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Communication in Distributed Systems
Part 1

Corso di Sistemi Distribuiti e Cloud Computing

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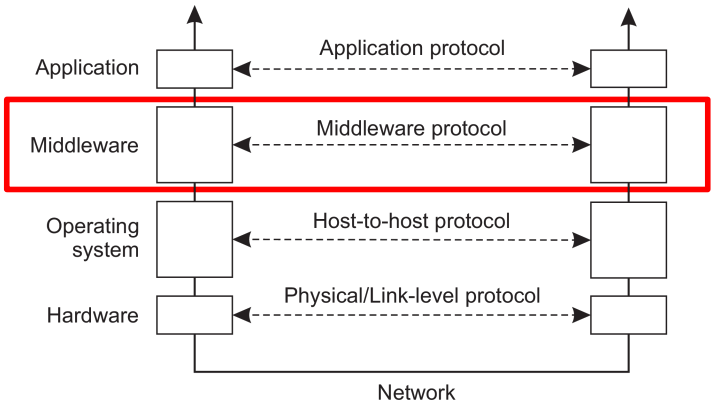
Laurea Magistrale in Ingegneria Informatica

Communication in distributed systems

- Based on message passing
  - Send and receive messages
- To allow for message passing, parties must agree on many low-level details
  - How many volts to signal a 0 bit and how many for a 1 bit?
  - How many bits for an integer?
  - How does the receiver know which is the last bit of the message?
  - How can the receiver find if a message has been corrupted and what to do then?

Basic networking model and its adaptation

- We know the solution: divide network communication in layers
  - The well known ISO/OSI reference model
  - We don't care about low-level details: for many distributed systems, the lowest-level interface is that of the network layer
- An adapted layering scheme



Middleware protocols

- **Middleware layer**: provides common services and general-purpose protocols
  - high-level
  - independent of specific applications
  - can be used by other applications
- Some examples:
  - Communication protocols: to call remote procedures or remote methods, queue messages, support multicasting and streaming
  - Naming protocols: to share resources among applications
  - Security protocols: to allow applications to communicate securely
  - Distributed consensus protocols, including distributed commit (to establish that a transaction is completed by all involved parties or has no effect)
  - Distributed locking protocols
  - Data consistency protocols

Types of communication

- Let's distinguish
  - Persistency
    - Transient versus persistent communication
      (volatili)
  - Synchronization
    - Synchronous vs. asynchronous communication
  - Time dependence
    - Discrete vs. streaming communication

importante è gestione errori di comunicazione

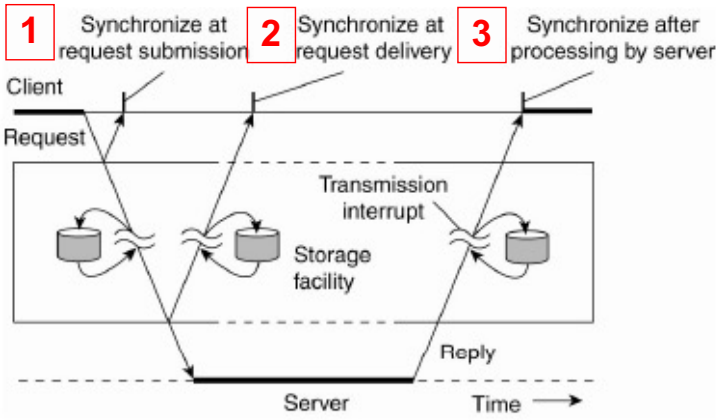
Persistent vs. transient communication

- Persistent communication
  - Message is stored by communication middleware as long as it takes to deliver it to receiver
  - Sender does not need to continue execution after submitting the message
  - Receiver does not need to be executing when message is submitted (msg memorizzato → non deve essere online quando viene inviato)
- Transient communication
  - Message is stored by middleware only as long as sender and receiver are executing: sender and receiver have to be active at time of communication
  - If delivery is not possible, message is discarded
  - Transport-layer example: routers store and forward, but discard if forward is not possible

Synchronous communication

- Once the message has been submitted, sender is blocked until operation is completed
- Send and receive are *blocking* operations
- How long is sender blocked? Alternatives:
  1. until middleware takes over request transmission
  2. until message is delivered to receiver
  3. until message is fully processed by receiver

1] bloccato fino a che middleware manda ACK inviato
2] aspetto ACK middleware che conferma arrivo msg.
3] aspetto processamento del messaggio.



Asynchronous communication

- Once message has been submitted, sender continues its processing: message is temporarily stored by middleware until it is transmitted
- Send is a non-blocking operation, receive can be blocking or non-blocking

↳ uso "notify"

Discrete vs. streaming communication

- Discrete communication
  - Each message forms a complete unit of information

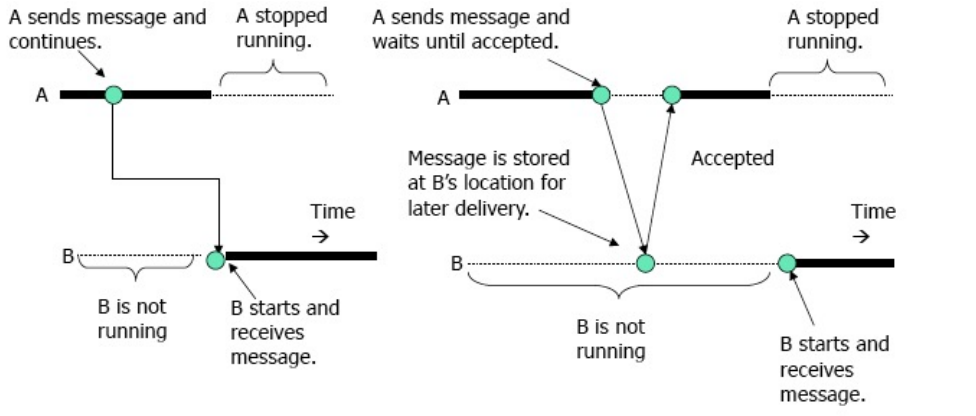
- Streaming communication
  - Involves sending multiple messages, in temporal relationship or related to each other by sending order, which is needed to reconstruct complete information

Combining communication types

- Combination of persistence and synchronization

a) Persistent and asynchronous communication
  - E.g., email, Teams chat

b) Persistent and synchronous communication
  - Sender blocked until the (guaranteed) message copy is delivered to receiver

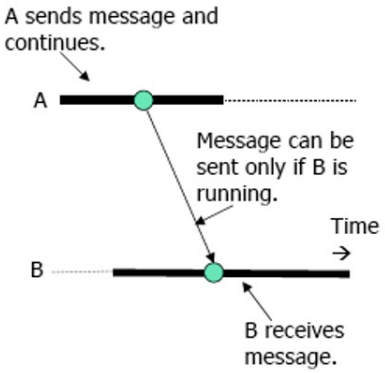


(a) Persistent asynchronous communication (b) Persistent synchronous communication

Combining communication types

- Combination of persistence and synchronization

c) Transient and asynchronous communication
  - Sender does not wait but message can be lost if receiver is unreachable (e.g., UDP)

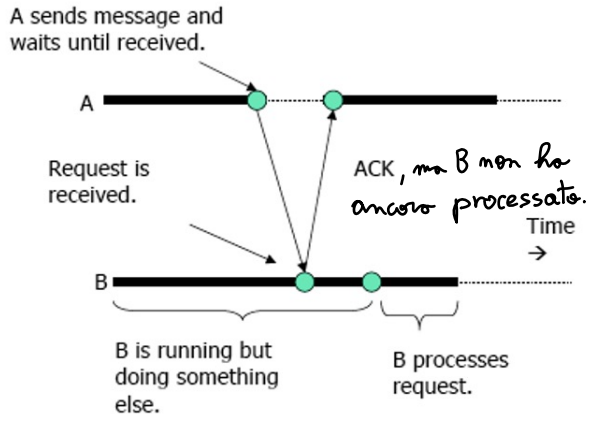


A e B presenti al momento dello scambio (transiente)
A, dopo aver inviato msg, fa altro (asincrona)

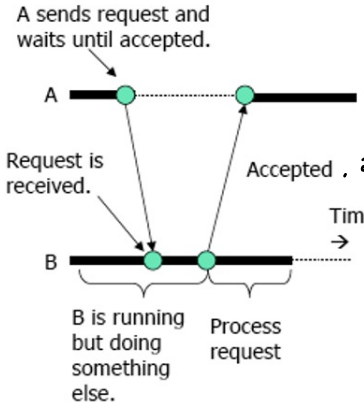
(c)Asynchronous communication

Combining communication types

- Multiple options for transient and synchronous communication
  - d) Receipt-based synchronous: sender blocked until message copy is in receiver space (e.g., asynchronous RPC)
  - e) Delivery-based synchronous: sender blocked until message is delivered to receiver



(d) Receipt-based synchronous communication

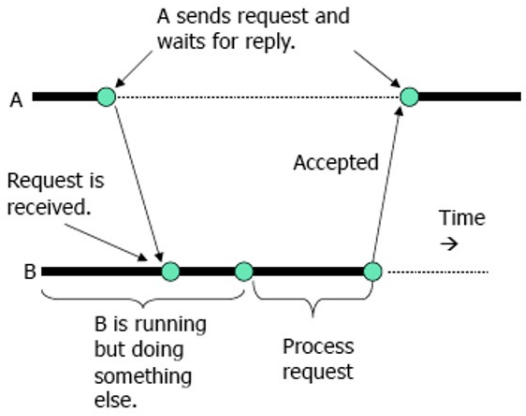


aspetto consegna al destinatario da parte del Middleware

(e) Delivery-based synchronous communication

Combining communication types

- Multiple options for transient and synchronous communication
  - f) Response-based synchronous: sender blocked until it receives a reply message from receiver (e.g., synchronous RPC and RMI)



(f) Response-based synchronous communication

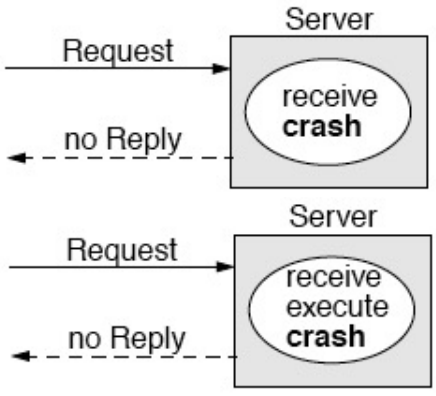
gestione

Failure semantics during communication

- Different types of failure in communication between sender (client) and receiver (server)

1. Request and/or reply message can be lost or delayed, or connection reset
   - *Network is reliable* ("The Eight Fallacies of Distributed Computing")
2. Server can crash
   - a) before performing the requested service
   - b) after performing the requested service
   - client cannot distinguish between a and b

client non sa distinguerle! → da risolvere nelle RPC / RMI



3. Client can crash

Failure semantics during communication

- What is the semantics of communication in the presence of failures in a DS?
  - **May-be** semantics
  - **At-least-once** semantics
  - **At-most-once** semantics
  - **Exactly-once** semantics

- Failure semantics applies both to service processing (e.g., RPC) and message delivery (e.g., MOM)
  - Let's focus on service processing

dobbiamo applicarle anche nel message delivery

Basic mechanisms for failure semantics

- Failure semantics depends on the combination of the following 3 basic mechanisms

1. Client side: Request Retry (RR1), ritrasmissione richiesta!
   - Client keeps trying until it gets a reply or is confident about server failure after a certain number of failed retries
2. Server side: Duplicate Filtering (DF)
   - Server discards any duplicate request from the same client
3. Server side: Result Retransmit (RR2)
   - Server keeps result to be able to retransmit it without recalculating in case it receives a duplicate request
     - Needed if operation performed by server is not idempotent

       Idempotent operation (i.e., without side effects): multiple executions of the operation produce the same effect/result as a single execution of the operation, e.g., read-only operation or x = 1

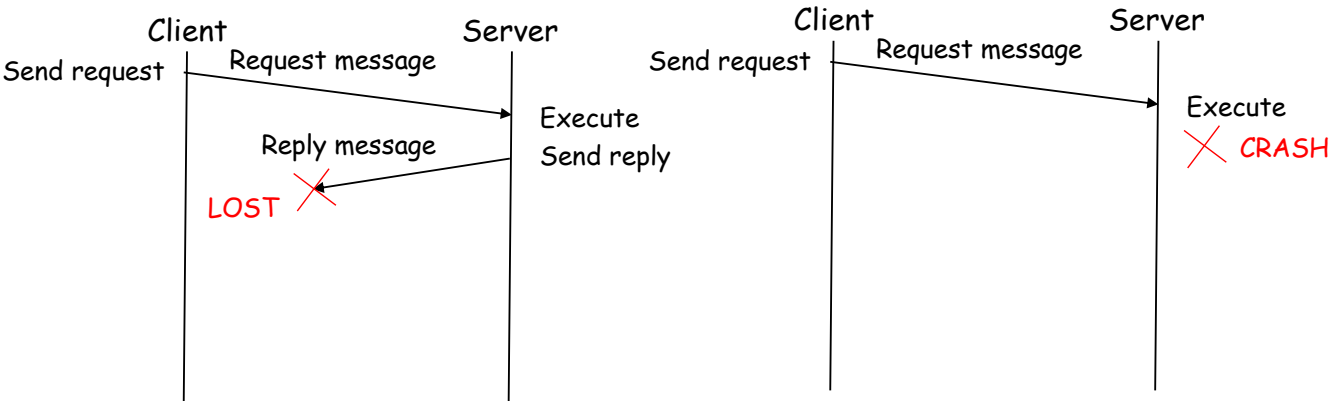
server ha già processato la richiesta? da inviare

Con servizi NON IDEMPOTENTI, poiché $f(f(f(x)))$ cambia!

deve informare il client!

May-be semantics ("best-effort")

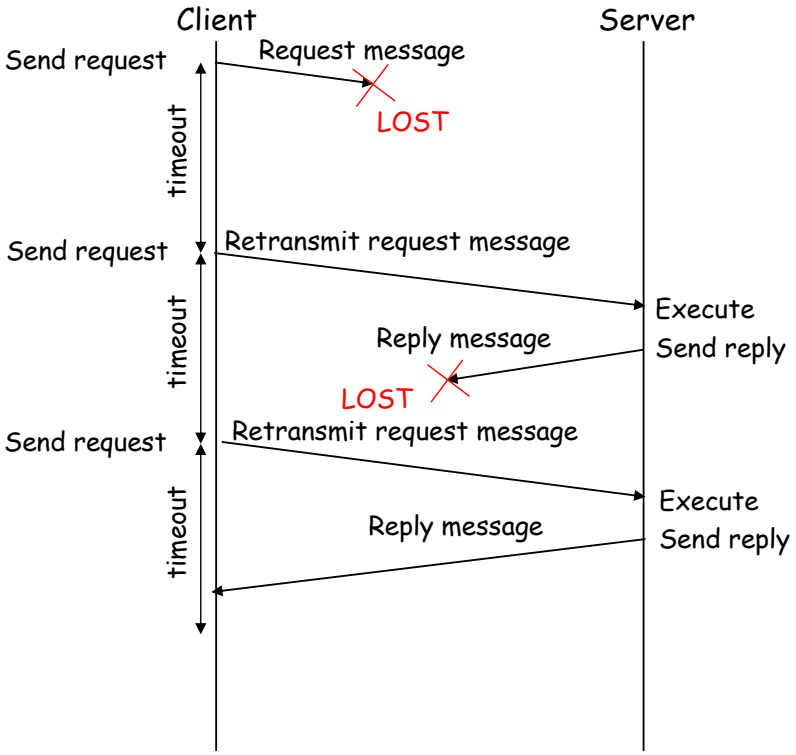
- No guarantee that the operation has been executed or not on server
- No action is taken to ensure the reliability of communication: no mechanism (RR1, DF, RR2) is used
- E.g., best-effort in UDP



At-least-once semantics

- The service, if executed, has been executed at least once
  - Could be several times, because of request duplication due to retransmissions
- Client uses RR1, server uses neither DF nor RR2
  - Server is not aware of duplicates
- Suitable for idempotent services (stateless server)
- Upon response receipt, client does not know how many times its request has been processed by server (at least once): client does not know about server status
  - The server may have executed the requested service but crashed before sending the response: when the timeout expires, the client resends the request and server executes the service again and sends the response to the client

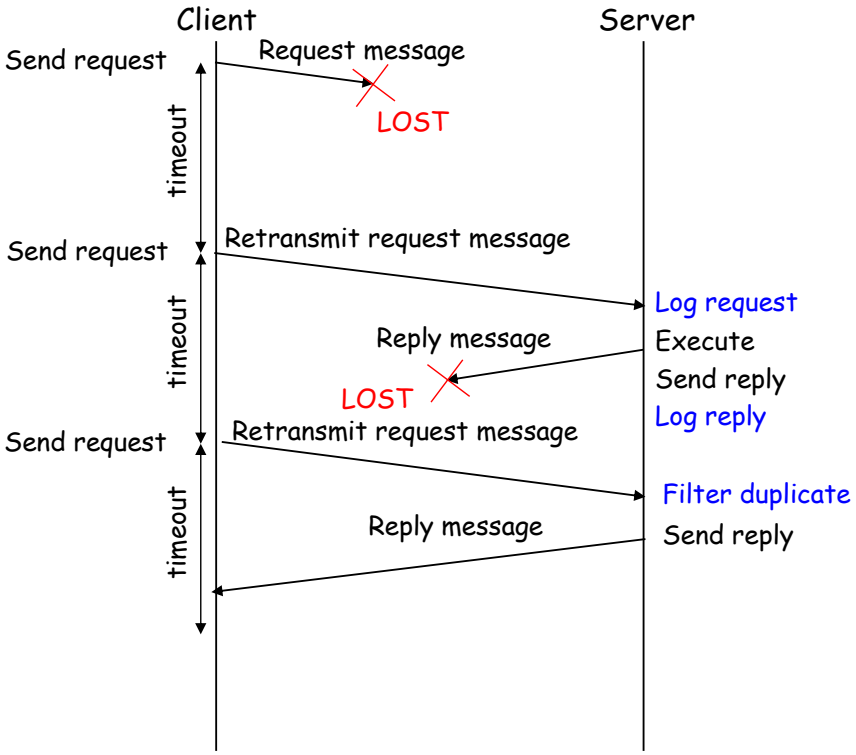
At-least-once semantics



At-most-once semantics

- Service, if performed, was carried out at most once
  - Client knows that if it receives the reply, it has been processed by server only once
  - In case of failure, no information (at-most-once: reply has been calculated at most once, but possibly also none)
- All basic mechanisms (RR1, DF, RR2) are used
  - Client retransmits request when timeout expires
  - Server maintains some state to identify duplicate requests and to not process the request more than once
- Suitable for any type of service
  - Even not idempotent
- No constraints on consequent actions
  - No coordination between client and server: in case of error, client does not know if server run the service, while server ignores if client knows that the service run
  - Possible inconsistency on the agreement between client and server

At-most-once semantics



At-most-once semantics: implementation

- Server detects duplicate requests and returns previous reply instead of re-running operation `handler()`
- How to detect duplicate request?
  - Client includes a unique ID (`xid`) with each request and uses same `xid` when re-sending
- Some at-most-once complexities
  - How to ensure `xid` is unique?
  - Server must eventually discard info about old requests: when is discard safe?
    - Can use sliding windows and sequence numbers
    - Can discard information older than maximum message lifetime
  - How to handle duplicate requests while original one is still executing?

Server:

```
if seen[xid]
 r = old[xid]
else
  r = handler()
  old[xid] = r
  seen[xid] = true
```

https://martinfowler.com/articles/patterns-of-distributed-systems/idempotent-receiver.html

Exactly-once semantics

- Strongest but most difficult guarantees to implement in DS, especially large-scale ones
- Requires full agreement on the interaction
  - Service is run only once or it is not run at all: all-or-nothing semantics
    - If everything goes well: the service runs only once, duplicates are found
    - If something goes wrong: client or server knows if the service is run (once - all) or if it has not run (no time - nothing)
- Semantics with concordant knowledge of each other's state and without hypotheses on the maximum duration of the interaction protocol between client and server
  - No constraint on maximum duration: barely practical in a real system!

Exactly-once semantics: mechanisms

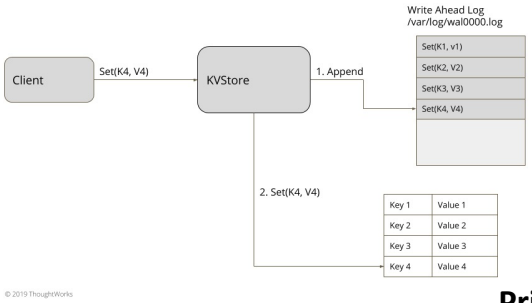
- Server-side basic mechanisms (RR1, DF, RR2) are not enough
- Additional mechanisms are required to tolerate server-side faults
  - Transparent server replication
  - Write-ahead logging (WAL)
  - Recovery
    - Mechanisms to recover from whatever state the failed server left behind and begin processing from a safe point
    - We will study distributed snapshot and state checkpointing

snapshot è la foto dello stato corrente, che voglio recuperare.
checkpoint è punto sicuro da cui riniziare

WAL pattern

- aka Commit log
- Goal
  - Provide durability guarantee by persisting every state change as a command to the append only log
- How
  - Each state change is stored as a log entry in a file on hard disk and the log is appended sequentially
  - The file can be read on every restart and the state can be recovered by replaying all the log entries

https://martinfowler.com/articles/patterns-of-distributed-systems/wal.html




```
public void put(String key, String value) {
    appendLog(key, value);
    kv.put(key, value);
}

private Long appendLog(String key, String value) {
    return wal.writeEntry(new SetValueCommand(key, value).serialize());
}
```

Prima il log, dopo l'operazione.
Questo perchè, se facessi il contrario, nel caso di fail dell'esecuzione perderei anche il suo log.

Summing up failure semantics

- At-least once and at-most once semantics are feasible and widely used in distributed systems
- We often choose the lesser of two evils, which is at-least-once semantics in most cases
  - At-least once semantics is also easier to scale

Distributed systems are all about trade-offs!

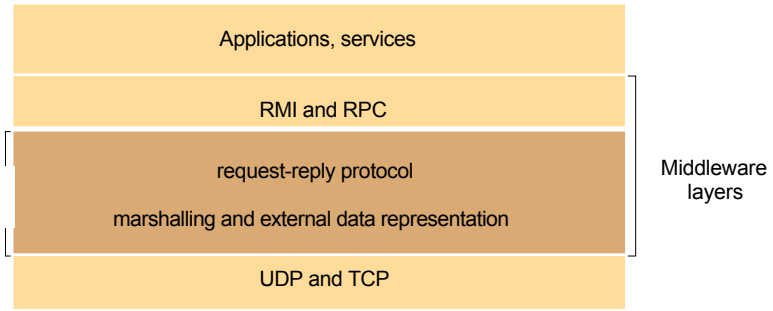
Distributed application programming

- You know explicit network programming
  - Operating system construct based on socket API and explicit management of message exchange
  - Used in most network applications (e.g. web browser, web server)
  - But distribution is not transparent and requires developer effort

- How to increase the abstraction level of distributed programming? By means of a communication middleware between OS and applications
  - Hide complexity of underlying layers
  - Free programmer from automatable tasks
  - Improve software quality by reusing known, correct and efficient solutions

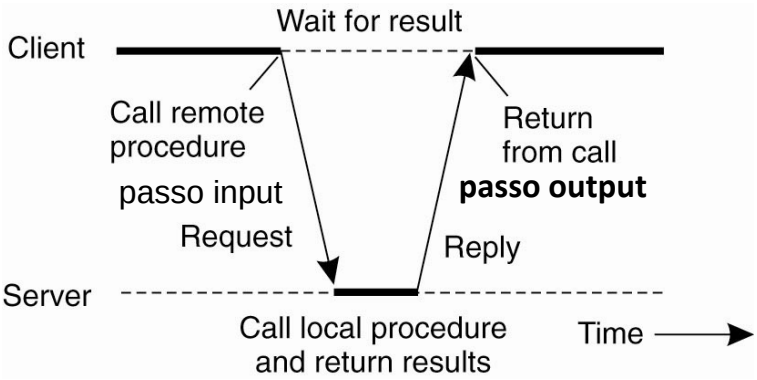
Distributed application programming

- **Implicit** network programming
  - Language-level construct
  - **Remote Procedure Call (RPC)**
    - Distributed app realized through procedure calls, but caller (client) and callee (server) are located on different machines and communication among them is hidden to programmer
  - **Remote method invocation (Java RMI)**
    - Distributed application in Java is realized by invoking methods of object running on a remote machine



Remote Procedure Call (RPC)

- Idea (by Birrel and Nelson, 1984): use client/server model to call procedures executed on other machines
  - Process on machine A calls procedure on machine B
  - Calling process on A is suspended
  - Called procedure is execute on B
  - Input and output parameters are transported into messages
  - No message passing is visible to programmer



Why RPC

- Used in many distributed systems, including cloud computing ones
- Developed and employed in many languages and frameworks, among which:
  - **C (Sun RCP)**
  - **Java (Java RMI)**
  - **Go**
  - **gRPC**
  - Remote Python Call (RPyC)
  - Distributed Ruby (DRb)
  - Ice
  - Microsoft .NET
  - JSON-RPC
  - CORBA

Our case studies

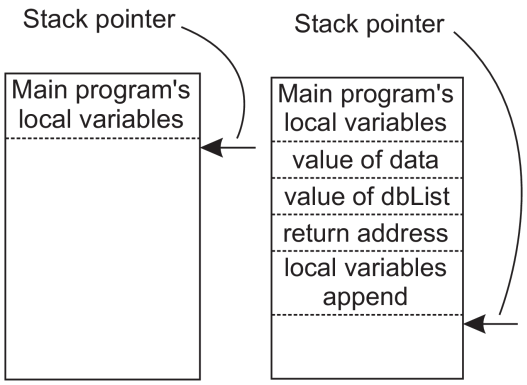
fatto da Google, permette lo scambio tra linguaggi di programmazione diversi. Quindi è indipendente dai linguaggi.

Local procedure call

- Example of local procedure call:

  newlist = append(data, dbList)

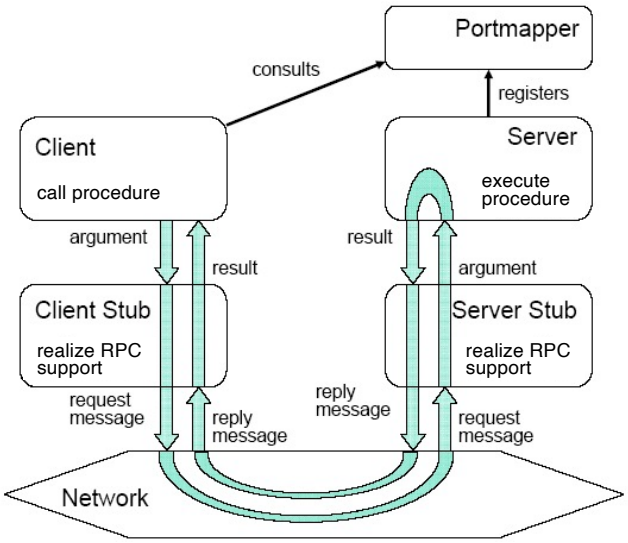
- Caller pushes to stack input parameters (data, dbList) and returns address
- When callee returns, control is back to caller



In case of RPC, how to make it appear to the developer that the call is local?

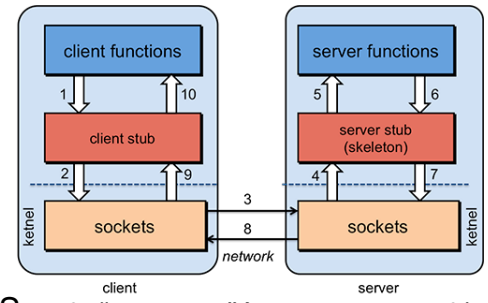
RPC: architecture

- Solution: create proxies (aka **stubs**)
- On the client side: the **client stub** has the service's interface
  - Client calls client stub that manages all the details: it packages parameters and calls the server
- On the server side: the **server stub** receives the request and calls the local procedure
- Goal: distribution transparency
  - Stubs are automatically generated
  - Developer focus is on application logic



RPC: Basic steps

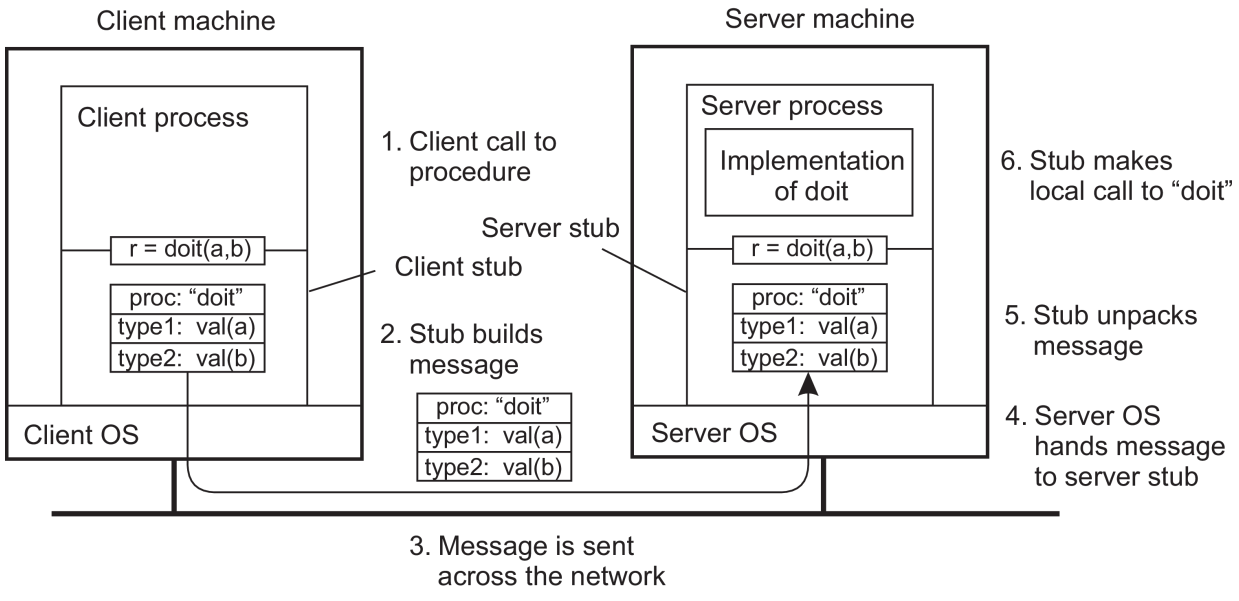
1. On client side, client calls a local procedure, called client stub
2. Client stub packs request message and call local OS
   - Parameter marshaling: arguments are converted from local to common format and packaged into a message
3. Client OS sends request message to remote OS
4. Remote OS gives request message to server stub
5. On server side, server stub unpacks request message and calls server as it was a local procedure
   - Parameter unmarshaling: arguments are extracted from message and converted from common to local format
6. Server executes local call and returns result to server stub
7. Server stubs packs reply message (marshals return value(s)) and calls OS
8. Server OS sends reply message to client OS
9. Client OS gives message to client stub
10. Client stub unpacks reply message (unmarshals return value(s)) and returns result to client



nb: "Remote OS" è inteso non come il 'server vero e proprio' (con cui si interfaccia solo il server stub) bensì come l'entità nella socket di destinazione.

RPC basic steps: example

- Call remote procedure `doit(a,b)`



RPC middleware requirements

- Exchange messages to call procedure/invoke method, so to make it appear to the user that the call is local: we need to:
  - Identify request and reply messages, remote procedure/method
  - Pass parameters
- Manage data heterogeneity
  - Which data? Parameters, return value(s)
  - Marshaling vs. serialization:
    - ***Serialization***: convert object into a sequence of bytes that can be sent over a network; serialization is used in marshaling
    - ***Marshaling***: bundle parameters into a form that can be reconstructed (unmarshaled) by another process
- Handle failures due to distribution
  - During communication
  - User errors

RPC issues

- Issues to address in order to transparently execute procedure call

1. How to manage heterogeneity in data representation?
   - Client and server also need to agree on transport protocol for message passing: TPC, UDP, both?
2. Client and server run on different hosts having their own address space: how to realize parameter passing by reference?
3. When failures occur, what does the client know about the execution of the server?
   - Local procedure call: exactly-once
   - Remote procedure call: at-least-once or at-most-once (in most cases)
4. How to bind to server, i.e., how do we locate the server endpoint?

Data heterogeneity

- Client and server may use different data representations
  - E.g., different character sets, byte ordering (little endian vs big endian), size of integers, floating point representation

- *General alternatives* (not only RPC) to handle heterogeneity in data representation:
  1. Specify encoding within the message itself
  2. Let message sender convert data into receiver encoding
  3. Convert data into standard encoding agreed between the parties **senza intermediari**
     - Sender: converts from local to standard
     - Receiver: converts from standard to local
  4. Let an intermediary convert between different encodings

queste sono 4 alternative, non sono step di un unico procedimento.

Data heterogeneity

- Let's compare alternatives 2 and 3, assuming *N* distributed components that communicate among them
- #2: each component knows all conversion functions

  Conversion is faster

  ✗ Higher number of conversion functions: *N**(*N*-1)
- #3: all components agree on standard encoding for data representation and each component knows how to convert from local to common format and vice versa

  Conversion is slower

  ✗ Lower number of conversion functions: 2**N*

Alternative 3 is the standard choice in RPC systems

Data heterogeneity: patterns

- Let's consider alternatives 3 and 4: how to realize?
- Proxy
  Sul client creo copia delle funzioni del server e viceversa. Quindi è presente sia sul client che sul server. Supporta trasparenza di accesso e locazione (esempio: permette a client di vedere le funzioni del server). E' "appartenente" al DS.
  - Aim: support access (and location) transparency
  - Control access to an object using another proxy object
    - The proxy is created in the local address space to represent the remote object and offers the same interface of the remote object
- Broker
  Incapsulo tutti i dettagli della comunicazione, così client e server non ci pensano. E' esterno al sistema distribuito (ma a sua volta può essere centralizzato o meno.
  - Aim: separate and encapsulate the details of communication from its functionality
  - Enables components to interact without handling remote concerns by themselves
  - Locates the server for the client, hides the communication details, etc.

Proxy (stub) is the standard choice in RPC systems

Who automatically generates stubs?

Parameter passing techniques

- Call by value
  - Parameter value is copied in a local isolated storage (usually stack)
  - The callee acts on copied data and changes will not affect the caller
- Call by reference
  - Reference (pointer) to parameter is copied into the stack
  - The callee acts directly on caller data
- Call by copy-restore
  - A somehow special case of call by reference: data is copied into the caller stack; when the procedure returns, the updated contents are copied back (restored)
  - Available in few programming languages (e.g., Ada, Fortran)

RPC parameter passing

- A reference is a memory address
  - Valid only in its context (local machine)
  - We need a pointerless representation

- Solution: simulate call by reference by using call by copy-restore
  - Client stub copies the pointed data in the request message and sends the message to server stub
  - Server stub acts on copy, using the address space of the receiver host
  - If the copy is modified, it will be then restored by client stub overwriting the original data
  - Size of data to be copied should be known
  - What happens if data contains a pointer?

Riapplico il ragionamento di prima: risolvo il puntamento e nel dato metto il valore puntato.

Semantics of remote call/method

- Exactly once semantics is costly: most RPC systems implement weaker semantics
- At-least-once semantics: if the client gest a reply from the server, it means that remote call/method has been executed at least once by the server
- At-most-once semantics: if the client gets a reply from the server, it means that the remote call/method has been executed at most once by the server

Server binding

- Binding: how to locate the server endpoint, including the proper process (port or transport address) on it
  - In principle: can be static or dynamic
- Static binding
  - At design time: server address and other info are wired into code
  - Easy and no overhead, but lacks transparency and flexibility
- Dynamic binding
  - At run-time
  - Increased overhead, but gains transparency and flexibility
    - E.g., we can redirect requests in case of server replication
  - Try to limit overhead

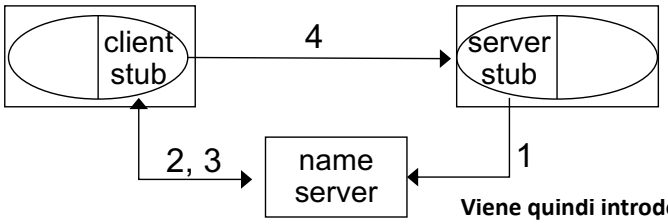
Server binding: dynamic

- Two phases in client/server relationship
- **Naming**: static phase, before execution
  - Client specifies to whom it wants to be connected, using a unique name that identifies the service
  - Unique names are associated with operations or abstract interfaces and binding is made to the specific service interface
- **Addressing**: dynamic phase, during execution
  - Server effectively binds to client when client invokes service
  - Depending on middleware implementation, multiple replica servers can be looked for
  - Addressing can be *explicit* or *implicit*
  - **Explicit addressing**: client sends request using broadcast or multicast, waiting only for first reply

specifico a chi voglio connettermi, fornendo nome univoco, associato a interfacce o operazioni. Mi collego a loro!

Server binding: dynamic

- **Implicit addressing**: there is a **name server** (aka binder, directory service, registry service) that registers services and manages a binding table
  - Service lookup, registration, update, and deletion



Viene quindi introdotto un componente aggiuntivo!

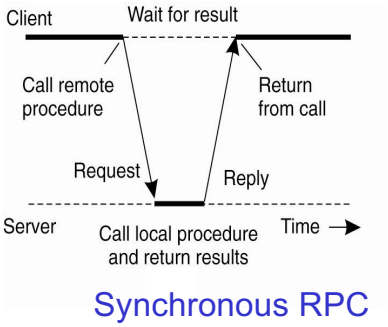
- Dynamic binding frequency
  - Each procedure call requires addressing
  - To reduce cost, binding result can be cached and re-used

RPC and OSI model

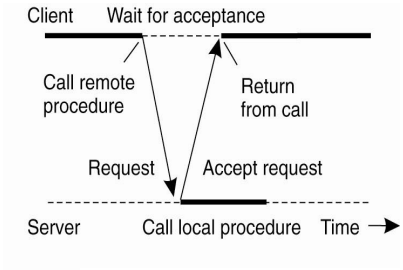
- Where is RPC in the OSI model?
  - Layer 5 (session): Connection management
  - Layer 6 (presentation): Marshaling/data representation
  - Uses the transport layer (layer 4) for communication (TCP/UDP)

More issues: Synchronous vs. asynchronous RPC

- Synchronous RPC: strict request-reply behavior
  - RPC call blocks client that waits for server reply
- Some RPC middleware supports asynchronous RPC
  - Client continues without waiting for server reply
  - Server can reply as soon as request is received and execute procedure later



Synchronous RPC



Asynchronous RPC

More issues: transparency

- Is RPC truly transparent? Can we really just treat remote procedure calls as local procedure calls?
  - Performance, failures, concurrent requests, replication, migration, …
- Performance
  - RPC is slower ... a lot slower: why?
  - Local call: maybe 10 cycles = ~3 ns
  - RPC: 0.1-1 ms on a LAN => ~100K slower
    - Major source of overhead: context switching, copies, inter-process communication
    - In WAN: can easily be millions of times slower

More issues: transparency

- Failures
  - Different failures can occur
    - Client cannot locate server
    - Lost request messages
    - Server crashes
    - Lost reply messages
    - Client crashes

More issues: security

- Authenticate client? Authenticate server?
  - Is the client sending messages to the correct server or is the server an impostor?
  - Is the server accepting messages only from legitimate clients? Can the server identify user at the client side?
- Messages may be visible over network
  - Messages may be sniffed (and modified) while they traverse the network: do we need to hide them?
  - Has the message been accidentally corrupted or truncated while on the network?
- RPC protocol may be subject to replay attacks
  - Can a malicious host capture a message and retransmit it at a later time?

Programming with RPC

- Language support
  - Many programming languages have no language-level concept of remote procedure calls (e.g., C, C++)
    - These compilers will not automatically generate client and server stubs

Java solo da una certa versione in poi!

  - Some languages have support that enables RPC (Java, Python, Haskell, Go, Erlang)
    - But we may need to deal with heterogeneous environments (e.g., Java communicating with a Python service)

- Common solution
  - **Interface Definition Language (IDL)**: describes remote procedures
  - Separate compiler that generates stubs (pre-compiler)

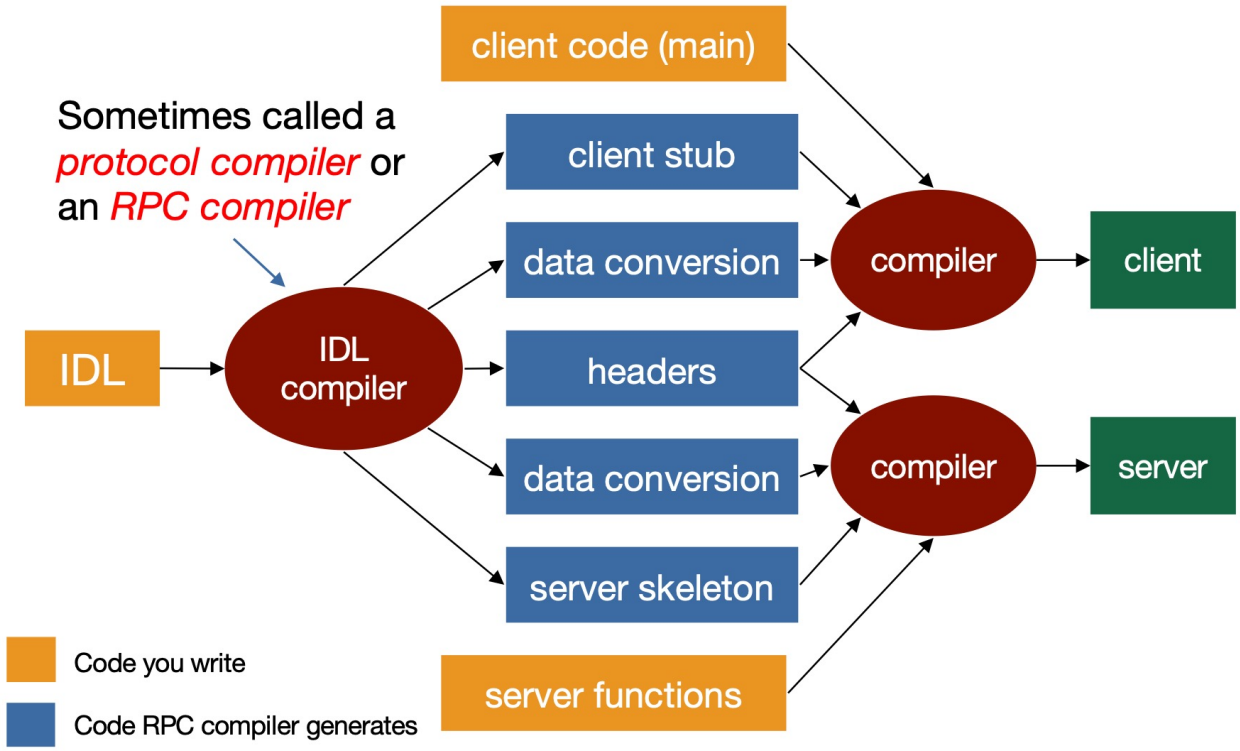
Interface Definition Language (IDL)

- Allow programmer to specify remote procedure interfaces (*names, parameters, return values*)

- IDL compiler can use this to generate client and server stubs
  - Marshaling code
  - Unmarshaling code
  - Network transport routines

- Conform to defined interface
  - An IDL looks similar to function prototypes

IDL and RPC compiler



RPC case studies

- Sun RPC
- Java RMI
- Go
- gRPC

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Implementing RPC: Sun RPC

- Example of first generation RPC
- Implementation and RPC middleware provided by Sun Microsystems: Open Network Computing (ONC) RPC, aka Sun RPC
  - Basic and widely used implementation
  - RFC 1831 (1995), RFC 5531 (2009)
- ONC is a suite of products including:
  - eXternal Data Representation (XDR) as IDL
  - Remote Procedure Call GENerator (RPCGEN): IDL compiler to automatically generate client stub and server stub
  - Port mapper: service to bind client to server
  - Network File System (NFS): distributed file system

How to define RPC program

- Two descriptive parts written in XDR and grouped in a file with extension .x
  - In our example: square.x

1. Definition: specifics of procedures (services) that is, identify procedures and their parameters' data types
2. XDR definitions: definitions of parameters' data types (if not defined in XDR) ⇝ se definiti, è facoltativa.

- Example: remote procedure to calculate square of integer number

Square example: define remote procedure

```
struct square_in {        /* input (argument) */
  long arg1;
};
struct square_out {       /* output (result) */
  long res1;
};
program SQUARE_PROG {
  version SQUARE_VERS {
    square_out  SQUAREPROC(square_in) = 1; /* procedure number = 1 */
  } = 1;                  /* version number */
} = 0x31230000;           /* program number */
```

Non necessaria con un solo dato, ma generalmente la usiamo!

Code: square.x

output

procedura

(posso avere >1 versioni)

(hex)

identificano univocamente la procedura lato server.

Let's define the remote procedure SQUAREPROC

- Each procedure has only one input parameter and one output parameter
- Identifiers are written in uppercase
- Each procedure is associated with a procedure number which is unique within the RPC program (in the example 1)

How to implement RPC program

- Programmer has to develop:
  - **Client program**: implements `main()` and the logic needed to find the remote procedure and bind to it (example: square_client.c)
  - **Server program**: implements the remote procedures provided by RPC server (example: square_server.c)
- Note: programmer does not write server-side `main()`
  - Who calls the remote procedure on server side? Lo fa server stub.

- Definisco file .x: tutto l'insieme delle procedure remote offerte dal server. Con comando rpcgen genero file .h, da includere nel client e nel server.
- Genero tramite rpcgen gli stub di client e server ed eventuali file di conversione dei dati. Lato server non ho completa trasparenza: devo specificare nome della procedura con versione e stare attento ai parametri di ritorno.
- Lato client uso funzione clnt create(): prende host, nome procedura e versione procedura, protocollo di trasporto. Ho anche funzioni per la gestione degli errori che possono avvenire durante la comunicazione.

Square example: local procedure

- Let's first consider a standard solution for the **local** procedure

Code: square_local.c

```
#include <stdio.h>
#include <stdlib.h>

struct square_in {  /* input (argument) */
  long arg;
};
struct square_out {  /* output (result) */
  long res;
};
typedef struct square_in square_in;
typedef struct square_out square_out;

square_out *squareproc(square_in *inp) {
  static square_out out;

  out.res = inp->arg * inp->arg;
  return(&out);
}
```

ATTENZIONE:
square_local.c è un esempio di PROCEDURA LOCALE, ovvero come la implementerei in un contesto locale. Dopo parlo di Procedura REMOTA, che non ha nulla a che fare con questa!!!

occorribile anche quando viene deallocato lo stack.

Square example: local procedure

- **Local** procedure *(continue)*

```
int main(int argc, char **argv) {
  square_in in;
  square_out *outp;

  if (argc != 2) {
    printf("usage: %s <integer-value>\n", argv[0]);
    exit(1);
  }
  in.arg = atol(argv[1]);

  outp = squareproc(&in);
  printf("result: %ld\n", outp->res);
  exit(0);
}
```

Which changes in case of remote procedure?

Codice per la procedura remota non e' esattamente uguale a quello per la procedura locale. Non c'e' completa trasparenza all'accesso: devo specificare alcuni parametri che permettono ai due proxy (lato client e lato server client e server stub) l'interazione.

Square example: remote procedure

- Code of remote procedure is *almost equal* to local procedure

Code: server.c

generato da generatore IDL

```
#include <stdio.h>
#include <rpc/rpc.h>
#include "square.h"    /* generated by rpcgen */
square_out *squareproc_1_svc(square_in *inp, struct svc_req
   *rqstp) {
   static square_out out;

   out.res1 = inp->arg1 * inp->arg1;
   return(&out);
}
```

obbligatorio, ma non usato "direttamente"

1: n° versione
SVC: chiamo lato server

- Notes:
  - Input and output parameters use pointers
  - Output parameter must be a pointer to a static variable (i.e., global memory allocation) so that pointed area exists when procedure returns
  - Name of RPC procedure changes slightly (we add _ suffixed by version number and _svc, e.g., _1_svc), all in lowercase

Square example: client

- Launch client with remote hostname and integer value; it calls the remote procedure

Code: client.c

```
#include <stdio.h>
#include <rpc/rpc.h>
#include "square.h"   /* generated by rpcgen */
int main(int argc, char **argv) {
  CLIENT *clnt;
  char *host;
  square_in in;
  square_out *result;
   if (argc != 3) {
    printf("usage: client <hostname> <integer-value>\n");
    exit(1);
  }
  host = argv[1];
  clnt = clnt_create(host, SQUARE_PROG, SQUARE_VERS, "tcp");
```

gestore trasporto lato client

nome host che passo da CMDLine.

```
CLIENT *clnt_create(char *host, unsigned long prog,
unsigned number vers, char *proto)
```

non dico la porta, ci pensa client stub quando fa binding.

in rpc.h

anche UDP

Square example: client

```
if (clnt == NULL) {
  clnt_pcreateerror(host);
  exit(1);
}
in.arg1 = atol(argv[2]);
if ((result = squareproc_1(&in, clnt)) == NULL) {
  printf("%s", clnt_sperror(clnt, argv[1]));
  exit(1);
}
printf("result: %ld\n", result->res1);
exit(0);
}
```

→ il server ?
→ procedura ∃? è disponibile?

qui in minuscolo con numero versione. Senza -svc perché lato client chiama server

← stampa errore, se ∃

numero procedura associata al nome, per questo non la specifico.

Trasparenza accesso parziale (non ho usato socket né parlato di eterogeneità, mi serve solo hostname, no PORTA) ma non è totale (nome proc. client ≠ nome proc. server, alcune operazioni non sono 1-1)

Square example: client

- `clnt_create()`: creates client transport manager to handle communication with remote server
  - TPC or UDP, default timeout for request retransmission
- Client must know:
  - Remote server hostname
  - Info to call remote procedure: program name, version number and remote procedure name
- To call remote procedure:
  - Procedure name changes slightly: we add _ followed by version number (name in lowercase)
  - Two input parameters:
    - The first is the effective input parameter
    - The latter is the client transport manager
  - Client gets *pointer* to result
    - Allows it to identify failed RPC (null return)
- Handling of errors that occur during remote call
  - `clnt_pcreateerror()` and `clnt_perror()`

Basic steps to program with SUN RPC

1. Define the RPC interface: procedures and data types (if needed) → writes square.x
2. Compile square.x with rpcgen, which generates client and server stubs and XDR routines to convert data to XDR format
   - square_**clnt.c**, square_**svc.c**, square_**xdr.c**, square.**h**
3. Write client program and server functions (client.c and server.c), compile all source files (client and server, client and server stubs, and conversion routines) and link object files
4. When you start server, it publishes services
   - Remote procedures are registered with name server (port mapper or rpcbind)
5. When you start client, it finds the service endpoint through port mapper

Sun RPC features

- A program typically contains multiple remote procedures
  - Multiple versions for each procedure
  - Single input and output parameter (call by copy-restore)
- Mutual exclusion guaranteed by server: by default, no concurrency on server side
  - Sequential server: only one call can be executed at one time
  - Multi-threaded server (no Linux): `rpcgen` with `-M` and `-A` options
- Client is synchronously blocked waiting for server reply
- At-least-once semantics
  - Request retransmission after a time-out interval expires
  - UDP as default transport protocol

eXternal Data Representation (XDR)

- Sun RPC uses a standard transfer format called XDR to handle data heterogeneity
  - Standard for the description and encoding of machine-independent data (RFC 4506)

- Built-in XDR conversion functions for:
  - Predefined primitive types
    - E.g., `xdr_bool()`, `xdr_char()`, `xdr_int()`
  - Predefined structured types
    - E.g., `xdr_string()`, `xdr_array()`

- XDR is a binary format using *implicit typing*
  - *Implicit typing*: only values are transmitted, not data types or parameter info

Definition of file.x

- First part of file
  - XDR definition of constants
  - XDR definition of data types of input and output parameters for all data types for which there is no corresponding built-in XDR function
- Second part of file
  - XDR definition of procedures
  - Example in square.x: `SQUAREPROC` is the procedure name, procedure number 1, version 1 of program number 0x31230000
  - According to Sun RPC:
    - Procedure number 0 is reserved for `NULLPROC` (Per testing, vedere attività e tempi risposta)
  - Each procedure has a single input and output parameter
  - Identifiers for program, version and procedure are in uppercase

Sun RPC: server binding

- Procedure must be registered before being called
  - Unique triple given by: program number (*prognum*), version number (*versnum*), procedure number
  - Transport *protocol* must also be specified
  - Client must know the port number on which the server responds
- RPC server registers the RPC program in the *port map*
  - Dynamic table of RPC services on that host machine
  - Each table line contains the triple {*prognum*, *versnum*, *protocol*} and port
  - Procedure number is not specified: all the procedures within a program share the same transport manager
- The port map table is managed by only one process (called *port mapper*) for each host

Port mapper (rpcbind)

- Port mapper (`rpcbind`) listens on port 111
- At startup, server stub registers the RPC services it offers on port mapper

  prognum, *versnum*, *protocol* and *port*
- Client stub contacts port mapper to find out the corresponding port before invoking the remote procedure
- Port mapper registers the services and supports:
  - Insert a service
  - Delete a service
  - Lookup for service port
  - List registered services

Port mapper (rpcbind)

- To list all the RPC programs on a given host: `rpcinfo -p` *`hostname`*

```
>$ rpcinfo -p
 program         vers     proto    port
   100000        4        tcp      111       rpcbind
   100000        4        udp      111       rpcbind
   824377344     1        udp      59528
   824377344     1        tcp      49311
```

824377344 (= 0x31230000) is the program number in square.x

- Available RPC programs are listed in `/etc/rpc`

SUN RPC: Development process

Given a service specification

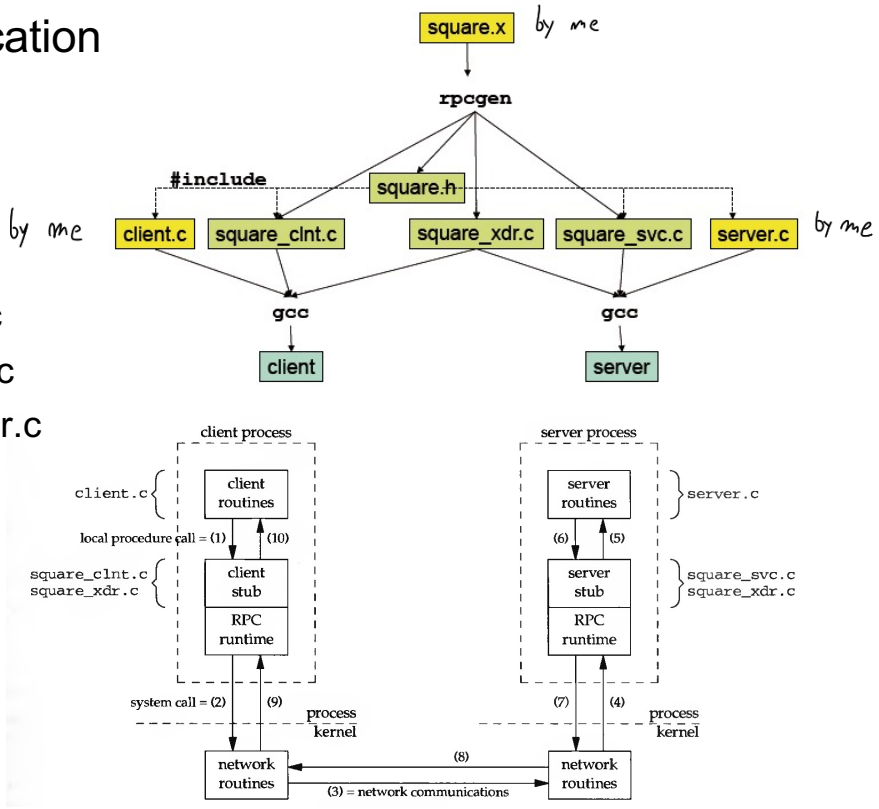
- Written in XDR: square.x

`rpcgen` generates

- Header: square.h
- Client stub: square_clnt.c
- Server stub: square_svc.c
- XDR routines: square_xdr.c

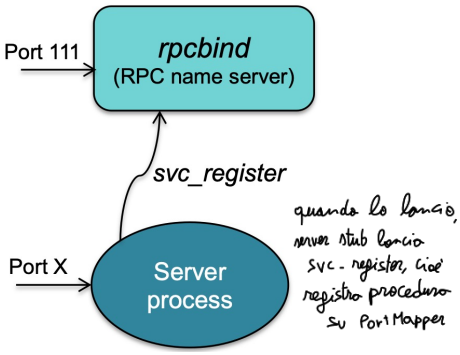
Developer writes

- Client program: client.c
- Server program: server.c



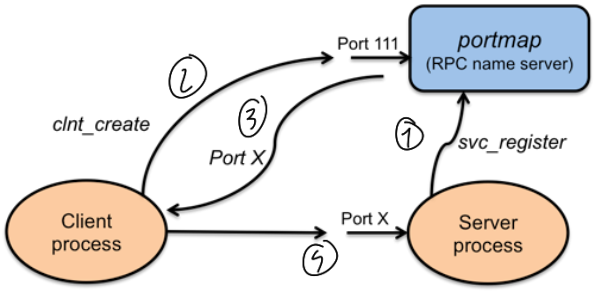
What goes on in the system: server side

- In `main()` server stub creates a socket and binds any available local port to it
- Calls `svc_register`, RPC library function (su Port mapper)
  - To register procedures with port mapper
    - Associates the specified program and version number pair with the specified dispatch routine
- Then waits for requests by calling `svc_run`, again in RPC library (esegue all'∞, permette esecuzione procedure richieste.)
  - `svc_run` invokes service procedures in response to RPC call messages



What goes on in the system: client side

- When we start the client program, `clnt_create` contacts port mapper on server side to find the port for that interface
  - Early binding: done once, not per each procedure call



- Client stub manages communication
  - Request timeout
  - Marshaling from local representation to XDR format and unmarshaling from XDR format to local representation

Examples in SUN RPC

- Examples of RPC programs
  http://www.ce.uniroma2.it/courses/sdcc2122/prog_rpc
  - square: find square of an integer
    - Let's examine client stub and server stub code
  - echo: repeat a sequence of characters
  - avg: find average value of a sequence of real numbers
  - rls: print listing of a remote directory
    - XDR routines in dir_xdr.c are automatically generated from the data types defined in dir.x: they allow to convert from local format to XDR and vice versa

Second generation of RPC

- In the 1990s second generation of RPC
- Support for object oriented languages: distributed objects
  - Microsoft DCOM
  - CORBA
  - **Java RMI**

Java RMI: motivations

- Goal: extend RPC concepts to distributed objects
  - Java RMI (**Remote Method Invocation**): RPC in Java
  - Allows programmer to create distributed applications where methods of remote objects can be invoked from other JVMs
  - Conceptually similar to RPC but supports the semantics of object invocation in different address spaces

- Java RMI: set of tools, policies and mechanisms that allow a Java application running on a host to invoke methods of a remote object running on another host
  - Goal: access transparency (local and remote invocations are as much as possible the same)
  - But distribution transparency is not yet complete (meglio di RPC)

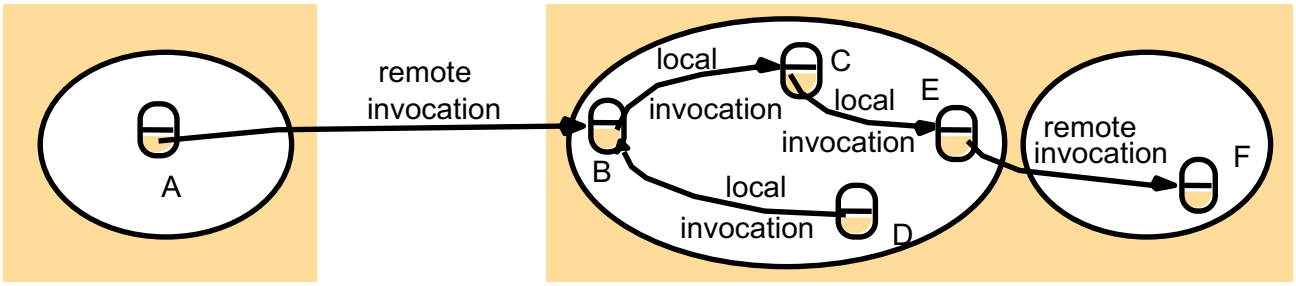
Java RMI references

- "Trail: RMI", The Java Tutorials
  http://docs.oracle.com/javase/tutorial/rmi/
  - Note: JDK 8 (current release JDK 17)

- Java Remote Method Invocation Specification
  https://docs.oracle.com/en/java/javase/17/docs/specs/rmi/

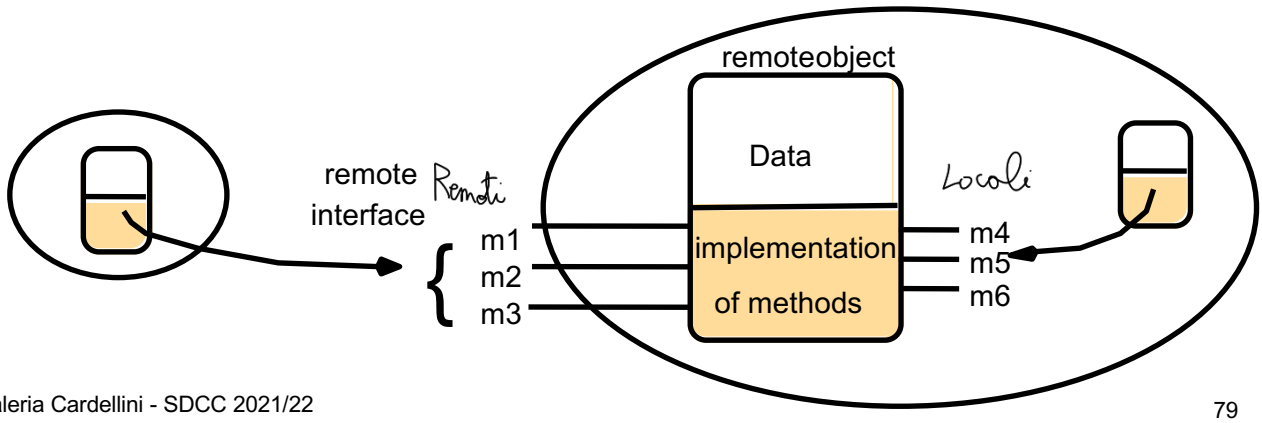
Java RMI basics

- Reference to remote object is created locally, but object is active on remote host
- Client invokes remote method through local reference
- Which are the differences with respect to invoking a local method?
  - Performance, reliability, communication, ...



Java RMI basics

- Separation between behavior definition (interface) and behavior implementation (class)
- Logical separation between interface and object allows for their physical separation
- Remote interface: specifies which object methods can be invoked remotely
  - Object internal state is not distributed!



Java RMI basics

- When binding client with remote server object, the copy of the server interface (**stub**) is loaded into the client's space
  - Role similar to RPC client stub
- The request arriving at the remote object is handled by a client agent, which is local to the server (**skeleton**)
  - Role similar to RPC server stub
- Single working environment as a consequence of Java language, but underlying systems heterogeneity
  - Thanks to Java code portability

stub client

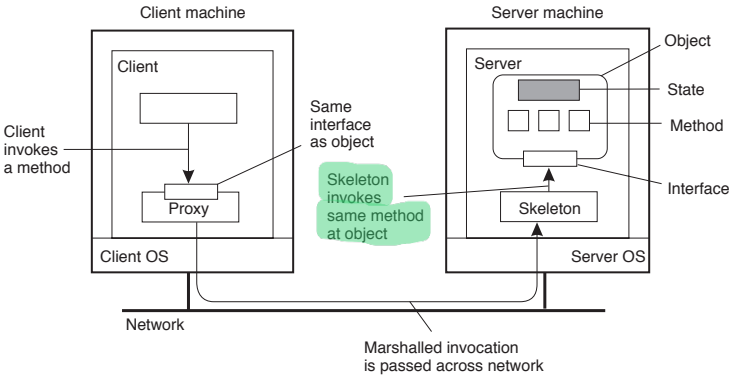
stub server

più semplice perché sfrutto la portabilità del codice in Java.

Il nostro client stub effettuerà SERIALIZZAZIONE, SKELETON DESERIALIZZA

(client) Stub and skeleton (server)

- Like RPC, RMI exploits **proxy pattern**: two proxies (client-side *stub* and server-side *skeleton*) hide the application distributed nature to application layer
  - Stub: client-side proxy for the remote object; communicates method invocations on remote objects to server
  - Skeleton: server-side proxy that calls the actual remote object implementation, deserializza richiesta e serializza l'output



- Automatic stub generation
  - Automatically built from Java files (differently from Sun RPC `rpcgen`)

non serve compilatore, perché non serve IDL, ma la serializzazione di Java.

Serialization/deserialization

- (De)serialization directly supported by Java
  - Thanks to bytecode, no need to (un)marshal as in RPC, but data is (de)serialized using language-level features
- Serialization: transforms the object into a sequence of bytes
  - `writeObject` method on an output stream
- Deserialization: decodes a sequence of bytes and builds a copy of the original object
  - `readObject` method from an input stream
- Stub and skeleton use these two features to exchange input and output parameters with the remote host

Serialization/deserialization

- Example of serializable Record object

```
Record record = new Record();
FileOutputStream fos = new FileOutputStream("data.ser");
ObjectOutputStream oos = new ObjectOutputStream(fos);
oos.writeObject(record);

FileInputStream fis = new FileInputStream("data.ser");
ObjectInputStream ois = new ObjectInputStream(fis);
record = (Record)ois.readObject();
```

- Only instances of serializable objects can be used, that is:
  - implement Serializable interface
  - contain only serializable objects (or object references)
- Upon deserialization, a copy of the object will be recreated using its class file and the received information
  - Class file must be available locally

Semanticamente diversi, ma stesso scopo.

Marshaling versus serialization

- Loosely synonymous but semantically different
- Marshaling: activity by which a stub converts local application data into network data (e.g., using XDR) and packages network data into packets for transmission
- Serialization: activity by which the state of an object is converted into a byte stream so that byte stream can be converted back into a copy of the object
- Difference becomes noticeable for objects
  - Objects have a codebase that also needs to be marshaled
  - Java serialization relies on codebase being present at receiver
- In Python (*pickle* module) marshaling and serialization are considered the same, but not in Java

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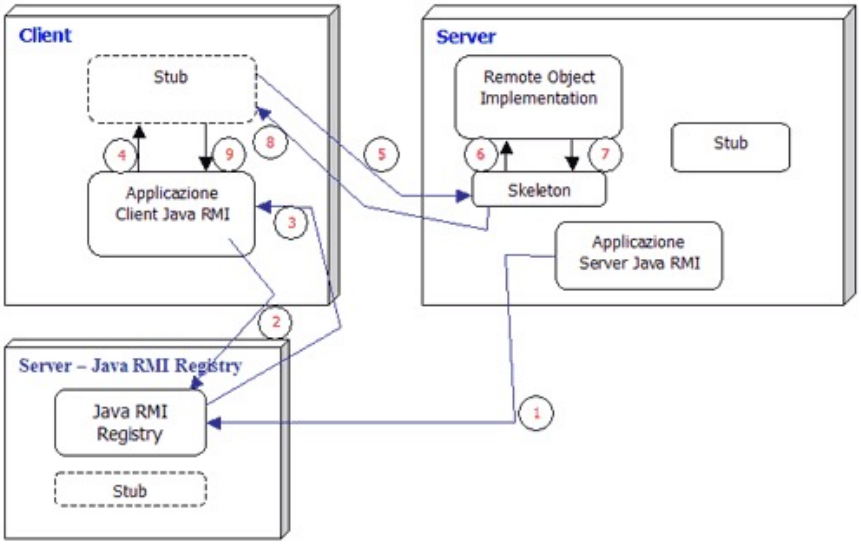
Interaction between stub and skeleton

- Steps for communication (RMI-registry operation)
  1. Client obtains a stub instance (*how*?)
  2. Client invokes methods on the stub
     - Remote invocation syntax is identical to local one (in RPC non c'è trasp. completa, qui è maggiore!)
  3. Stub serializes the information needed for the invocation (method's ID and parameters) and sends them to skeleton in a message
  4. Skeleton receives the message and deserializes received data, invokes the call on the object that implements the server (*dispatching*), serializes the return value and sends it to stub in a message
  5. Stub deserializes the return value and returns the result to the client

RMI registry

(permette al server di andare a registrare metodi remoti offerti)

- RMI Registry: binder for Java RMI (port 1099)
- Allows server to publish service and allows client to obtain the proxy to access it (/stub)



- RMI URL: starts with `rmi:` and contains the hostname (optional), the port number (optional) and the name of the remote object
- Some limit: no location transparency, no security management

(devo conoscere hostname di chi offre il servizio)

(non è offerta nativamente)

Server-side steps

(configurazione)

- Realize *server-side* remote components
  1. Behavior definition: interface that (1° cosa da definire)
     - is **`public`** so that it can be used by any class in any package
     - extends **`java.rmi.Remote`** so that its methods can be invoked by other JVMs
     - each remote method must declare that it may the remote exception **`java.rmi.RemoteException`** to indicate that either a communication failure or a protocol error has occurred
  2. Behavior implementation: class that
     - Implements the remote interface
     - Extends **`java.rmi.UnicastRemoteObject`**
     - **`unicast`**: the remote object is non-replicated (trasp. replicazione: Framework direziona le richieste, non sono io che scelgo. è non-replicata! Non supportata. Dovrei implementare io proxy intermedio remoto che faccia da server per i client e da client per il server, reindirizzando il carico come fosse un Load Balancer.)
     - In general each class should at least:
       - Declare the remote interface being implemented
       - Define the constructor for the remote object
       - Provide an implementation for each remote method in the remote interface

Server-side and client-side steps

- Realize *server-side* remote components
  3. Server code:
     - Create an instance of the remote object
     - Register the remote object with the RMI registry, using **`bind`** or **`rebind`** (in **`java.rmi.Naming`**); **`rebind`** replaces any existing association
       - For security reasons, an application can only bind, unbind, or rebind remote object references with a registry running on the same host

- Realize *client-side* local components
  1. Obtains the reference to the remote object by invoking **`lookup`** on RMI registry
  2. Assigns it to a variable that has the remote interface as its type

Main steps to use Java RMI

- After coding:
  1. Compile classes
  2. Start RMI registry (`rmiregistry` command), which is launched in a separate process and has a standard structure and behavior
     - Alternatively, you can create your own local registry using `createRegistry` method in `java.rmi.registry`
     - RMI registry is local to the server for security reasons
  3. Start server
  4. Start client

Echo example: remote interface

- The interface extends the **`Remote`** interface
- Each remote method
  - Has to declare that it throws a **`RemoteException`**
    - To handle communication failure or protocol error
    - Remote method invocation **is not** completely transparent
  - Returns only one result and has zero, one or more input parameters
  - Parameter passing for remote method:
    - By value in case of primitive data types (boolean, char, int, …) or objects that implement the **`java.io.Serializable`** interface: serialization/deserialization managed by stub/skeleton
    - By reference in case of **`Remote`** objects (passo stub oggetto remoto)

```
import java.rmi.Remote;
import java.rmi.RemoteException;

public interface EchoInterface
    extends Remote{
 String getEcho(String echo)
    throws RemoteException;
}
```

Java RMI supporta At most Once

Echo example: server

- The class that implements the server
  - Has to extend the **`UnicastRemoteObject`** class
  - **`super()`** method calls the class constructor **`UnicastRemoteObject`** which executes all the needed initialization to allow the server to wait for service requests and serve them
  - Has to implement all the methods declared in the interface

```
public class EchoRMIServer
  extends UnicastRemoteObject
  implements EchoInterface{
  //Costruttore
  public EchoRMIServer()
   throws RemoteException
  { super(); }
  // Implement the remote method declared
  // in the interface
  public String getEcho(String echo)
    throws RemoteException
   { return echo; }
  public static void main(String[] args) {
    // Service registration
  try
  { EchoRMIServer serverRMI =
          new EchoRMIServer();
Naming.rebind("EchoService", serverRMI); }
   catch (Exception e)
  {e.printStackTrace(); System.exit(1); }
 }
}
```

Echo example: server

- In **`main`** the server object instance is created; then, it is ready to accept remote requests
- The RMI registry local to the server registers the services
  - **`bind`**/**`rebind`** methods in class **`Naming`** (**`rebind`** replaces an already existing binding)
  - Makes as many `bind`/`rebind` as the server objects to register, each one identified with a logical name
- Registering service provided by the RMI registry
  - Accepts `bind`/`rebind` requests only by the local registry

```
public class EchoRMIServer
  extends UnicastRemoteObject
  implements EchoInterface{
  //Costruttore
  public EchoRMIServer()
   throws RemoteException
  { super(); }
  // Implement the remote method declared
  // in the interface
  public String getEcho(String echo)
    throws RemoteException
   { return echo; }
  public static void main(String[] args) {
    // Service registration
  try
  { EchoRMIServer serverRMI =
          new EchoRMIServer();
Naming.rebind("EchoService", serverRMI); }
   catch (Exception e)
  {e.printStackTrace(); System.exit(1); }
 }
}
```

oggetto

Echo example: client

- Services used exploiting an interface variable, obtained by sending a **`lookup`** request to the RMI registry
- Lookup of a remote reference
  - Namely a stub instance of the remote object (using a lookup and assigning it to a interface variable)
- Remote method invocation
  - Synchronous blocking call using the parameters declared in the interface

See code on course site

```
public class EchoRMIClient
{
  // Start RMI client
  public static void main(String[] args)
{
  bufferedReader stdIn =
    new BufferedReader(
      new InputStreamReader(System.in));
try
{
  // Connect to remote RMI service
  EchoInterface serverRMI = (EchoInterface)
       Naming.lookup("EchoService");
  // Interact with user
  String message, echo;
  System.out.print("Message? ");
  message = stdIn.readLine();
  // Invoke remote service
  echo = serverRMI.getEcho(message);
  System.out.println("Echo: "+echo+"\n");
}
catch (Exception e)
{e.printStackTrace(); System.exit(1); }
 }
}
```

stringa su cui fare echo

Echo example: compile and run

SKIP

- Server side
  1. Compile interface source file and server class

     ```
     javac EchoInterface.java
     javac EchoRMIServer.java
     ```

  2. Start RMI registry and server

     ```
     rmiregistry [registryPort]
     java EchoRMIServer
     ```

- Client client
  1. Compile client class

     ```
     javac EchoRMIClient.java
     ```

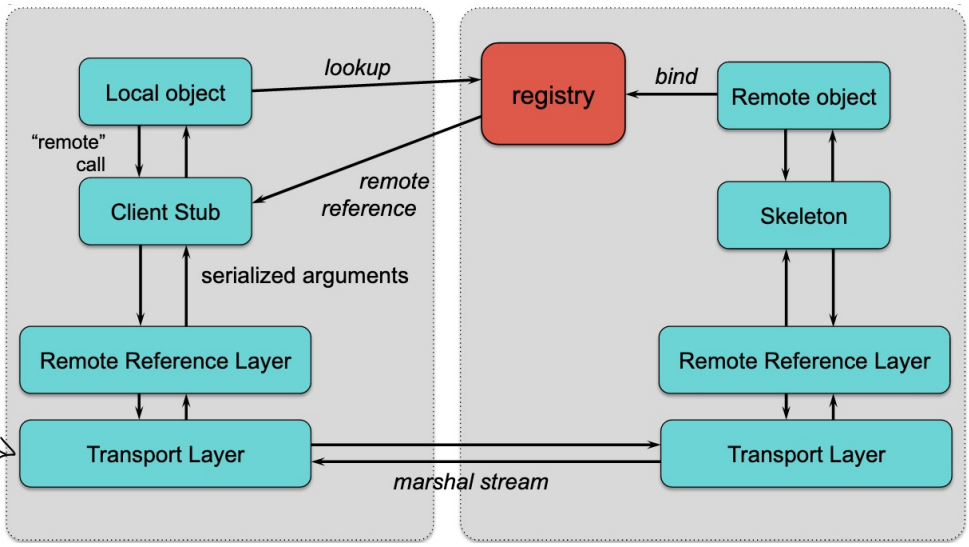
  2. Start client

     ```
     java EchoRMIClient
     ```


Java RMI: parameter passing

- Local method invocation:
  - By value: primitive types
  - By reference: all Java objects
- Remote method invocation:
  - By value: **primitive data types** and **serializable objects**
    - **Serializable objects**: object whose location is not relevant to the state are passed by value: the instance is serialized, sent to the destination and deserialized to build a local copy
  - By remote reference: **remote objects via RMI** (quindi passo stub)
    - Objects whose utility is bounded to the location in which they run (the server) are passed by remote reference: their stub gets serialized and dispatched to the other peer
    - Each stub instance identifies a single remote object to which it refers through an identifier which is unique in the context of the JVM in which the target object exists

Java RMI: architecture



responsabile comunicazione con protocollo proprietario Tra Java RMI client/server.

- Remote Reference Layer: manages remote references, parameters and stream-oriented connection abstraction
- Transport Layer
  - Manages connections between different JVMs
  - Can use different transport protocols, as long as they are connection-oriented (typically TCP)
  - Uses a proprietary protocol

Java RMI: concurrency support

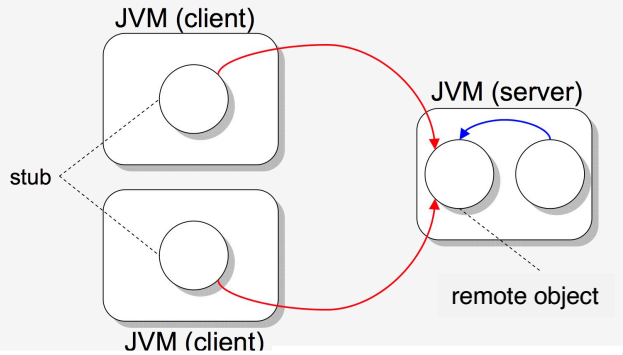
- Methods of a remote object can be invoked concurrently by multiple clients

  From Java RMI specification: "*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*"
  https://docs.oracle.com/en/java/javase/15/docs/specs/rmi/arch.html
- To protect a remote method from "dangerous" concurrent accesses while guaranteeing thread safety, it must be defined as `synchronized`
- Example: remote method to increase a counter

L'obiettivo è come garbage collection locale

Java RMI: distributed garbage collection

- How to delete remote objects that are no longer referenced by clients?
  - The remote object mush know how many client stubs are using it
  - But network failures, client crashes, …
- To address distributed garbage collection, RMI requires a high degree of coordination
  - Con: no large-scale apps



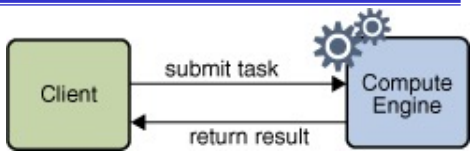
Java RMI: distributed garbage collection

- Within a JVM, Java uses reference counting and schedules objects for garbage collection when the reference count goes to zero, solo dopo de-alloco.
- Across JVMs, with RMI, Java supports two operations (`dirty` and `clean`) to realize a lease-based garbage collection → non lo fa continuamente, me lo fa Java RMI.
  - Client JVM periodically sends `dirty` message to server JVM when a remote object is in use
    - Dirty is refreshed based on lease time given by server
  - Client JVM sends `clean` message when there are no more local references to the object (= client stub non sta usando oggetto remoto)
  - If server JVM does not receive either `dirty` or `clean` before the lease time expires, object can be scheduled for deletion if it is not referenced by anyone
    - If a client does not renew the lease before it expires, server assumes that remote object is no longer referenced by that client

L'alternativa prevederebbe le richieste mandate lato server, ma troppo carico da gestire.

Example: compute engine

SKIP



- Realize a compute engine
  - Remote object on server that that takes tasks from clients, runs tasks, and returns any result
  - Tasks are defined by clients but executed on server machine
    - Powerful server machine or specialized hardware
  - Tasks can be arbitrary: the task class only needs to implement a particular interface
  - Compute engine downloads task code and runs it into its JVM
- Two interfaces to implement the compute engine
  - Remote interface `Compute` enables tasks to be submitted to the engine
  - Interface `Task` defines how the compute engine executes a submitted task

Code: http://docs.oracle.com/javase/tutorial/rmi/

SKIP

Compute engine: remote interface and argument

- Compute engine's remote interface

```
package compute;

import java.rmi.Remote;
import java.rmi.RemoteException;

public interface Compute extends Remote {
        <T> T executeTask(Task<T> t) throws RemoteException;
}
```

- Task interface: type of parameter to `executeTask` method in `Computeinterface`

```
package compute;

public interface Task<T> {
        T execute();
}
```

Compute engine: server

skip

```
package engine;

import java.rmi.RemoteException;
import java.rmi.registry.LocateRegistry;
import java.rmi.registry.Registry;
import java.rmi.server.UnicastRemoteObject;
import compute.Compute;
import compute.Task;

public class ComputeEngine implements Compute {
    public ComputeEngine() {  super(); }
    public <T> T executeTask(Task<T> t) {
        return t.execute();
    }
```


Compute engine: server

skip

```
    public static void main(String[] args) {
        if (System.getSecurityManager() == null) {
            System.setSecurityManager(new SecurityManager());
        }
        try {
            String name = "Compute";
            Compute engine = new ComputeEngine();
            Compute stub =
             (Compute) UnicastRemoteObject.exportObject(engine,0);
            Registry registry = LocateRegistry.getRegistry();
            registry.rebind(name, stub);
            System.out.println("ComputeEngine bound");
        } catch (Exception e) {
            System.err.println("ComputeEngine exception:");
            e.printStackTrace();
        }
    }
}
```

Compute engine: client

SKIP

```
public class ComputePi {
    public static void main(String args[]) {
        if (System.getSecurityManager() == null) {
            System.setSecurityManager(new SecurityManager());
        }
        try {
             String name = "Compute";
             Registry registry = LocateRegistry.getRegistry(args[0]);
             Compute comp = (Compute) registry.lookup(name);
             Pi task = new Pi(Integer.parseInt(args[1]));
             BigDecimal pi = comp.executeTask(task);
             System.out.println(pi);
         } catch (Exception e) {
             System.err.println("ComputePi exception:");
             e.printStackTrace();
         }
    }
}
```


Compute engine: client's compute object

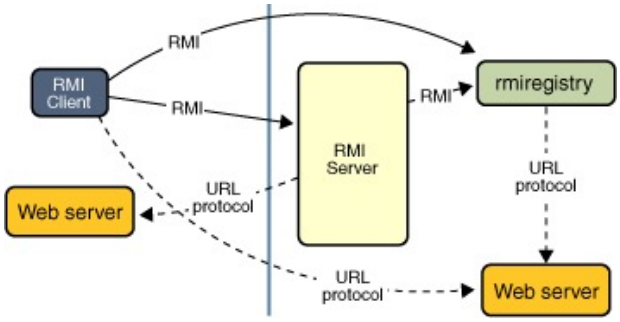
SKIP

```
package client;

import compute.Task;
import java.io.Serializable;
import java.math.BigDecimal;

public class Pi implements Task<BigDecimal>, Serializable {
    private final int digits;
    public Pi(int digits) {  this.digits = digits;  }
    // lot of stuff deleted ...
    public BigDecimal execute() {
        return computePi(digits);
    }
    // more stuff deleted ...
}
```

Example: compute engine

SKIP

- Java RMI can use dynamic class loading and security manager to transport Java classes safely
- In Compute engine example:
  - Dynamic class loading through web server



  - Install security manager and define related security policy files
    - So that loaded classes can perform only granted operations

    https://docs.oracle.com/javase/tutorial/rmi/running.html

Comparing SUN RPC and Java RMI

- SUN RPC: process oriented, incomplete access transparency, no location transparency
- *Entities that can be requested*: operations or functions
- *Communication*: synchronous and asynchronous
- *Communication semantics* (default): at-least-once
- *Maximum duration and exceptions*: timeout for retransmission and error handling
- *Server binding*: port mapper on the server
- *Data presentation*: specific IDL (XDR) and automatic generation of client stubs and server stubs
- *Parameter passing*: by copy-restore
- Various extensions, including broadcast (multiple responses from multiple servers rather than just one) and security

Comparing SUN RPC and Java RMI

- Java RMI: object oriented, access transparency, no location transparency, distribution is not totally transparent (semantics of parameter passing, remote interface definition and remote exceptions)
- *Entities that can be requested*: methods of objects via interfaces
- *Communication*: synchronous
- *Communication semantics*: at-most-once
- *Maximum duration and exceptions*: error handling
- *Server binding*: RMI registry
- *Data presentation*: Java as IDL and automatic generation of stubs and skeletons
- Parameter passing : by value (primitive types and serializable objects), by reference in case of objects with remote interfaces (remote objects)

Fine slide, 4/11/22

RPC in Go

- Let us analyze:
  - Main features of Go programming language
  - How Go supports RPC

  http://www.ce.uniroma2.it/courses/sdcc2122/slides/Go.pdf

Perché google si è speso per implementare questo nuovo middleware RPC?
E' emerso un nuovo paradigma: quello di creare applicazioni distribuite a microservizi.

L'architettura a microservizi permette di realizzare applicazioni distribuite composte da servizi che sono dei componenti indipendenti/autonomi e lascamente accoppiati tra loro.

Il vantaggio di questi microservizi è che essi possono essere inclusi all'interno di un cointaner. Il deployment può essere fatto in modo indipendente su nodi differenti. (La scalabilità con i container è facile da gestire).

Nell'esempio mostrato possiamo vedere che la comunicazione tra i vari microservizi avviene attraverso RPC.

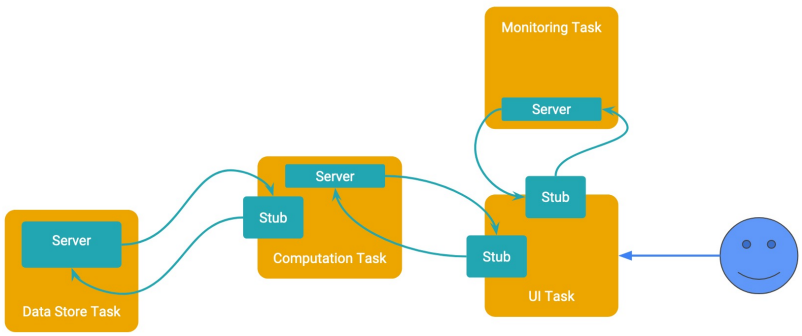
Comparing RPC implementations

- How do SUN RPC, Java RMI and Go differ in terms of distribution transparency?

Al link:
https://github.com/GoogleCloudPlatform/microservices-demo
è possibile osservare un esempio 'reale' di architettura a microservizi.
'Loadgenerator' è un microservizio esterno comunicante col frontend mediante HTTP

Motivation for new RPC middleware

- Large-scale distributed applications composed of **microservices**
  - Microservices architecture: building a software application as a collection of *independent*, *autonomous* (developed, deployed, and scaled independently), *business capability–oriented*, and *loosely coupled* services
  - Even multi-language (i.e. polyglot) development
  - Use communication predominantly structured as RPCs



Framework di nuova generazione, molto usato per realizzazione di applicazioni basate sullo stile architetturale a micro-servizi.

gRPC

- High-performance, open source universal RPC framework https://grpc.io/
- Can run in any environment
  - Multi-language, multi-platform framework
- Main usage scenarios
  - Connect polyglot microservices that use request-response style communication
  - Connect mobile devices to backend services
  - Generate efficient client libraries
- Used by many companies and in many distributed systems
  - Google, IBM, Netflix, Dropbox, …, etcd, CockroachDB , …
- Reference
  - Indrasiri and Kuruppu, "gRPC - Up and Running", O'Reilly, 2020

Tra gli utenti piu` noti di gRPC c'e' Netflix, primo big provider ad usare stile architetturale a micro-servizi (applicazioni composte da migliaia di micro-services).
Da un punto di vista di RPC, gRPC sfrutta il proxy pattern, quindi ci saranno stub che interagiscono fra di loro

gRPC: Main features

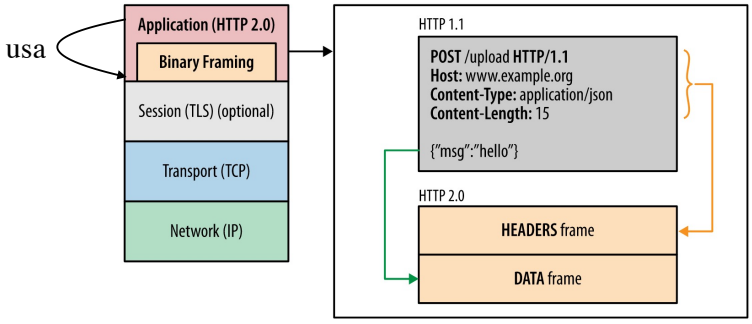
- HTTP/2 for transport
- Protocol buffers as IDL
- Plus authentication, bidirectional streaming and flow control, blocking or non-blocking bindings, and cancellation and timeouts

Prima di JSON, componenti di in linguaggi diversi comunicavano in XML, però il parsing era pessimo (richiedeva molte risorse). Protocol Buffer è alternativa proposta da Google, indipendente dal linguaggio sottostante. E' però binario e quindi non human readable.

HTTP/2 e' piu` efficiente dal punto di vista delle connessioni TCP, ogni messaggio e' diviso in frame (unita' minima), e' un protocollo binario e c'e' layer posto sopra lvl4 che fa framing del messaggio lvl5 e comprime binary stream, come anche compressione header. Ciò rende le trasmissioni più efficienti.

gRPC: HTTP/2

- Transport over **HTTP/2**
  - Basic idea of gRPC: treat RPCs as references to HTTP objects
- HTTP/2: major revision of HTTP that provides significant performance benefits over HTTP 1.x
- HTTP/2 in a nutshell
  - Binary framing layer: HTTP/2 request/response is divided into small messages and framed in binary format, making message transmission efficient



gRPC: HTTP/2

- HTTP/2 in a nutshell
  - From request/response messages to streams
    - *Stream*: bidirectional flow of bytes within an established connection, which may carry one or more messages
    - *Message*: complete sequence of frames that map to a logical request or response message
    - *Frame*: smallest unit of communication in HTTP/2, each containing a frame header, which at a minimum identifies the stream to which the frame belongs, codificati in binario
  - Request/response multiplexing (usage of a single connection per client): allows for efficient use of TCP connections and avoids head-of-line blocking at HTTP level, cioè grazie agli streams evito blocchi.
  - Native support for bidirectional streaming
  - HTTP header compression: to reduce protocol overhead

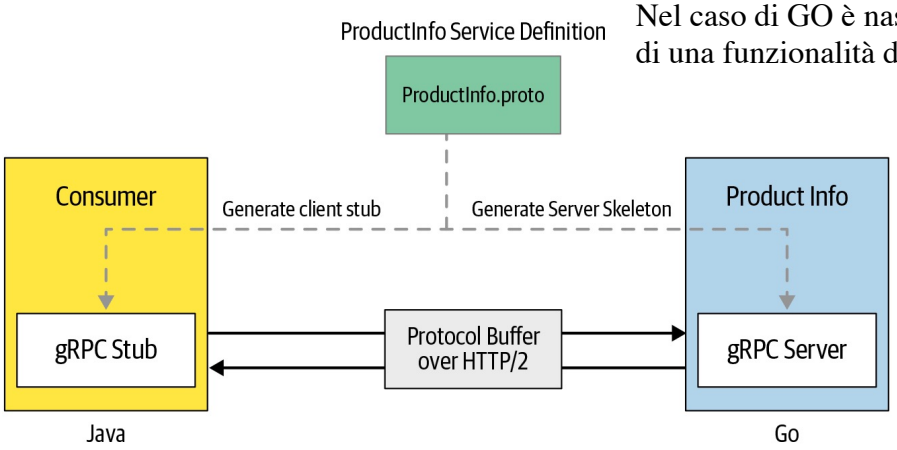
https://developers.google.com/web/fundamentals/performance/http2?hl=it

Gestisce in maniera efficiente scambio di strutture dati scambiandole in formato binario: ho file .proto in cui definisco le mie strutture, avro` message <nome_messaggio> con i campi e i rispettivi tipi di dato. Uso un compiler per l'IDL, che e' protoc, che permette di generare classi per l'accesso ai dati nel linguaggio preferito.

gRPC: Protocol buffers

- gRPC can use **protocol buffers** as both its IDL to define the service interface and as its underlying message interchange format
  - Automatically generates client stubs and abstract server classes
- Based on usual proxy pattern (*stub* and *server*)

Nel caso di GO è nascosto, poichè si tratta di una funzionalità del linguaggio.



Protocol buffers

- Google's mature open-source mechanism for serializing structured data
- Binary data representation
- Strongly typed , cioè fortemente indirizzato verso i "tipi"

```
message Person {
  string name = 1;
  int32 id = 2;
  bool has_ponycopter = 3;
}
```

"1", "2", "3" indentificano i campi nel msg.

- Data types are structured as messages
  - Each message is a small logical record of information containing a series of name-value pairs called fields
  - Fields have unique field numbers (e.g., `string name = 1`) that are used to identify the fields in the message binary format

Protocol buffers: example

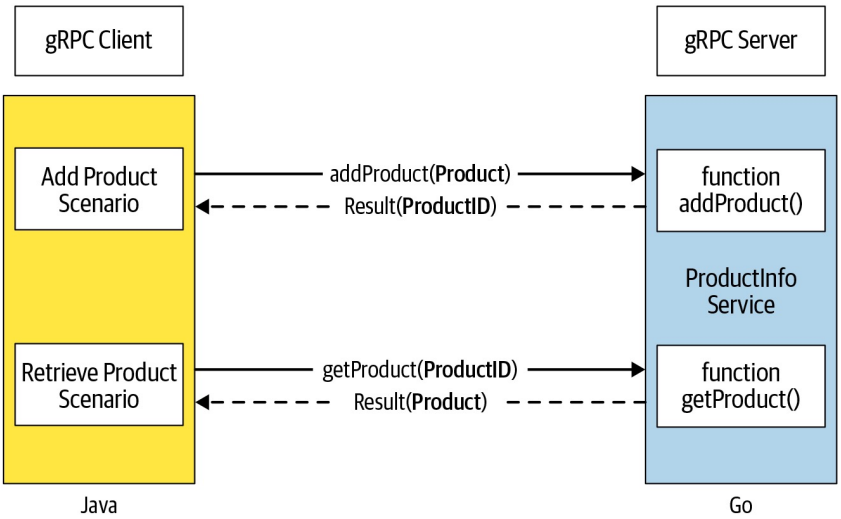
- ProductInfo service interface (slide 114)

Specifica dell'interfaccia tramite Protocol Buffer

```
// ProductInfo.proto
syntax = "proto3";
package ecommerce;

service ProductInfo {
    rpc addProduct(Product) returns (ProductID);   // inserimento prodotto
    rpc getProduct(ProductID) returns (Product);   // info sul prodotto
}

message Product {
    string id = 1;
    string name = 2;
    string description = 3;
}

message ProductID {
    string value = 1;
}
```


Client-server interaction: example

Da file 'proto' verranno creati automaticamente gli stub per la comunicazione.



gRPC: basic steps

1. Define the service (collection of remote methods) and the message types that are exchanged between client and service in a `.proto` file using protocol buffers as IDL Cioè ho definito l'interfaccia.
2. Generate server and client code using `protoc` (protocol buffer compiler) in your preferred language(s) from your proto definition
   - Go: compile manually
   - Java: use build automation tools like Bazel, Maven, or Gradle
3. Use the gRPC API in your preferred language (e.g., Go, Java, Python) to write the service client and server

gRPC: greeting example in Go

- See Quick start/ and helloworld example

1. Define the service (`helloworld.proto` file)

(Passo '1' degli step appena definiti)

```
package helloworld;

// The greeting service definition.
service Greeter {
  // Sends a greeting
  rpc SayHello (HelloRequest) returns (HelloReply) {}
}

// The request message containing the user's name.
message HelloRequest {
  string name = 1;
}

// The response message containing the greetings
message HelloReply {
  string message = 1;
}
```

metodo 'SayHello' remoto, invia 'HelloRequest' e ottiene 'HelloReply'

tipo

Definisco i tipi di messaggi scambiati

gRPC: greeting example

2. Compile the service definition:

```
$ protoc --go_out=. --go_opt=paths=source_relative \
    --go-grpc_out=. --go-grpc_opt=paths=source_relative \
    helloworld/helloworld.proto
```

Percorso dell'interfaccia, la compilo.

- Generated files:
  - `helloworld.pb.go`: contains all the protocol buffer code to populate, serialize, and retrieve request and response message types, codice per gestire msg richiesta/risposta.
  - `helloworld_grpc.pb.go`: contains
    - An interface type (or *stub*) for clients to call with the methods defined in the Helloworld service
    - An interface type for servers to implement, also with the methods defined in the Helloworld service

Mancano da definire solo alcuni aspetti client-server.

gRPC: greeting example

3. Create the server: two parts

Non esaminato nel dettaglio, ci server però per "gestire la comunicazione"

a. Implement the service interface generated from the service definition: doing the actual "work" of the service

```
func (s *server) SayHello(ctx context.Context,
   in *pb.HelloRequest) (*pb.HelloReply, error) {
    …
}
```

in questo ' punto "a" ' implemento "che cosa fa"

b. Run a gRPC server to listen for requests from clients and dispatch them to the right service implementation

```
lis, err := net.Listen("tcp", port)
if err != nil {
    log.Fatalf("failed to listen: %v", err)
}
s := grpc.NewServer()
pb.RegisterGreeterServer(s, &server{})
s.Serve(lis)
```

//metto server gRPC in ascolto.

gRPC: greeting example

4. Create the client
   - To call service methods, we first need to create a gRPC channel to communicate with the server using `Dial` (Non in "Go")

```
conn, err := grpc.Dial(address, opts…)
```

   - Then we need a client stub to perform RPCs: we get it using `pb.NewGreeterClient` provided by the pb package generated from `.proto` file.

```
c := pb.NewGreeterClient(conn)
```

   - Then we call the service method on the client stub: we create and populate a request protocol buffer object (`HelloRequest`) and also pass a `context` object which lets us change our RPC's behavior if necessary, such as time-out/cancel an RPC in flight

```
r, err := c.SayHello(ctx, &pb.HelloRequest{Name: name})
```

Sfruttando la sintassi di GO, porto sempre con me una variabile "err" per gestire eventuali errori

gRPC: greeting example

- As next step, we can update the gRPC service adding a new `SayHelloAgain()` method
  1. Update `.proto` file
  2. Regenerate gRPC code using `protoc`
  3. Update server code to implement new method

```
func (s *server) SayHelloAgain(ctx context.Context, in
*pb.HelloRequest) (*pb.HelloReply, error) {
    log.Printf("Received: %v", in.GetName())
    return &pb.HelloReply{Message: "Hello again " +
in.GetName()}, nil
}
```

  4. Update client code to call new method

```
r, err = c.SayHelloAgain(ctx, &pb.HelloRequest{Name: name})
 if err != nil {
    log.Fatalf("could not greet: %v", err)
 }
 log.Printf("Greeting: %s", r.GetMessage())
```

gRPC: ProductInfo example

- Let's analyze the ProductInfo example

1. Define the service
2. Implement server in Go
3. Implement client in Go
4. Implement client/server in Java

See Go code on course web site

See Java code on github

14/11/22

gRPC: types of RPC methods

- Multiple types of methods can be defined in .proto file
- *Simple RPC:* client sends a request to server and waits for a response to come back

```
rpc SayHello (HelloRequest) returns (HelloReply) {}
```

- *Server-side streaming RPC:* client sends a request to server and gets a stream to read a sequence of messages back

```
rpc ListFeatures(Rectangle) returns (stream Feature) {}
```

- *Client-side streaming RPC:* client writes a sequence of messages and sends them to server

```
rpc RecordRoute(stream Point) returns (RouteSummary) {}
```

- *Bidirectional streaming RPC:* both sides send a sequence of messages using a read-write stream

```
rpc RouteChat(stream RouteNote) returns (stream RouteNote) {}
```

See routeguide example

gRPC: Weaknesses

- Limited browser support
  - Impossible to directly call a gRPC service from a browser because of lack of HTTP/2 support
  - gRPC-Web can be used to provide gRPC support in browser, but limited features (only simple RPC and limited server streaming)

- Non-human readable format
  - Protocol bufffers is efficient to send and receive, but its binary format is not human readable
  - Developers need additional tools (e.g., gRPC command-line tool) to analyze Protobuf payloads on the wire, write manual requests, and perform debugging