Distributed Systems

Remote Invocation

Prof. Dr. Oliver Hahm

Frankfurt University of Applied Sciences
Faculty 2: Computer Science and Engineering
oliver.hahm@fb2.fra-uas.de
https://teaching.dahahm.de

13.05.2024

How can we achieve access transparency?

Agenda

- Motivation
- Basic Principles
- Binding
- Error Handling
- RPC Systems

Agenda

- Motivation
- Basic Principles
- Binding
- Error Handling
- RPC Systems

Motivation

- Message oriented communication
  - asynchronous exchange of messages
  - explicitly via `send()` and `receive()` operations
  - Summary
    - + very flexible, all communication patterns possible
    - - explicit, I/O paradigm

Motivation

- Message oriented communication
  - asynchronous exchange of messages
  - explicitly via `send()` and `receive()` operations
  - Summary
    - + very flexible, all communication patterns possible
    - - explicit, I/O paradigm
- Goal of remote invocation
  - Communication transparency
  - Appears like an usual local procedure call
  - → Remote Procedure Call
- Supports ...
  - Service orientation → Service = Set of functions
  - RPC for calling the functions
  - Object orientation → Remove Method Invocation (RMI)

History

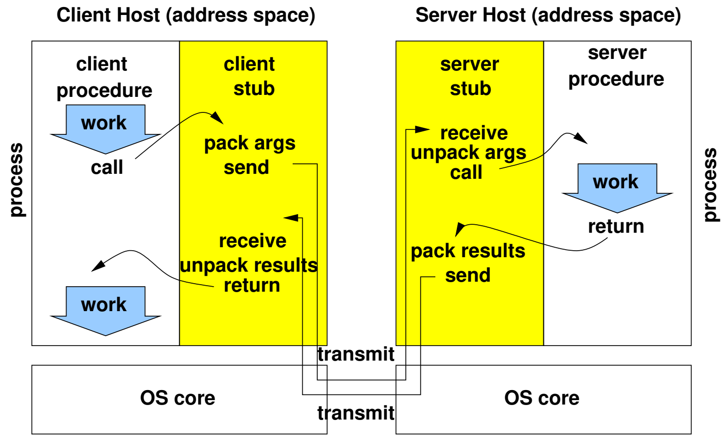
- First comprehensive presentation:
  - Dissertation *Nelson* (1981, *XPARC*)
  - Derived Paper Birrel/Nelson (1984, *ACM ToCS*)
- Definition:
  - RPC as a **synchronous** mechanism *"which **transfers control flow** and **data** as a procedure call between **two [separated] address spaces** over a narrowband network."*
- Nelson's Thesis:
  - RPC is an efficient concept for implementing distributed applications
  - RPC facilitates the development of distributed systems

History

- First comprehensive presentation:
  - Dissertation *Nelson* (1981, *XPARC*)
  - Derived Paper Birrel/Nelson (1984, *ACM ToCS*)
- Definition:
  - RPC as a **synchronous** mechanism *"which* ***transfers control flow*** *and* ***data*** *as a procedure call between* ***two [separated] address spaces*** *over a narrowband network."*
- Nelson's Thesis:
  - RPC is an efficient concept for implementing distributed applications
  - RPC facilitates the development of distributed systems
- Today:
  - Nelson's vision has been widely accepted
  - Many produces work on RPC systems
  - Typical examples: SunRPC and NFS, OSF DCE RPC, Apache Thrift, D-Bus

Agenda

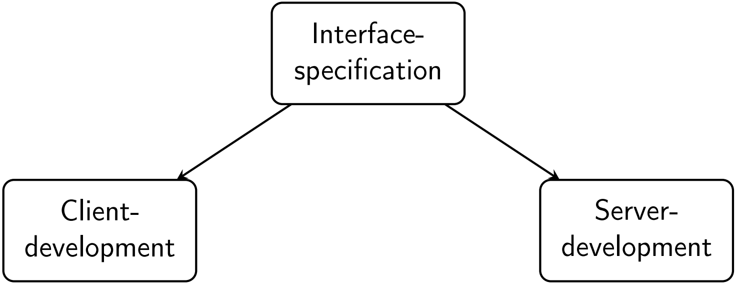
Main Principle



pack/unpack = marshalling/unmarshalling
Proxy components: stub, proxy, skeleton

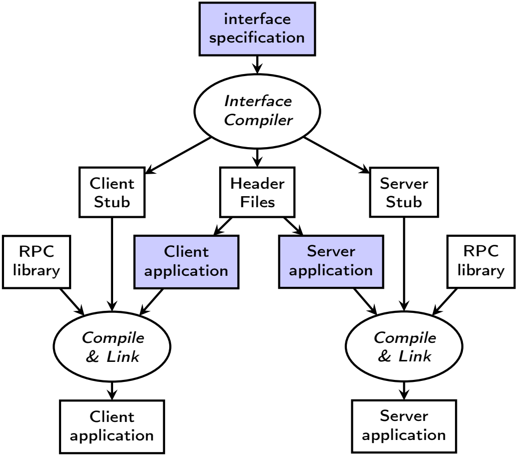
Application Development (high level)

Coarse structure:



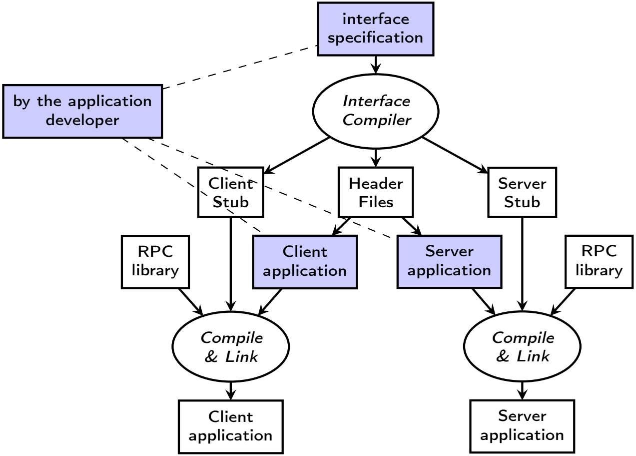
Application Development (Zoom in)

more detailed, but still independent of the particular RPC system:

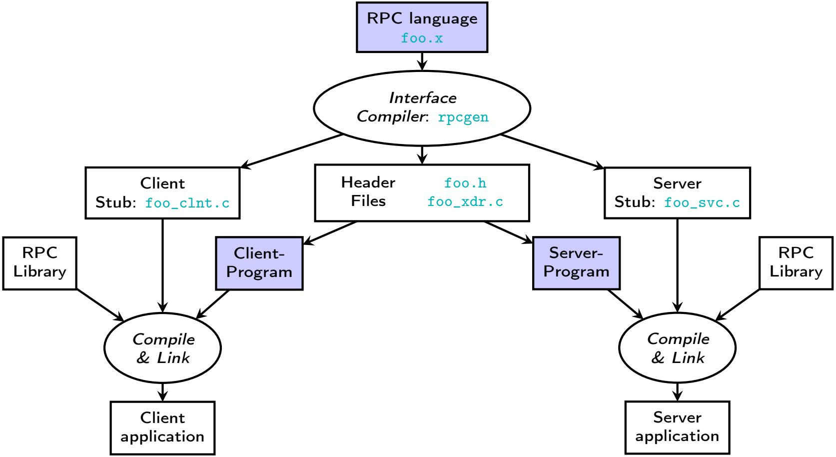


Application Development (Zoom in)

more detailed, but still independent of the particular RPC system:



Example: SunRPC



Interface Description

Which information needs to be included in the interface description?

Example: Interface Description SunRPC (1)

```
const MAX_FILENAME_LEN = 255;
typedef string t_filename<MAX_FILENAME_LEN>;
const MAX_CONTENT_LEN = 255;
typedef string t_content<MAX_CONTENT_LEN>;
```

```
struct s_filewrite {
    t_filename filename;
    t_content content;
};
struct s_chmod {
    t_filename filename;
    long mods;
};
```

```
struct s_fstat {
    long dev;
    long ino;
    long mode;
    long nlink;
    long uid;
    long gid;
    long rdev;
    long size;
    long blksize;
    long blocks;
    long atime;
    long mtime;
    long ctime;
};
```

Example: Interface Description SunRPC (2)

```
program fileservice {
    version fsrv {
        int fsrv_mkdir(string) = 1;
        int fsrv_rmdir(string) = 2;
        int fsrv_chdir(string) = 3;
        int fsrv_writefile(s_filewrite) = 4;
        string fsrv_readfile(string) = 5;
        s_fstat fsrv_fileattr(string) = 6;
        int fsrv_chmod(s_chmod) = 7;
    } = 1;
} = 0x30000001;
```

Example: Interface Description DCE

```
[ uuid(5ab2e9b4-3d48-11d2-9ea4-80c5140aaa77),
version(1.0), pointer_default(ptr)
]
interface echo {
    typedef [ptr, string] char * string_t;
    typedef struct {
        unsigned32 argc;
        [size_is(argc)] string_t argv[];
    } args;
    boolean ReverseIt(
        [in] handle_t h,
        [in] args* in_text,
        [out] args** out_text,
        [out,ref] error_status_t* status
        );
}
```

Example: Interface Description Thrift

```
typedef i32 MyInteger
enum Operation { ADD = 1,
                 SUBTRACT = 2,
                 MULTIPLY = 3,
                 DIVIDE = 4
}
struct Work {
    1: MyInteger num1 = 0,
    2: MyInteger num2,
    3: Operation op,
    4: optional string comment,
}
exception InvalidOperation { 1: i32 what, 2: string why }
service Calculator {
    void ping(),
    i32 add(1:i32 num1, 2:i32 num2),
    i32 calculate(1:i32 logid, 2:Work w)
    throws (1:InvalidOperation ouch),
    oneway void quit()
}
```

Agenda

- Motivation
- Basic Principles
- **Binding**
- Error Handling
- RPC Systems

Binding

- Binding
  - **Problem:** Binding of a client to a server is mandatory
  - Problem exists for other paradigms as well
  - **Aspects**: Naming & Locating

Binding

- Binding
  - **Problem:** Binding of a client to a server is mandatory
  - Problem exists for other paradigms as well
  - **Aspects**: Naming & Locating

⇒ Naming
  - How does the client specify what it wants to be bound to (→ service)
  - Interface names are structured in a system wide *namespace*
  - Extending this concept by interface attributes → Trading

  → Directory and name services

Binding

- Binding
  - **Problem:** Binding of a client to a server is mandatory
  - Problem exists for other paradigms as well
  - **Aspects**: Naming & Locating

⇒ Naming

- How does the client specify what it wants to be bound to (→ service)
- Interface names are structured in a system wide *namespace*
- Extending this concept by interface attributes → Trading

→ Directory and name services

⇒ Locating

- Determine the (location dependent) *address* of a server which exports the desired interface and can be used for the service
- often: IP address of the host and port number

Locating Types

- Static address as part of the application
  - **Benefit:** requires no search process
  - **Drawback:** often not flexible enough

  ⇒ binding too early

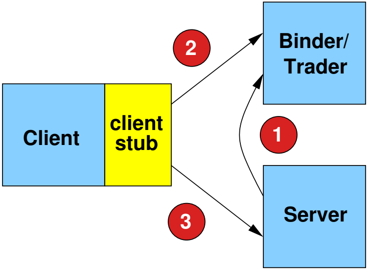
Locating Types

- Static address as part of the application
  - **Benefit:** requires no search process
  - **Drawback:** often not flexible enough
  - $\Rightarrow$ binding too early
- Search for exporting servers at runtime, e.g., via broadcast
  - **Benefit:** very flexible
  - **Drawback:** increased runtime
  - **Drawback:** Broadcasting across subnet boundaries is not desirable
  - $\Rightarrow$ binding too late

Locating Types

- Static address as part of the application
  - **Benefit:** requires no search process
  - **Drawback:** often not flexible enough
  - ⇒ binding too early
- Search for exporting servers at runtime, e.g., via broadcast
  - **Benefit:** very flexible
  - **Drawback:** increased runtime
  - **Drawback:** Broadcasting across subnet boundaries is not desirable
  - ⇒ binding too late
- Manage binding information via intermediary instance
  - Mediating instance is called binder, trader, or broker
  - Exporting server registers interface (along with all attributes)
  - Binding request of an importing client causes assignment by the binder

Basic Procedure



1. Exporting the interface
   - Register the interface at binder
   - Binder has known address
2. Importing
   - At first use of the service from stub
   - Provides handle with address
3. Remote invocation
   - Client stub uses the address for the call to server

Binder/Trader

Typical interface

`Register(` service name, version, address[, attributes])

`Deregister(` services name, version, address)

`Lookup(` name, version[, attributes]) $\Rightarrow$ address

- Advantages:
  - Very flexible
  - Works with multiple servers of the same type
  - Basis for *load balancing* between equivalent servers
- Drawbacks:
  - Additional effort for exporting and importing of a services is required
  - Can be problematic with short-lived servers and clients

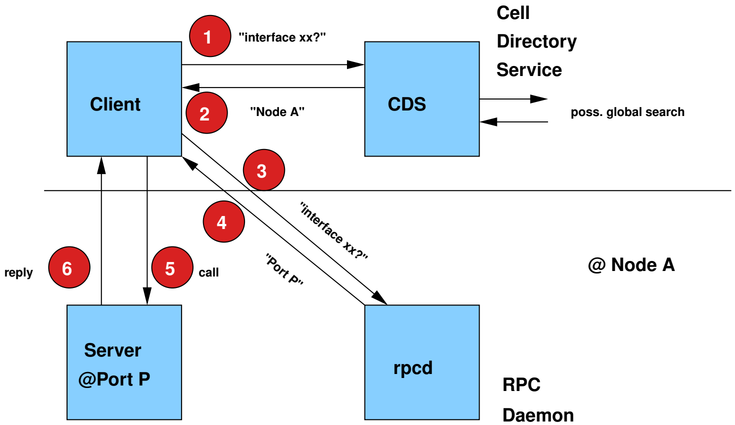
Example: SunRPC

- Names
  - Pairs (Program number, version number)
- Addresses
  - Pairs (IP address of host, port number)
- Binder: *Portmapper*
  - Mapping from names to port numbers
  - IP address of host must be known → the portmapper located there will be used
  - The portmapper itself is a SunRPC service (port 111)

Example: DCE RPC

- Names
  - *UUID (Universal Unique Identifier)*
  - Worldwide unique string
  - Generated by the tool `uuidgen`
- Addresses
  - Pairs (IP address of host, port number)
- Binding
  - Two-tiered within a DCE cell
  - No additional knowledge required
  - Binder is called RPC daemon

Example: DCE RPC (2)



Agenda

- Motivation
- Basic Principles
- Binding
- **Error Handling**
- RPC Systems

Error Problem

- Local function call:
  → Caller and callee are aborted simultaneously
- RPC:
  → Failure of single components in a distributed environment is possible
- Additional error cases caused by the messaging system itself need to be considered
  - Message loss
  - Unknown transmission times
  - Out of order delivery of messages
- Different RPC systems implement different error semantics

RPC Error Semantics: at-least-once

- at-least-once semantics
  - successful execution of the RPC
    $\Rightarrow$ called procedure is executed at least once,
    i.e., multiple executions may happen
  - Can cause arbitrary effects in an error case
  - In general, only suited for idempotent operations, i.e., multiple executions do not change state and result
- **Implementation**
  - Most simple form
  - If the client does not receive a result in time, the call is repeated by the stub ($\rightarrow$ timeout)
  - No precautions on the server are are necessary

What is an idempotent operation?

RPC Error Semantics: at-most-once

- at-most-once semantics
  - Successful execution of the RPC
    $\Rightarrow$ Called procedure gets executed exactly once
  - Unsuccessful execution of the RPC
    $\Rightarrow$ Called procedure gets never executed
  - No partial error effects can be left behind
- **Implementation**
  - More complex
  - Requires duplicate detection

How can one implement duplicate detection?

RPC Error Semantics: exactly-once

- exactly-once semantics
  - Successful execution of the RPC
    $\Rightarrow$ Called procedure is executed exactly once
- **Implementation**
  - Very complex

Orphan Problem

- **Problem:** The client dies after calling an RPC
- Generated call may cause further activities even though no one is waiting for it any more
- After restart responses from a *former life* may be received

Orphan Problem

- **Problem:** The client dies after calling an RPC
- Generated call may cause further activities even though no one is waiting for it any more
- After restart responses from a *former life* may be received
- **Solutions**:
  - Extermination: Targeted abort of orphaned RPCs based on stable memory

Orphan Problem

- **Problem:** The client dies after calling an RPC
- Generated call may cause further activities even though no one is waiting for it any more
- After restart responses from a *former life* may be received
- **Solutions**:
  - Extermination: Targeted abort of orphaned RPCs based on stable memory
  - (Gentle) Reincarnation: Introduce epochs on client side

Orphan Problem

- **Problem:** The client dies after calling an RPC
- Generated call may cause further activities even though no one is waiting for it any more
- After restart responses from a *former life* may be received
- **Solutions**:
  - Extermination: Targeted abort of orphaned RPCs based on stable memory
  - (Gentle) Reincarnation: Introduce epochs on client side
  - Expiration: RPCs are extended by timeouts

Agenda

- Motivation
- Basic Principles
- Binding
- Error Handling
- RPC Systems

RPC Protocol

- RPC protocol: rules for processing of RPCs
- Depends on the underlying transport system
  - Datagram service (e.g., UDP)
    - + resource-efficient, low latency
    - - Duplicates (via timeouts), permutations and loss are possible
  - Reliable transport service (e.g., TCP)
    - + Less error causes on the upper layers
    - - Potentially possible performance reducing

$\Rightarrow$ The selection happens dependent on the service requirement

Example: SunRPC

- Also: Open Network Computing (ONC) RPC
- Embedding in the C language
- Underlying transport service:
  - TCP or UDP
  - Does not add any reliability enhancing measures
    - ⇒ UDP plus timeouts on the application layer can be used for a at-least-once semantics
    - ⇒ TCP and message transaction IDs on the application layer can be used for a at-most-once semantics
- Binding via portmapper
  - Portmapper protocol itself is based on RPC
- Parameters
  - only call-by-value
- Security
  - Authentication: Null, UNIX, DES

Example: SunRPC

- Also: Open Network Computing (ONC) RPC
- Embedding in the C language
- Underlying transport service:
  - TCP or UDP
  - Does not add any reliability enhancing measures
    - ⇒ UDP plus timeouts on the application layer can be used for a at-least-once semantics
    - ⇒ TCP and message transaction IDs on the application layer can be used for a at-most-once semantics
- Binding via portmapper
  - Portmapper protocol itself is based on RPC
- Parameters
  - only call-by-value
- Security
  - Authentication: Null, ~~UNIX~~, ~~DES~~, RPCSEC_GSS

OSF DCE/RPC

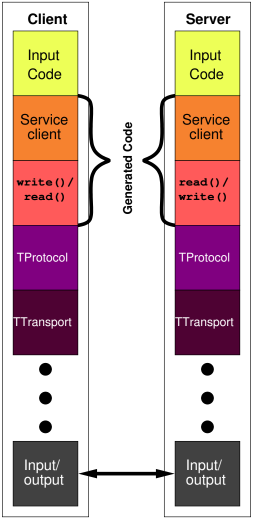
- Part of the OSF Distributed Computing Environments
- Foundation of Microsoft's DCOM and ActiveX
- Embedding for C/C++
- Multiple semantics possible (at-most-once as default)
- Arbitrary parameter types

→ *long* parameters via *pipe* mechanism

- Security is based on the Kerberos framework
- Relevancy has decreased

Modern RPC system: Apache Thrift

- Apache Thrift project (`http://thrift.apache.org/`)
  - Origins at Facebook, published in 2007
  - Supports all common programming languages
  - Simple Thrift IDL
  - IDL Compiler generates client and server stubs
  - Multiple server architectures available:
    - TNonBlockingServer
    - TThreadedServer
    - TThreadPoolServer
    - TForkingServer
    - ...
  - Multiple protocols and transports can be configured
  - Protocols: binary and text based (like JSON)
    $\Rightarrow$ low overhead
  - Transports: Tsocket, TMemoryTransport, ...
- Well-known users
  - Facebook, last.fm, Pinterest, Uber, NSA



Transparency of RPC Systems

- Access transparency
- Location transparency
- Migration transparency
- Failure transparency
- Concurrency transparency
- Replication transparency
- Performance transparency
- Scaling transparency

Transparency of RPC Systems

- Access transparency
  Yes, the same operation gets executed
- Location transparency
- Migration transparency
- Failure transparency
- Concurrency transparency
- Replication transparency
- Performance transparency
- Scaling transparency

Transparency of RPC Systems

- Access transparency
  Yes, the same operation gets executed
- Location transparency
  Yes, via the locating
- Migration transparency
- Failure transparency
- Concurrency transparency
- Replication transparency
- Performance transparency
- Scaling transparency

Transparency of RPC Systems

- Access transparency
  Yes, the same operation gets executed
- Location transparency
  Yes, via the locating
- Migration transparency
  Yes, via the naming service
- Failure transparency
- Concurrency transparency
- Replication transparency
- Performance transparency
- Scaling transparency

Transparency of RPC Systems

- Access transparency
  Yes, the same operation gets executed
- Location transparency
  Yes, via the locating
- Migration transparency
  Yes, via the naming service
- Failure transparency
  Maybe, depends on the used error semantics
- Concurrency transparency
- Replication transparency
- Performance transparency
- Scaling transparency

Transparency of RPC Systems

- Access transparency
  Yes, the same operation gets executed
- Location transparency
  Yes, via the locating
- Migration transparency
  Yes, via the naming service
- Failure transparency
  Maybe, depends on the used error semantics
- Concurrency transparency
  No
- Replication transparency
- Performance transparency
- Scaling transparency

Transparency of RPC Systems

- Access transparency
  Yes, the same operation gets executed
- Location transparency
  Yes, via the locating
- Migration transparency
  Yes, via the naming service
- Failure transparency
  Maybe, depends on the used error semantics
- Concurrency transparency
  No
- Replication transparency
  Sometimes
- Performance transparency

- Scaling transparency

Transparency of RPC Systems

- Access transparency
  Yes, the same operation gets executed
- Location transparency
  Yes, via the locating
- Migration transparency
  Yes, via the naming service
- Failure transparency
  Maybe, depends on the used error semantics
- Concurrency transparency
  No
- Replication transparency
  Sometimes
- Performance transparency
  No
- Scaling transparency

Transparency of RPC Systems

- Access transparency
  Yes, the same operation gets executed
- Location transparency
  Yes, via the locating
- Migration transparency
  Yes, via the naming service
- Failure transparency
  Maybe, depends on the used error semantics
- Concurrency transparency
  No
- Replication transparency
  Sometimes
- Performance transparency
  No
- Scaling transparency
  For RMI yes, by the object orientation, for other RPCs sometimes

Important takeaway messages of this chapter

- RPCs provide a possibility to call functions on a remote host as if this would happen locally
- Important elements of an RPC system are the IDL, its compiler, and the binder
- Multiple error semantics exist which can be handled below or on top of the RPC system