RPC: Remote Procedure Call

February 24, 2017

Roadmap

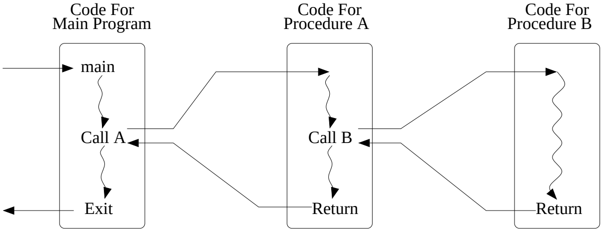
Roadmap

Remote Procedure Call (RPC)

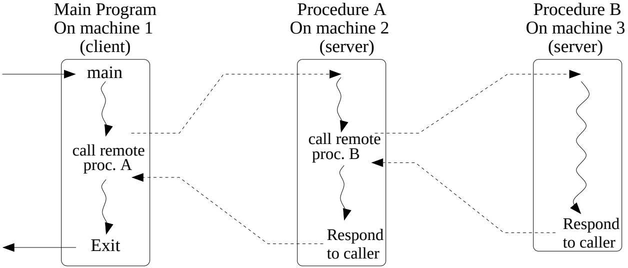
- Message-based programming with `send()`/`receive()` primitives is not convenient
  - depends on the communication protocol used (TCP vs. UDP)
  - requires the specification of an application protocol
  - akin to I/O
- Function/procedure call in a remote computer
  - is a familiar paradigm
  - eases transparency
  - is particularly suited for client-server applications

RPC: the Idea

Local procedure call:

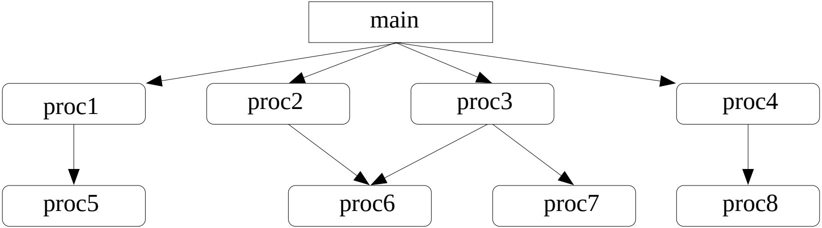


Remote procedure call:

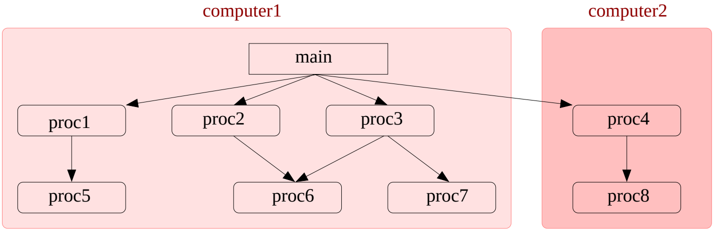


Program Development with RPCs: the Vision

- Design/develop an application ignoring distribution



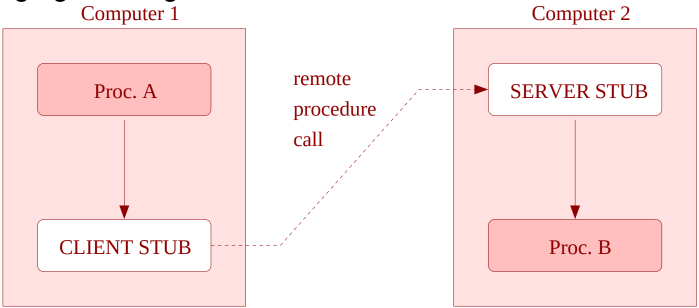
- Distribute *a posteriori*



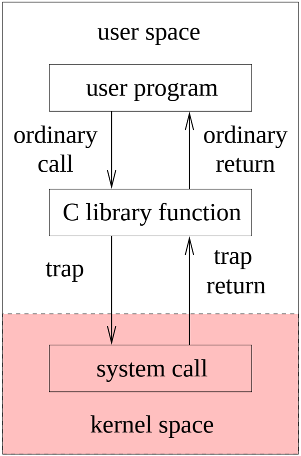
Roadmap

RPC Stub Routines

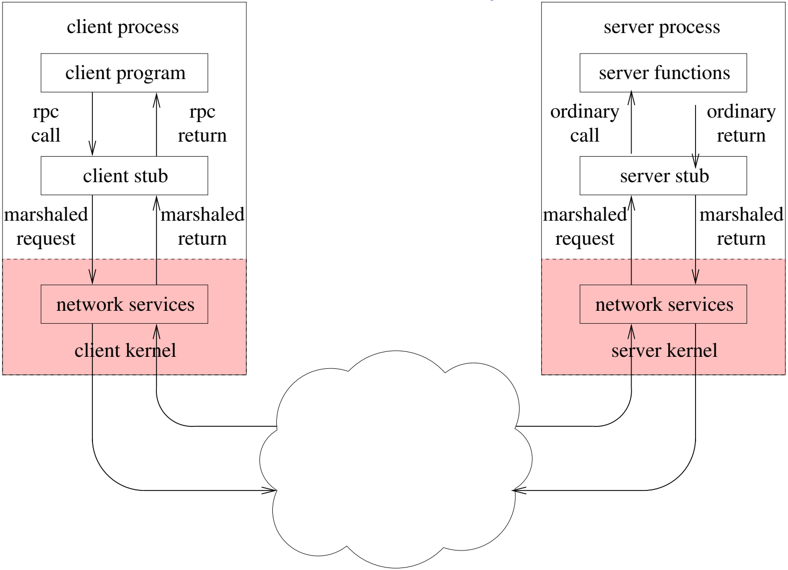
- Ensure RPC transparency
  - Client invokes the **client stub** – a local function
  - Remote function is invoked by the **server stub** – a local function
- The stub routines communicate with one another by exchanging messages



Well Known Trick: also Used for System Calls



Typical Architecture of an RPC System



Obs. RPC is typically implemented on top of the transport layer (TCP/IP)

Client Stub

Request

1. Assembles message: **parameter marshalling**
2. Sends message, via `write()`/`sendto()` to server
3. Blocks waiting for response, via `read()`/`recvfrom()`
   - Not in the case of **asynchronous RPC**

Response

1. Receives responses
2. Extracts the results (**unmarshalling**
3. Returns to client
   - Assuming **synchronous RPC**

Server Stub

Request

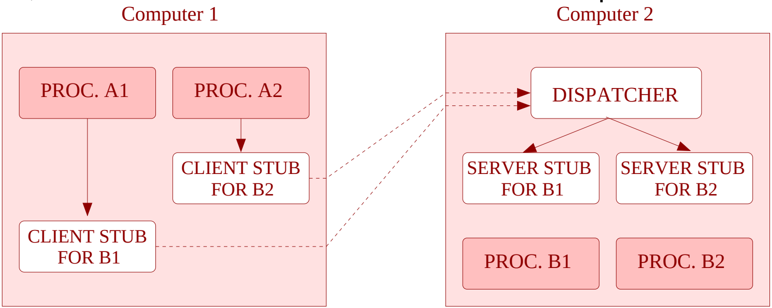
1. Receives message with request, via `read()`/`recvfrom()`
2. Parses message to determine arguments (**unmarshalling**
3. Calls function

Response

1. Assembles message with the return value of the function
2. Sends message, via `write()`/`sendto()`
3. Blocks waiting for a new request

RPC: Dispatching

- Often, **RPC services** offer more than one remote procedure:



- The identification of the procedure is performed by the **dispatcher**
  - This leads to a hierarchical name space **(service, procedure)**

Roadmap

Transparency: Platform Heterogeneity

Problems at least two:

1. Different architectures use different formats
   - 1's-complement vs. 2's complement
   - big-endian vs. little-endian
   - ASCII vs. UTF-??
2. Languages or compilers may use different representations for composite data-structures

Solution mainly two:

standardize format in the wires

+ needs only two conversions in each platform
– may not be efficient

receiver-makes-right

Transparency: Addresses as Arguments

Issue: The meaning of an address (C pointer) is specific to a process

Solution: Use **call-by-copy/restore** for parameter passing

+ Works in most cases
- Complex
  - The same address may be passed in different arguments
- Inefficient
  - For complex data structures, e.g. trees

Transparency in the Presence of Faults

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Issue A client cannot distinguish between loss of a request, loss of a response or a server crash

- The absence of a response may be caused by a slow network/server

Roadmap

RPC Semantics in the Presence of Faults (Spector82)

Question What can a client expect when there is a fault?

Answer Depends on the semantics in the presence of faults provided by the RPC system

At-least-once Client stub must keep retransmitting until it obtains a response

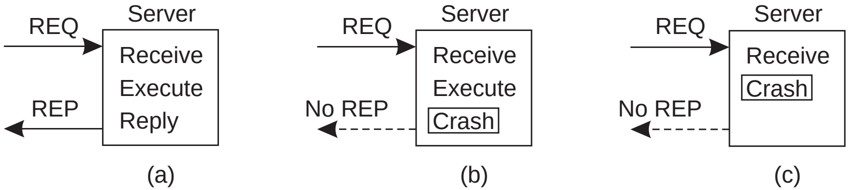
- Be careful with non-idempotent operations
- Spector allows for zero executions in case of server failure

At-most-once Not trivial if you use a non-reliable transport, e.g. UDP.

- If the RPC uses TCP, it may report an error when the TCP connection breaks

Exactly-once Not always possible to ensure this semantics, especially if there are external actions that cannot be undone

Faults and Exactly-once Semantics



Problem In the case of external actions, e.g. file printing, it is virtually impossible to ensure Exactly-once Semantics

Server strategy One of two:

1. Send an `ACK` after printing
2. Send an `ACK` before printing

Client strategy One of four:

1. Never resend the request
2. Always resend the request
3. Resend the request when it receives an `ACK`
4. Resend the request when it does not receive an `ACK`

Server Faults and Exactly-once Semantics

Scenario Server crashes and quickly recovers so that it is able to handle client retransmission, but **it has lost all state**

Let

`A`: `ACK` `P`: print `C`: crash

Fault scenarios (`ACK->P`)

1. `A->P->C`
2. `A->C(->P)`
3. `C(->A->P)`

Fault scenarios (`P->ACK`)

1. `P->A->C`
2. `P->C(->A)`
3. `C(->P->A)`

Client	**Server**					
	Strategy A→P			**Strategy P→A**		
Reissue Strategy	**APC**	**AC(P)**	**C(AP)**	**PAC**	**PC(A)**	**C(PA)**
Always	Dup	OK	OK	Dup	Dup	OK
Never	OK	Zero	Zero	OK	OK	Zero
When Ack	Dup	OK	Zero	Dup	OK	Zero
When not Ack	OK	Zero	OK	OK	Dup	OK

OK = Text printed once Dup = Text printed twice Zero = Text not printed at all

Conclusion No combined strategy works on every fault scenario

```
At-least-once versus at-most-once?
  let's take an example: acquiring a lock
    if client and server stay up and no message loss, client receives lock
    if client fails, it may know it has the lock or not (server needs a plan!)
    if server fails, client may have lock or not
      at-most-once:  client may receive an exception
      at-least-once: client keeps trying until, it has the lock or gives up
    what does a client do in the case of an exception?
      need to implement some application-specific protocol
        ask server, do i have the lock?
    server needs to have a plan for remembering state across reboots
        e.g., store locks on disk.
    at-least-once
      clients keep trying.  server may run procedure several times
      server must use application state to handle duplicates
        if requests are not idempotent
            but difficult to make all request idempotent
              e.g., server could store on disk who has lock and req id
                check table for each requst
                even if server fails and reboots, we get correct semantics
  Which is right?
    depends where RPC is used.
       simple applications:
         at-least-once is easiest if procedure is idempotent
         at-most-once is cool (more like procedure calls)
       more sophisticated applications:
         need an application-level plan in both cases
     not clear at-most-once gives you a leg up
=> Need to handle failures makes RPC very different than procedure calls
```

src: based F. Kaashoek (according to Dave Andersen)

Roadmap

Further Reading

- Tanenbaum e van Steen, *Distributed Systems, 2nd Ed.*
  - Section 4.2 *Remote Procedure Call*, except subsection 4.2.4
  - Subsection 8.3.2 *RPC Semantics in the Presence of Failures*
- Birrel and Nelson, *"Implementing Remote Procedure Calls"*, ACM Transactions on Computer Systems, Vol. 2, No. 1, February 1984, Pages 39-59
- A. Spector, *"Performing Remote Operations Efficiently on a Local Computer Network"*, Communications of the ACM, Vol. 25, No. 4, April 1982, Pages 246-260