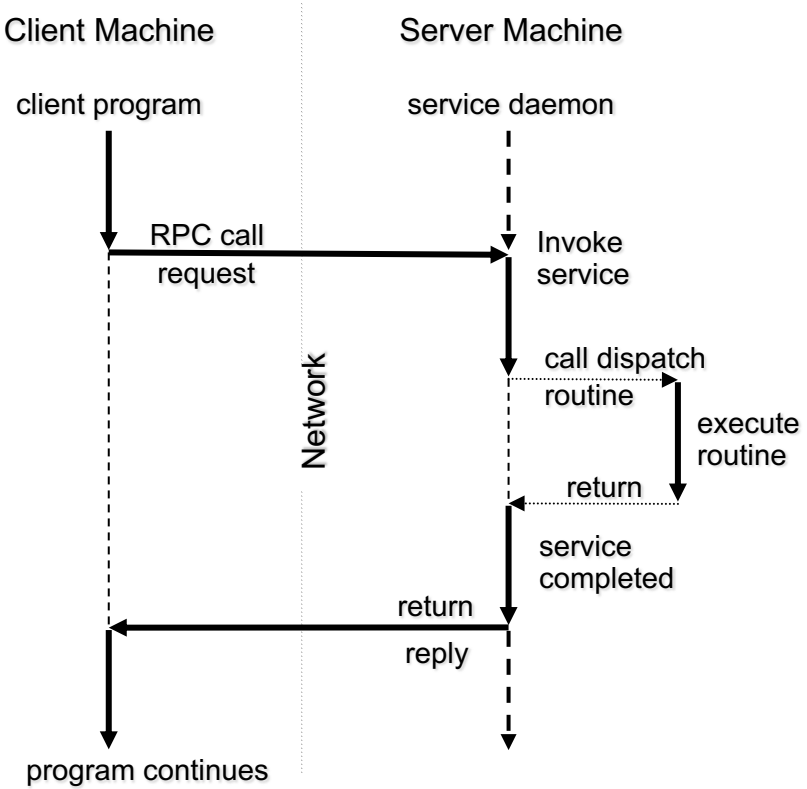
The three fields uniquely identify the procedure to be called.

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 the server.

Concurrent invocations might interfere when accessing shared objects – might need ***synchronization.***



An RPC Syntax

- Modules (Servers)

```
module mname
        interface, i.e. headers of exported operations;
body
      variable declarations;
      initialization code;
      procedures for exported operations;
      local procedures and processes;
end mname
```

- Exported operation (method of a remote interface)

```
op opname(formal identifiers) [returns result]
```

- Procedure – operation implementation

```
proc opname(formal identifiers) returns result identifier
      declarations of local variables;
      statements
end
```

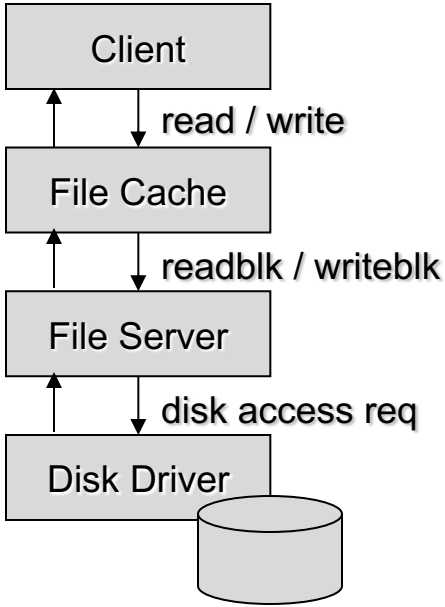
- Client makes a remote call to a module (server):

```
call mname.opname(arguments)
```

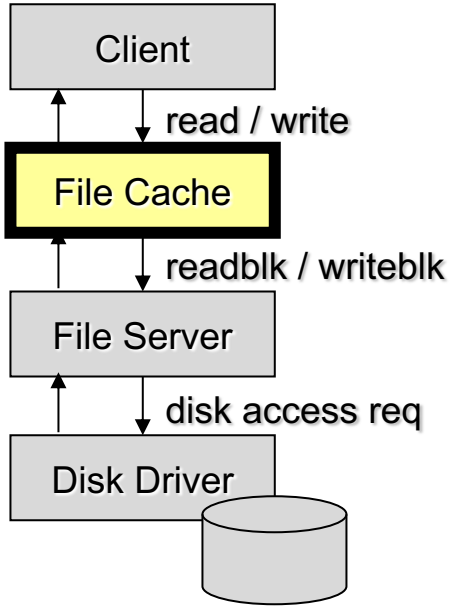
Example: A Distributed File System Using RPC

Modules (servers):

- **`FileCache`**
  - A write-back allocate-on-write cache of file blocks
  - Exports **`read`** and **`write`** operations
  - On a miss, calls remote **`FileServer`**
- **`FileServer`**
  - Provides access to file blocks stored on a disk
  - Exports **`readblk`** and **`writeblk`**
  - Uses the local **`DiskDriver`** process to access the disk.



The File Cache

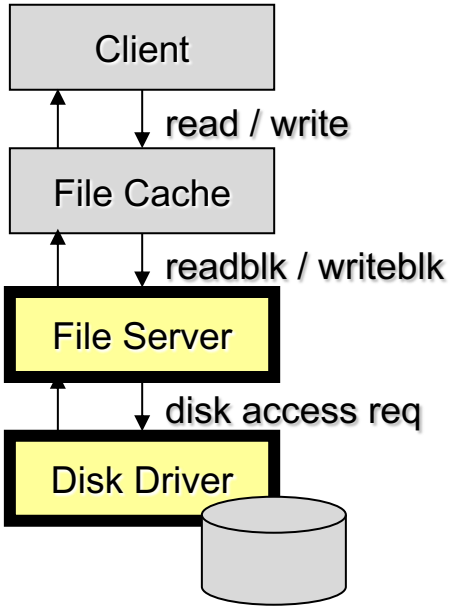



```
module FileCache    # located on each diskless workstation
  op read(int count; result char buffer[*]);
  op write(int count; char buffer[]);
body
  cache of file blocks;
  variables to record file descriptor information;
  semaphores for synchronization of cache access (if needed);

  proc read(count,buffer) {
    if (needed data is not in cache) {
      select cache block to use;
      if (need to write out the cache block)
        FileServer.writeblk(...);
      FileServer.readblk(...);
    }
    buffer = appropriate count bytes from cache block;
  }

  proc write(count,buffer) {
    if (appropriate block not in cache) {
      select cache block to use;
      if (need to write out the cache block)
        FileServer.writeblk(...);
    }
    cache block = count bytes from buffer;
  }
end FileCache
```

File Server and Disk Driver




```
module FileServer   # located on a file server
  op readblk(int fileid, offset; result char blk[1024]);
  op writeblk(int fileid, offset; char blk[1024]);
body
  cache of disk blocks;
  queue of pending disk access requests;
  semaphores to synchronize access to the cache and queue;
  # N.B. synchronization code not shown below

  proc readblk(fileid, offset, blk) {
    if (needed block not in the cache) {
      store read request in disk queue;
      wait for read operation to be processed;
    }
    blk = appropriate disk block;
  }

  proc writeblk(fileid, offset, blk) {
    select block from cache;
    if (need to write out the selected block) {
      store write request in disk queue;
      wait for block to be written to disk;
    }
    cache block = blk;
  }

  process DiskDriver {
    while (true) {
      wait for a disk access request;
      start a disk operation; wait for interrupt;
      awaken process waiting for this request to complete;
    }
  }
end FileServer
```

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 at the original place 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 a remote object, i.e., an object in another computer or virtual machine.

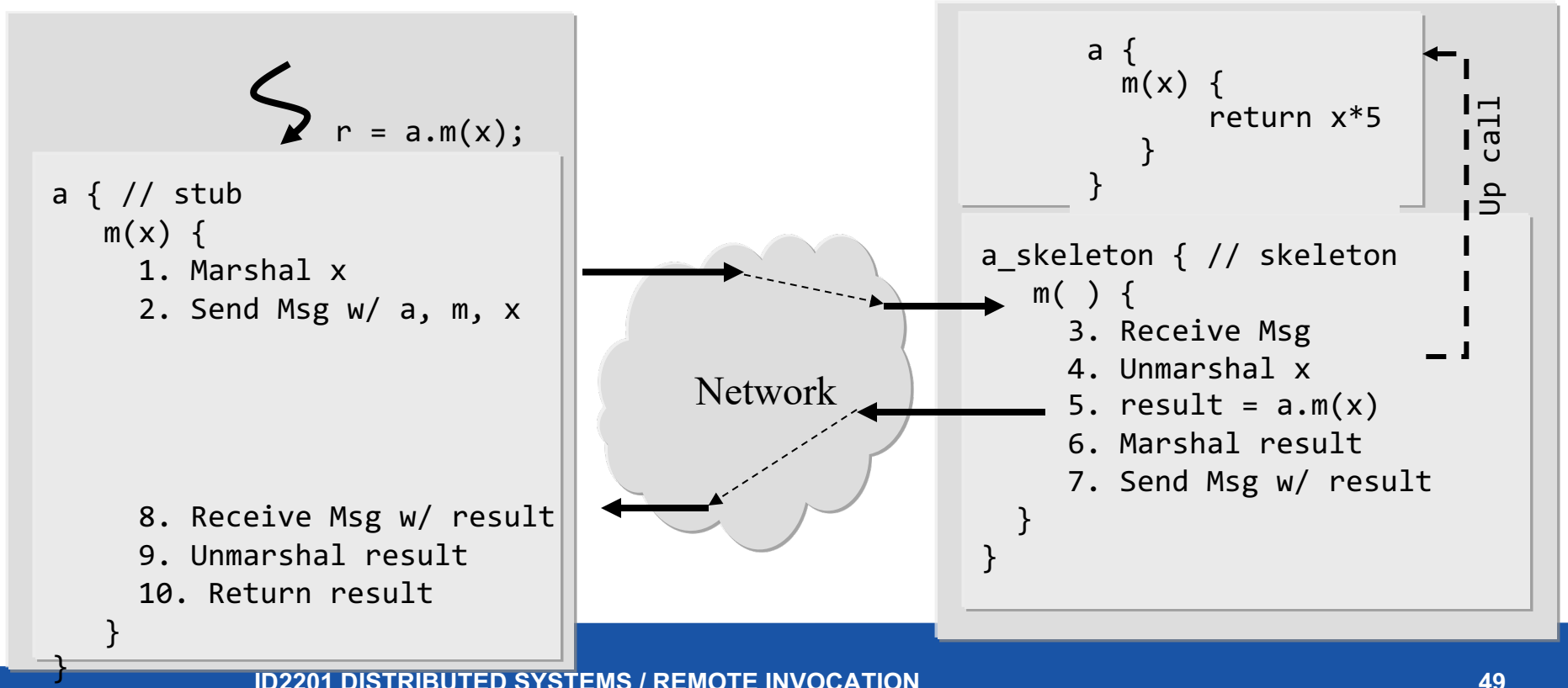
RMI is the object-oriented analog of RPC in a distributed OO environment, e.g., OMG CORBA, Java RMI, .NET

- 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 calls across a network and returns results via stack

Remote Method Invocation



Locating Objects

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

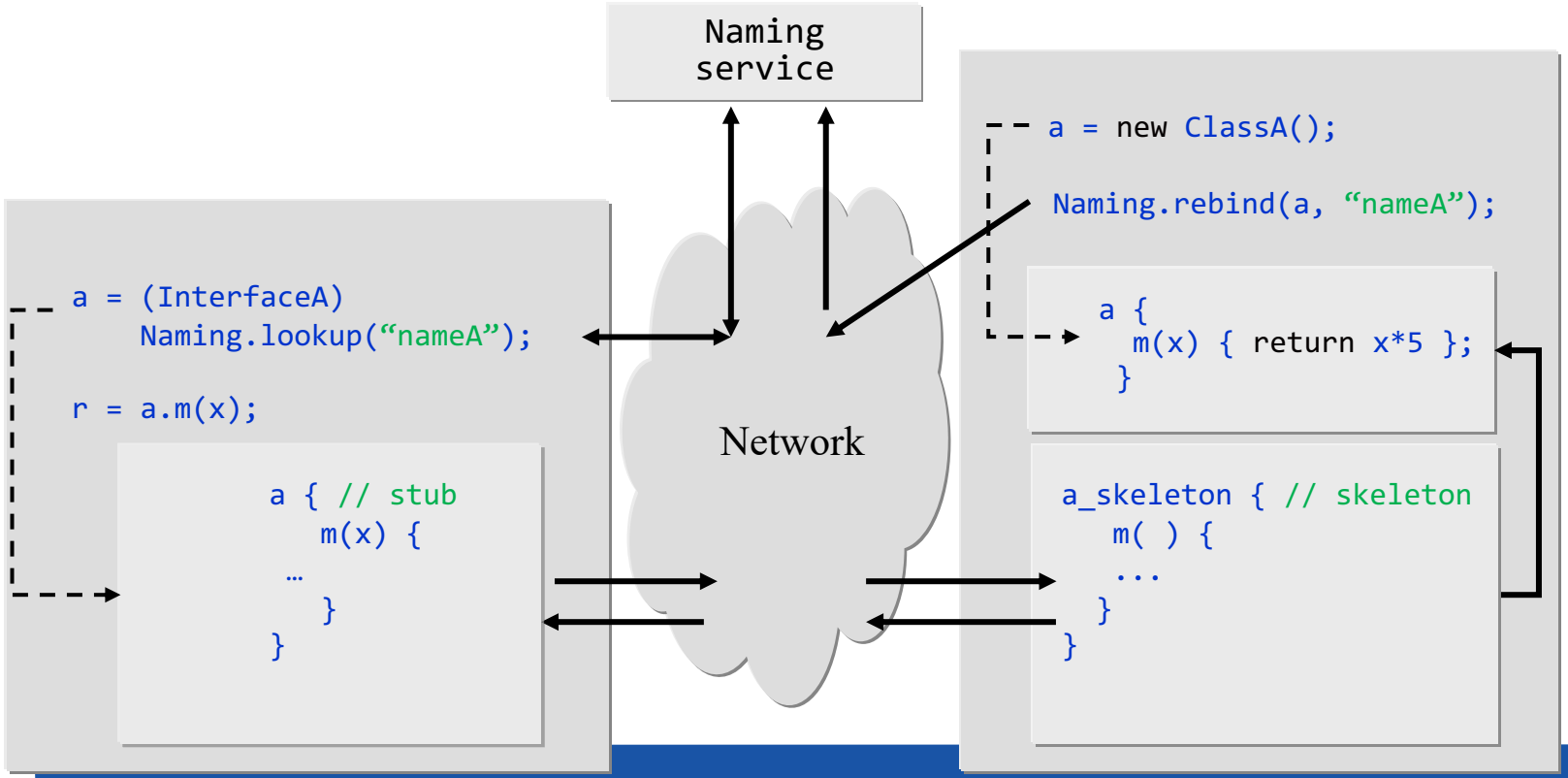
One approach is to use a ***Naming Service***:

- 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.

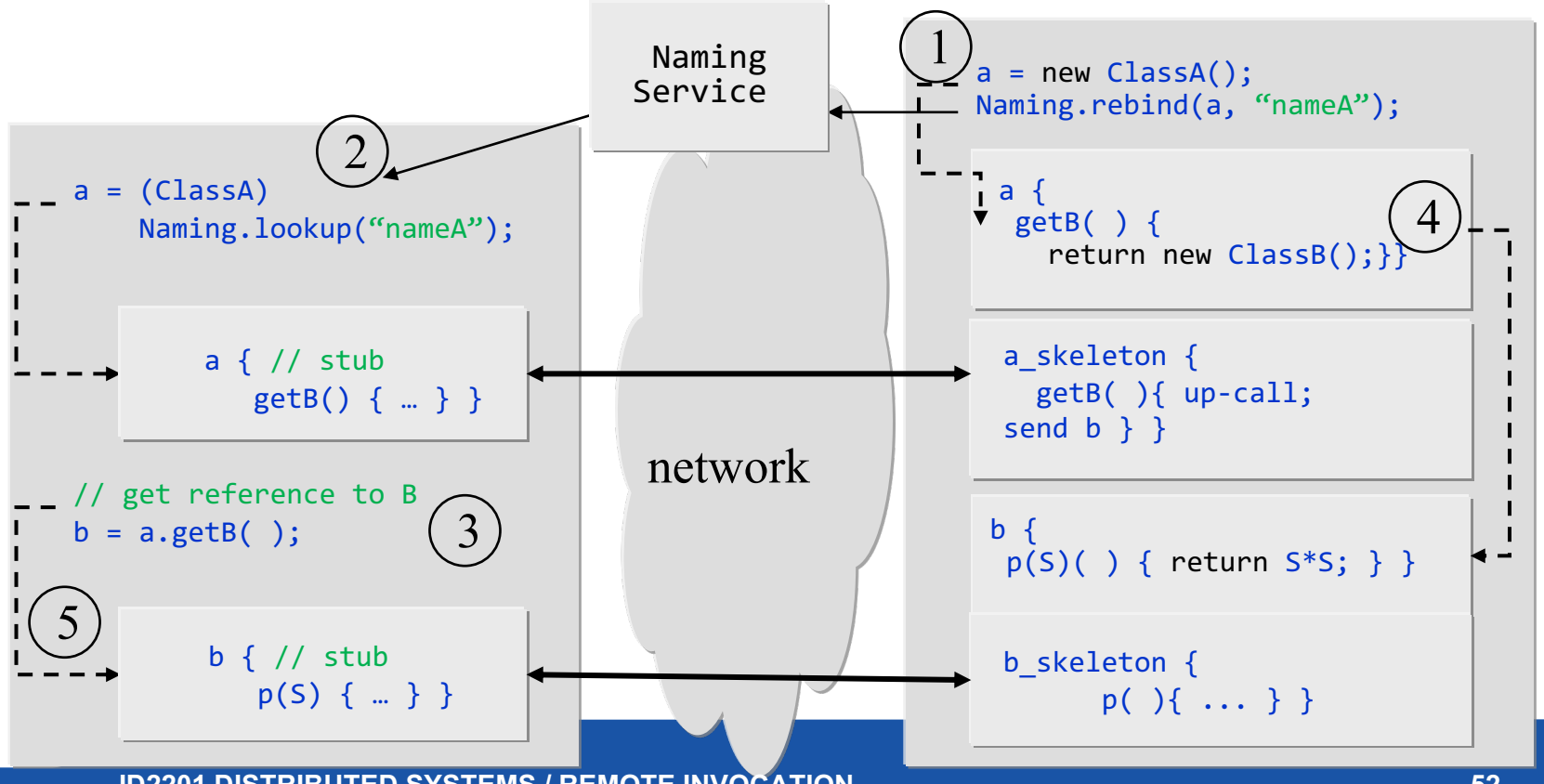
The primary reference problem: How to locate the Naming Service?

- Configuration problem: URL of the naming service

Use of Naming Service



Remote Reference in Return



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 an object located in another JVM.

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

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

- Remote reference (stub) is treated as a 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`

- The interface that indicates interfaces whose methods may be invoked from non-local JVM – remote interfaces.

`java.rmi.Naming`

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

`java.rmi.RemoteException`

- The common superclass for several communication-related RMI exceptions.

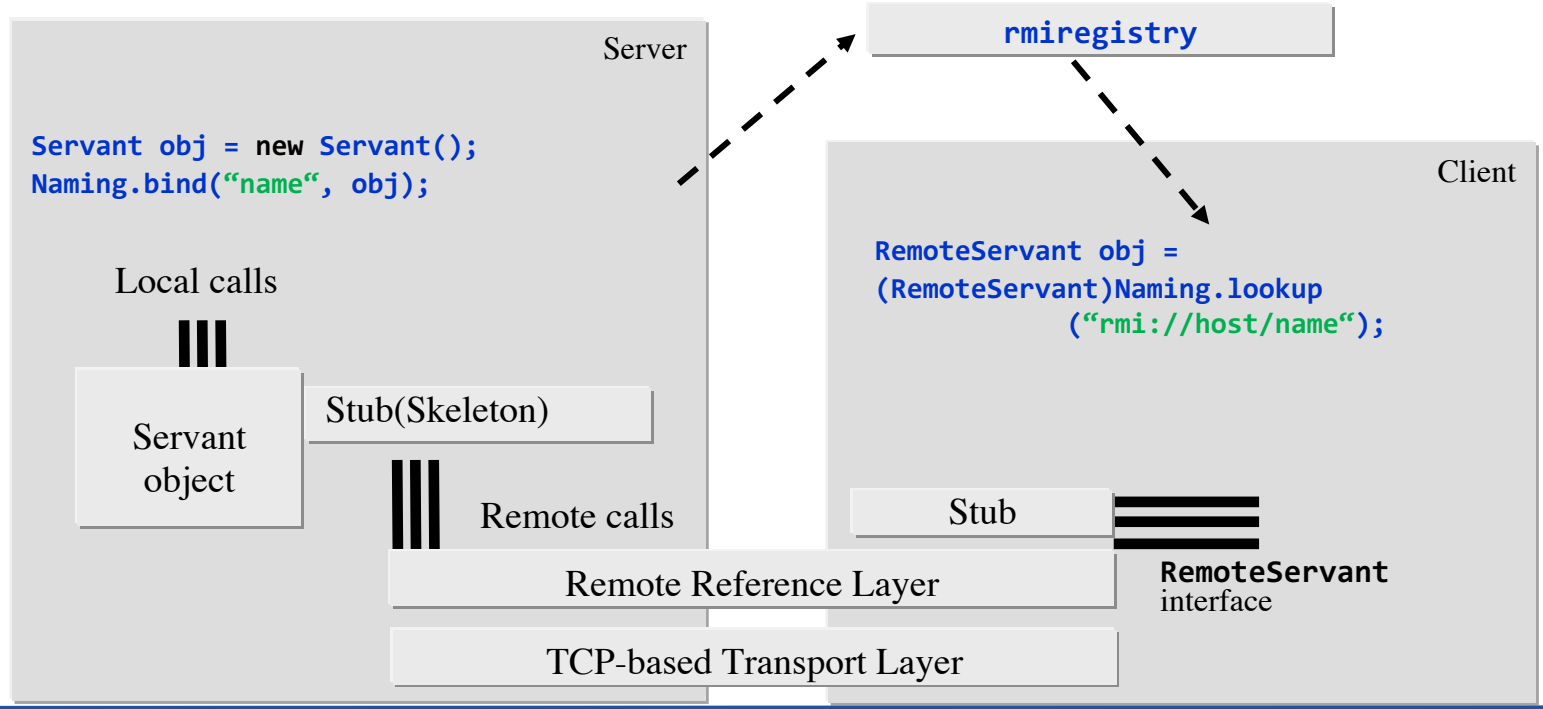
`java.rmi.server.UnicastRemoteObject`

- 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



Example: A Bank Manager

An application that controls accounts.

Remote interfaces:

- `Account` – deposit, withdraw, balance;
- `Bank` – create a new account, delete an account, get an account;

Classes that implement the interfaces:

- `BankImpl` – a bank servant class that implements the `Bank` interface used to create and delete accounts;
- `AccountImpl` – an account servant class implements the `Account` interface to access accounts.

Bank and Account Remote Interfaces

The **Bank** interface

```
package bankrmi;
import java.rmi.*;
import bankrmi.Account;
import bankrmi.Rejected;
public interface Bank extends Remote {
  public Account newAccount(String name) throws RemoteException, Rejected;
  public Account getAccount (String name) throws RemoteException;
  public boolean deleteAccount(String name) throws RemoteException, Rejected;
}
```

The **Account** interface

```
package bankrmi;
import java.rmi.*;
import bankrmi.Rejected;
public interface Account extends Remote {
  public float balance() throws RemoteException;
  public void deposit(float value) throws RemoteException, Rejected;
  public void withdraw(float value) throws RemoteException, Rejected;
}
```

A Bank Implementation

```
package bankrmi;
import java.rmi.server.UnicastRemoteObject;
import java.util.Hashtable;
import java.rmi.*;
import bankrmi.*;
public class BankImpl extends UnicastRemoteObject implements Bank {
  private String _bankname = "Noname";
  private Hashtable _accounts = new Hashtable(); // accounts
  public BankImpl(String name) throws RemoteException {
    super(); _bankname = name;
  }
  public BankImpl()  throws RemoteException {
    super();
  }
  public synchronized Account newAccount(String name) throws RemoteException, Rejected {
    AccountImpl account = (AccountImpl) _accounts.get(name);
    if (account != null) {
      System.out.println("Account [" + name + "] exists!!!");
      throw new Rejected("Rejected: Bank: " + bankname +  " Account for: " + name + " already exists: " + account);
    }
    account = new AccountImpl(name);
    _accounts.put(name, account);
    System.out.println("Bank: " + _bankname + " Account: " + name + " Created for " + name);
    return (Account)account;
  }
  . . .
```

An Account Implementation

```
package bankrmi;
import java.rmi.server.UnicastRemoteObject;
import java.rmi.*;
import bankrmi.*;
public class AccountImpl extends UnicastRemoteObject implements Account {
  private float _balance = 0;
  private String _name = "noname";
  public AccountImpl(String name) throws RemoteException {
    super();
    this.name = name;
  }
  public AccountImpl() throws RemoteException  {
    super();
  }
  public synchronized void deposit(float value) throws RemoteException, Rejected {
    if (value < 0) throw new Rejected("Rejected: Account " + name + ": Illegal value: " + value);
    _balance += value;
    System.out.println("Transaction: Account "+name+": deposit: $" + value + ", balance: $" + _balance);
  }
  public synchronized void withdraw(float value) throws RemoteException, Rejected {
    …
  }
  public synchronized float balance() throws RemoteException { return _balance; }
}
```

The Server

```
package bankrmi;
import java.rmi.*;
import bankrmi.*;
public class Server {
  static final String USAGE = "java bankrmi.Server <bank_url>";
  static final String BANK = "NordBanken";
  public Server(String[] args) {
    String bankname = (args.length > 0)? args[0] : BANK;
    if (args.length > 1 || bankname.equalsIgnoreCase("-h")) {
      System.out.println(USAGE);
      System.exit(1);
    }
    try {
      Bank bankobj = (Bank)(new BankImpl(bankname));
      Naming.rebind(bankname, bankobj);
      System.out.println(bankobj + " is ready.");
    } catch (Exception e) { System.out.println(e); }
    Object sync = new Object();
    synchronized(sync) { try { sync.wait();} catch (Exception ie) {}}
  }
  public static void main(String[] args) {
    new Server(args).start();
  }
}
```

A Client

```
package bankrmi;
import bankrmi.*;
import java.rmi.*;
public class SClient {
    static final String USAGE = "java Client <bank_url> <client> <value>";
    String bankname = “Noname", clientname = “Noname"; // defaults
    float value = 100;
    public SClient(String[] args) {
                // Read and parse command line arguments (see Usage above)
        ...
                try {
                  Bank bankobj = (Bank)Naming.lookup(bankname);
                  Account account = bankobj.newAccount(clientname);
                  account.deposit(value);
                  System.out.println (clientname + "'s account: $" + account.balance());
                } catch (Exception e) {
                  System.out.println("The runtime failed: " + e);
                  System.exit(0);
        }
    }
    public static void main(String[] args) {
      new SClient(args);
    }
}
```

Summary

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

Try to see similarities between different implementations.

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