RPC: Remote Procedure Call

February 23, 2018

Roadmap

Idea

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Transparency

RPC Semantics in the Presence of Faults

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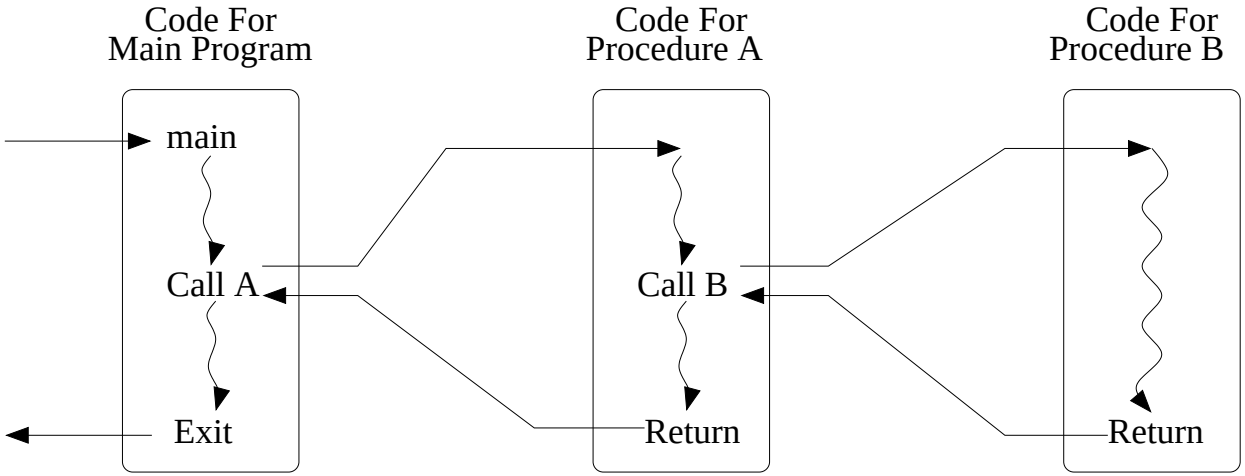
Remote Procedure Call (RPC)

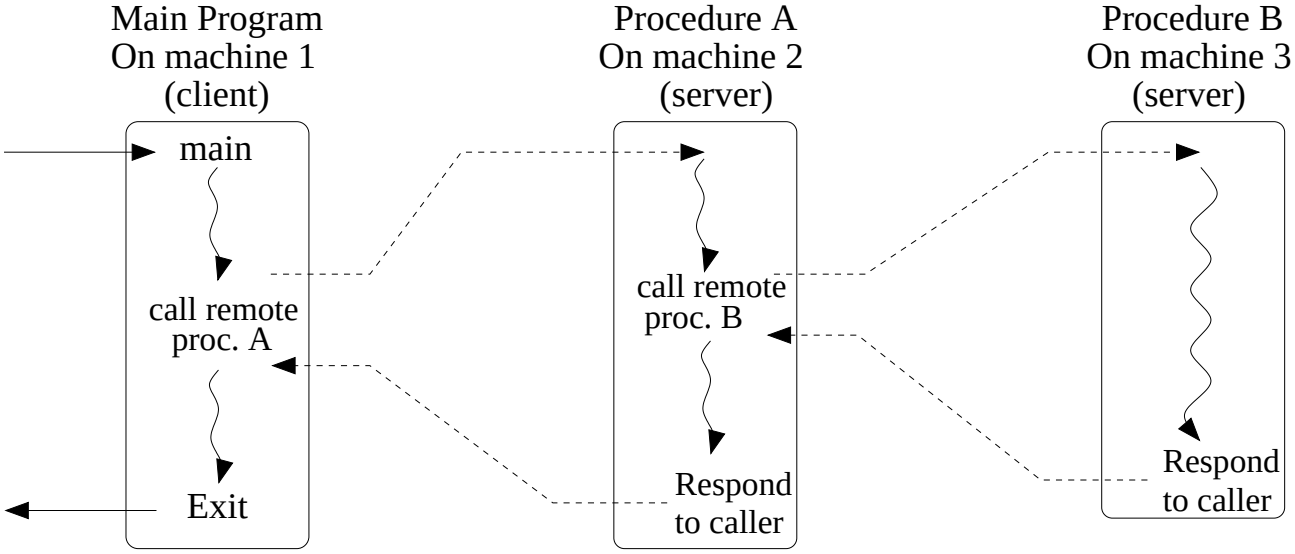
- Message-based programming with `send()/receive()` primitives is not convenient
  - depends on the communication protocol used (TCP vs. UDP)
  - requires the specification of an application protocol
  - akin to I/O
- Function/procedure call in a remote computer
  - is a familiar paradigm
  - eases transparency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

RPC: the Idea

Local procedure call:

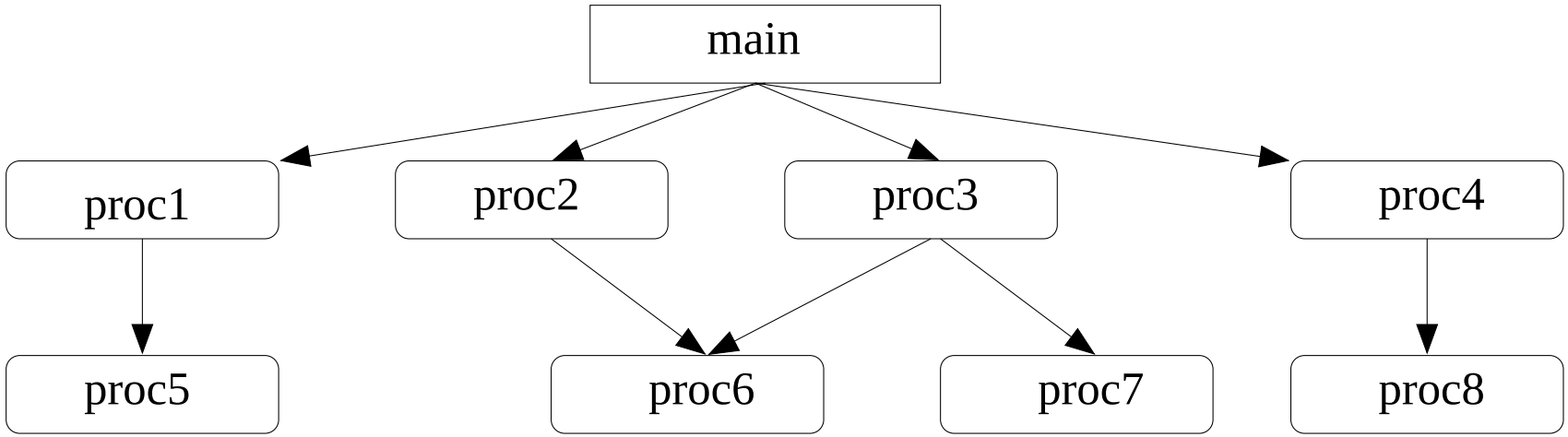


Remote procedure call:

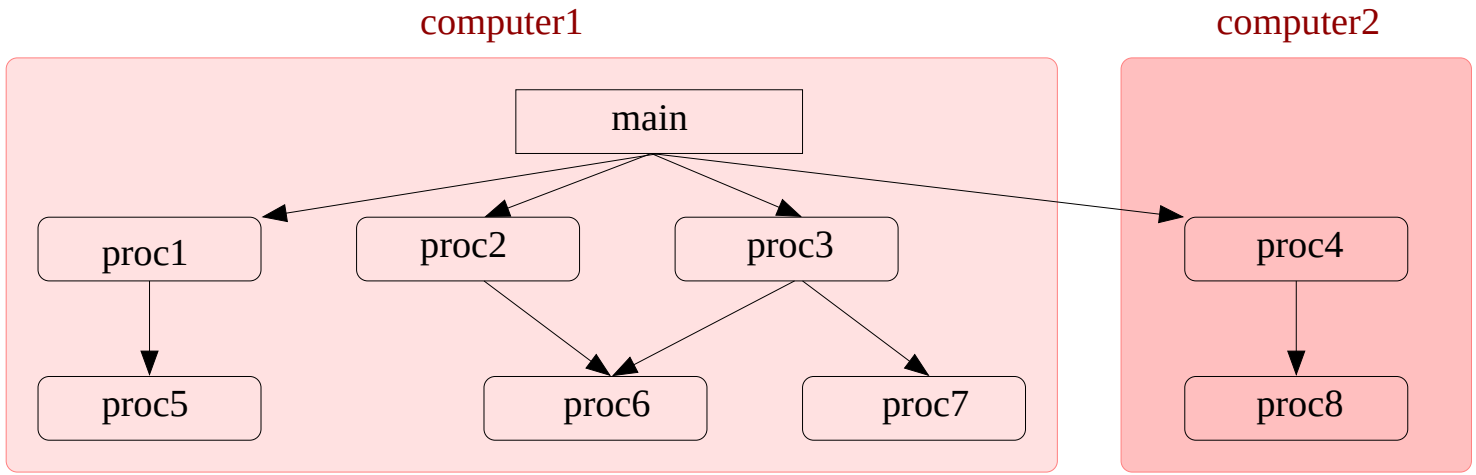


Program Development with RPCs: the Vision

- Design/develop an application ignoring distribution



- Distribute *a posteriori*



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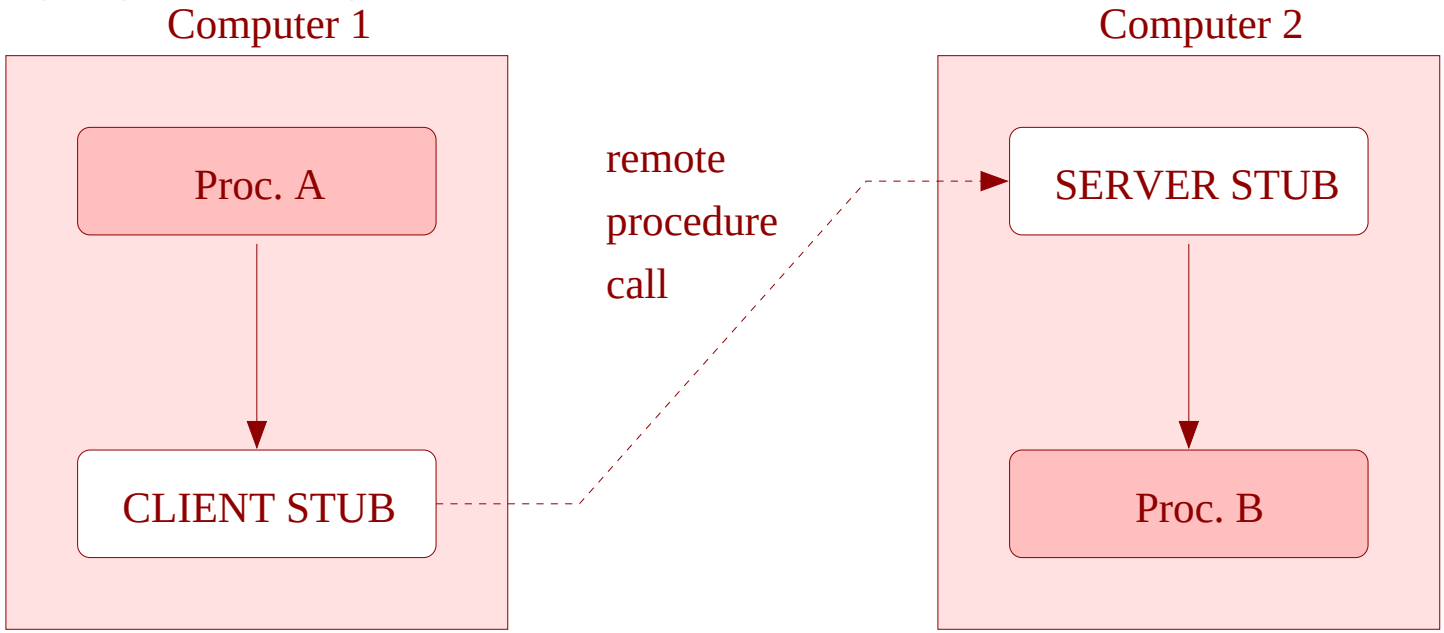
RPC Stub Routines

- Ensure RPC transparency

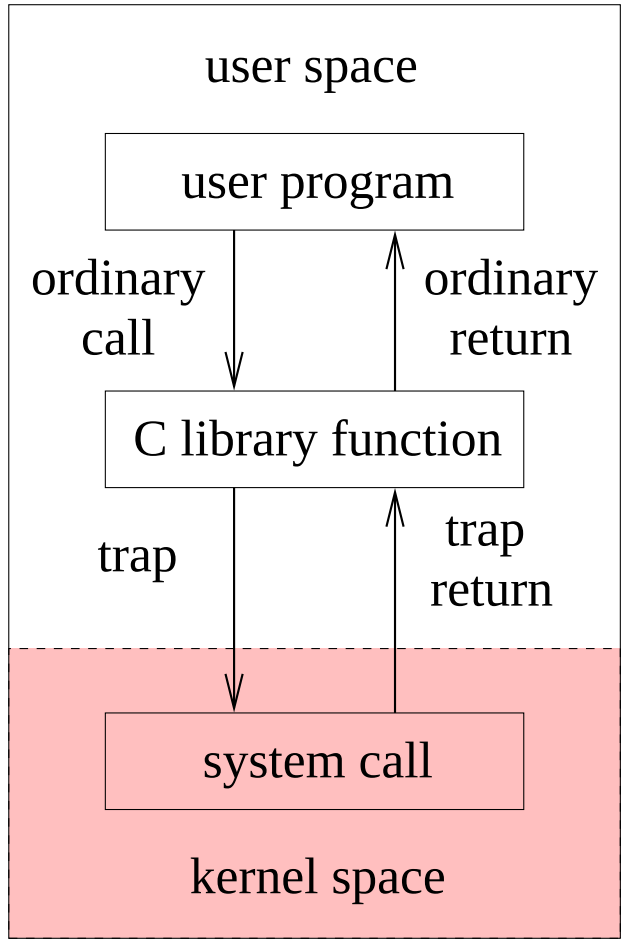
  Client invokes the **client stub** – a local function

  Remote function is invoked by the **server stub** – a local function

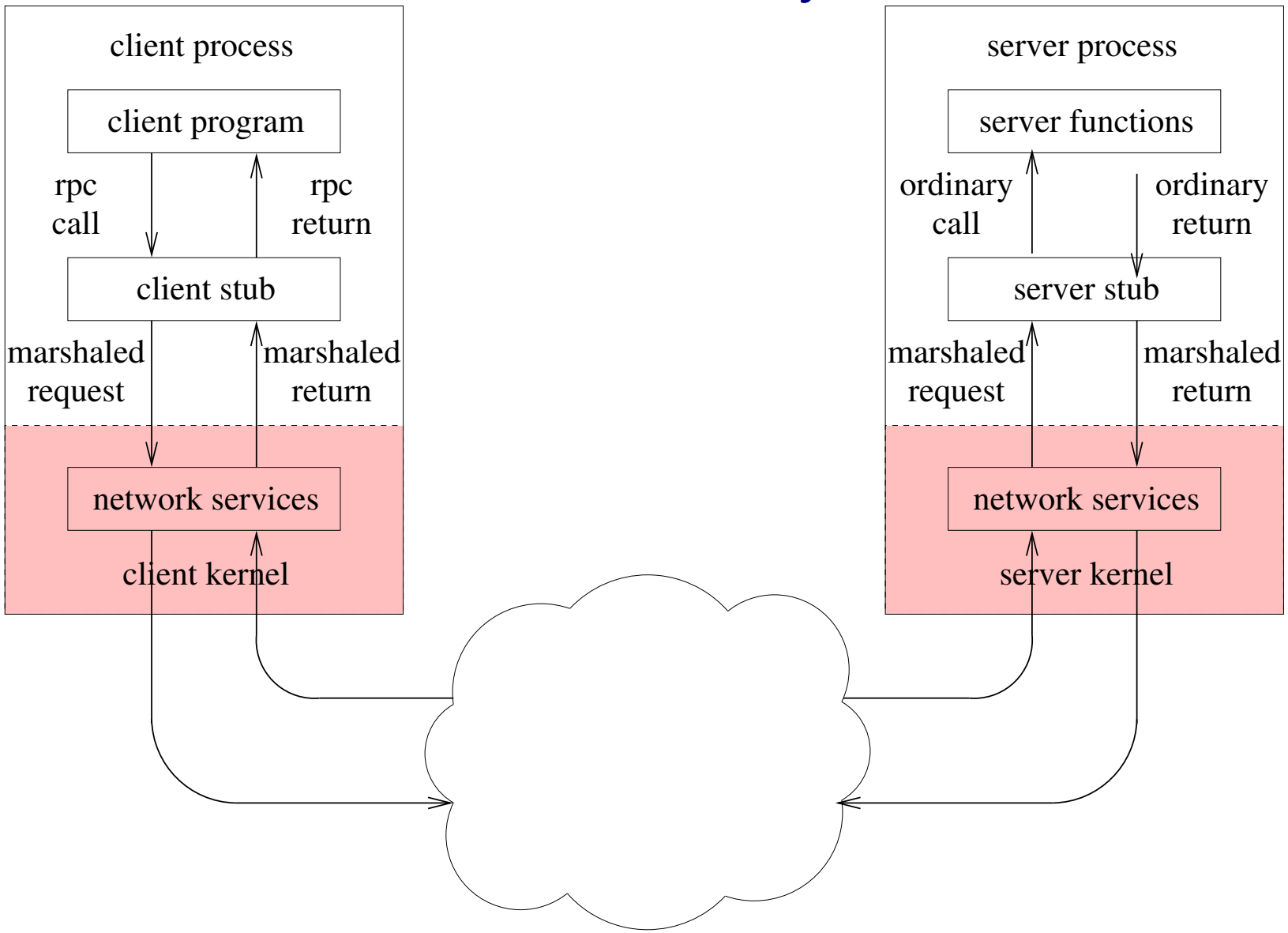
- The stub routines communicate with one another by exchanging messages



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

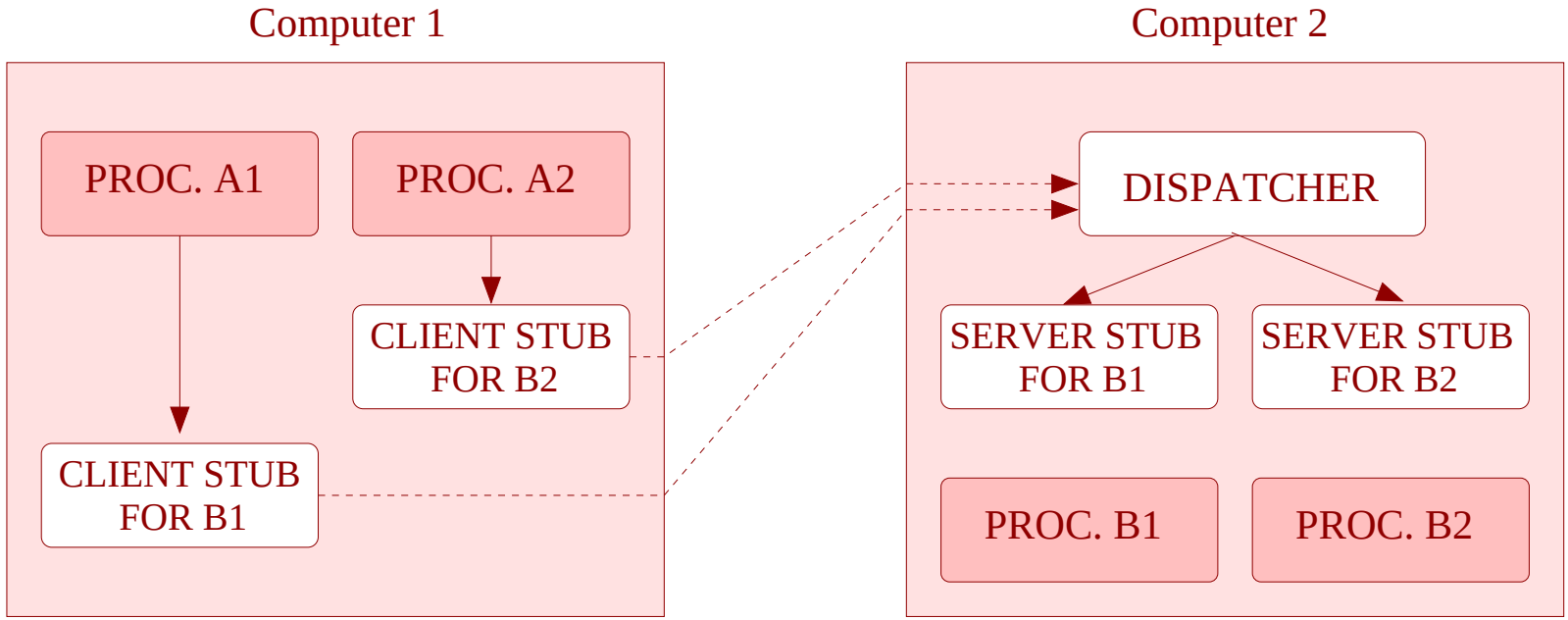
1. Receives message with request, via `read()/recvfrom()`
2. Parses message to determine arguments (**unmarshalling**
3. Calls function

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)**

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RPC Semantics in the Presence of Faults

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

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RPC Semantics in the Presence of Faults

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

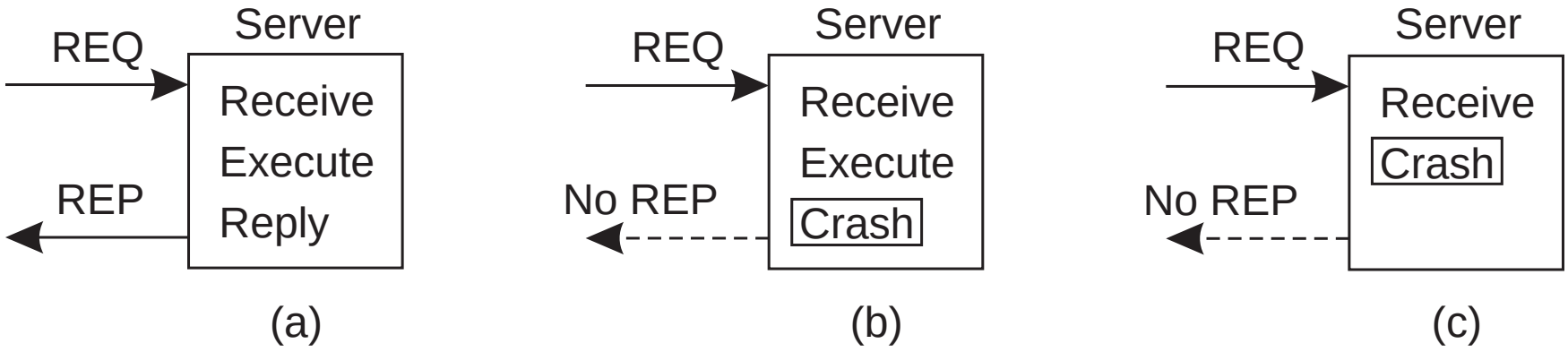
- Be careful with non-idempotent operations
- Spector allows for zero executions in case of server failure

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

Reissue Strategy	Strategy A→P: APC	Strategy A→P: AC(P)	Strategy A→P: C(AP)
Always	Dup	OK	OK
Never	OK	Zero	Zero
When Ack	Dup	OK	Zero
When not Ack	OK	Zero	OK

OK = Text printed once

Dup = Text printed twice

Server

Strategy P→A: PAC	Strategy P→A: PC(A)	Strategy P→A: C(PA)
Dup	Dup	OK
OK	OK	Zero
Dup	OK	Zero
OK	Dup	OK

Zero = Text not printed at all

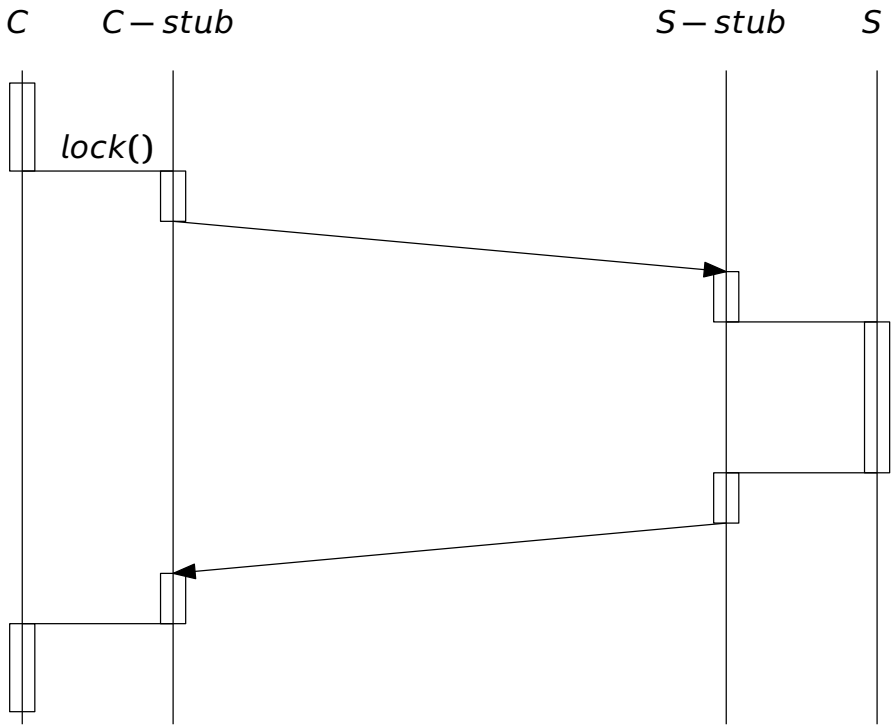
Conclusion No combined strategy works on every fault scenario

At-least-once vs. At-most-once

- Consider a locking service using two RPCs:

  `lock()`
  `unlock()`

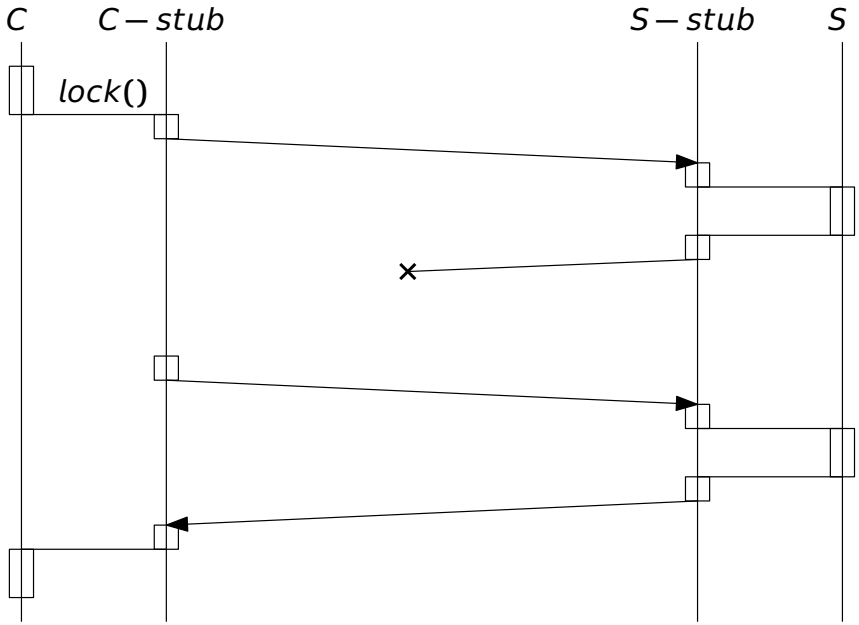
No failures and no message loss



- It does not matter the semantics supported by the RPC library

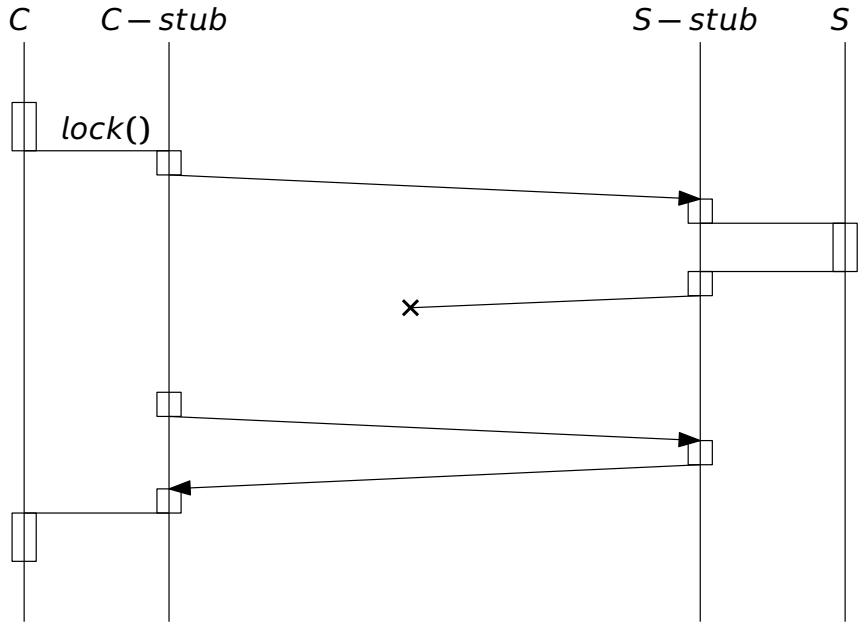
At-least-once vs. At-most-once: Lost Response

At-least-once



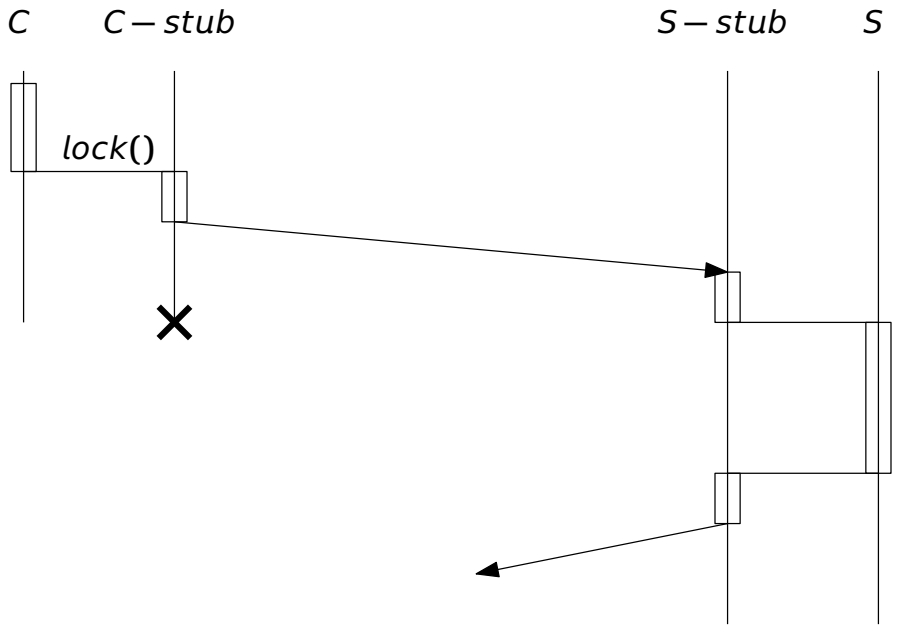
- Remote procedure may be invoked more than once
  - If procedure is not **idempotent**:
    - RPC must include an id as argument
    - Server must keep table with responses

At-most-once



- The RPC middleware itself ensures that the procedure is not executed more than once

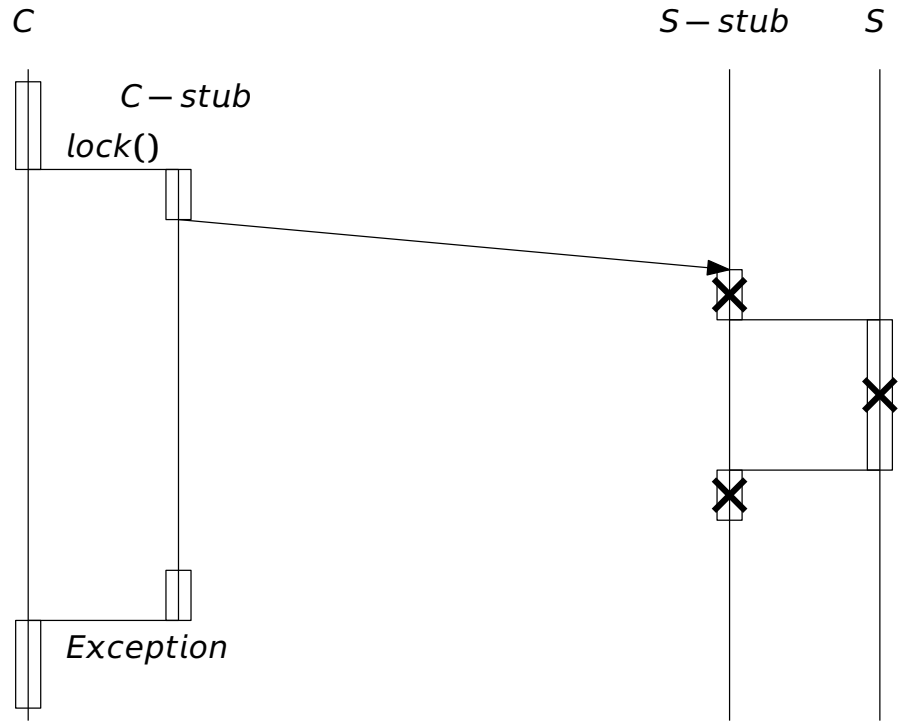
At-least-once vs. At-most-once: Client crash



- Again, the RPC semantics is irrelevant

At-least-once vs. At-most-once: Server crash

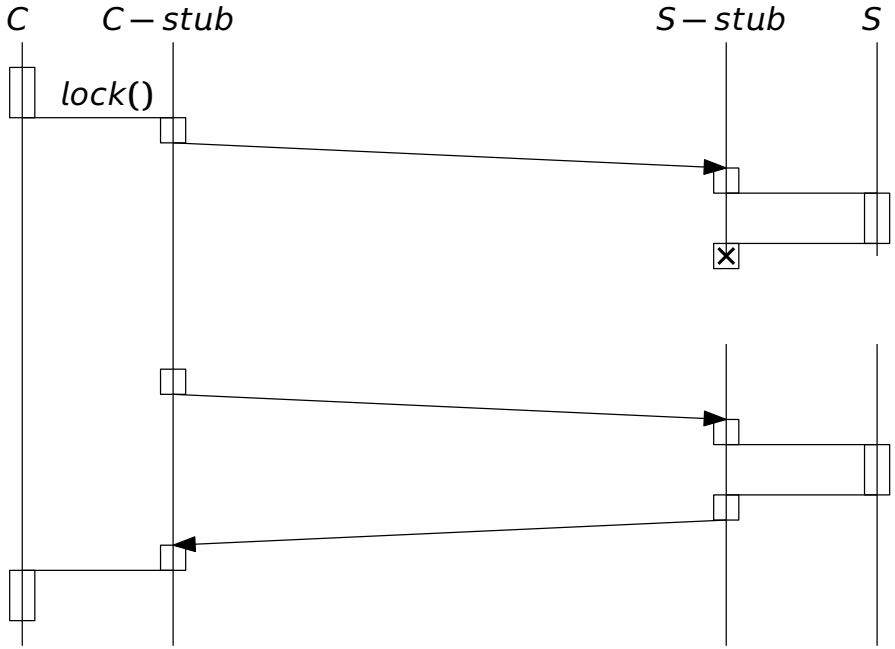
At-most-once



- Client does not know if server granted it the lock
  - Depends on when the server crashed
- Client, **not RPC**, may ask the server (or just retry)
  - Server needs to remember state across reboots
    - E.g. store locks state on disk

At-least-once vs. At-most-once: Server crash

At-least-once



- Server may run the procedure several times
  - Client stub may send several requests before giving up
- Server needs to remember previous requests across reboots (if requests are not **idempotent**). E.g.:
  - Store table request ids on disk
  - Check the request table on each request

At-least-once vs. At-most-once: Conclusions

Message loss

At-least-once

- Suits if requests are idempotent

At-most-once

- Appropriate when requests are not idempotent

Server crashes

- No clear advantage: the service itself may have to take special measures

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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