MONASH University
Information Technology

FIT3142 Distributed Computing

Topic 1 – Reading Materials: Inter Process Communications & Remote Procedure Call Mechanisms

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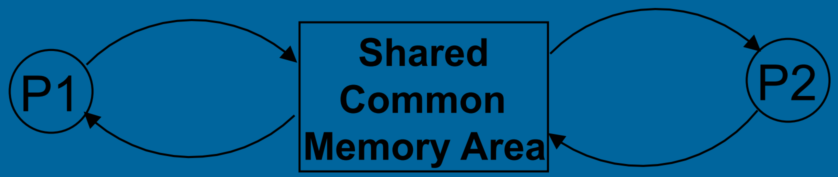
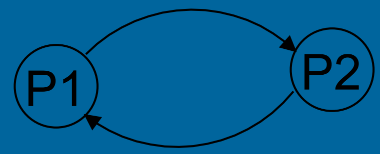
Inter-process Communication (IPC)

- **IPC basically requires information sharing among two or more processes. Two basic methods-**
  - Original sharing (Shared data approach)
  - Copy Sharing (Message passing approach)



Shared data approach



Message passing approach

Message Passing System

- **A *message-passing system* is a sub-system of a distributed system that provides a set of message-based IPC protocols and does so by shielding the details of complex network protocols and multiple heterogeneous platforms from programmers.**

- **It enables processes to communicate by exchanging messages**

- **Allows programs to be written by using simple communication primitives, such as *send* and *receive*.**

- **Serves as a suitable infrastructure for building other higher level IPC systems, such as RPC (Remote Procedure Call) and DSM (Distributed Shared Memory).**

Desirable features of a good message passing system

- **Simplicity**
- **Uniform semantics**
  - Same primitives for local and remote communication
- **Efficiency**
  - Reduce the number of message as far as possible
  - Some optimization normally adopted for efficiency include-
    - > Avoiding the cost of establishing and terminating connections between the same pair of processes for each and every message exchange between them
    - > Minimizing cost of maintaining connections
    - > Piggybacking of acknowledgment of previous message with the next message.

Desirable features of a good message passing system

- **Reliability**
  - Lost and duplicate message handling
- **Correctness**
  - Atomicity
  - Ordered delivery
  - Survivability
- **Flexibility**
  - Can drop one or more correctness properties

Desirable features of a good message passing system

- **Security**
  - Authentication of sender and receiver
  - Encryption of messages

- **Portability**
  - Message passing system should itself be portable
  - The application written by using primitives of the IPC protocol should be portable.

Issues in IPC by message passing

- **A typical message structure**
  - Header
    - Addresses
      - ✓ Sender address
      - ✓ Receiver address
    - Sequence number
    - Structural information
      - ✓ Type
      - ✓ Number of bytes
  - Message

In the Design an IPC protocol

- **Some of the main issues will be:**
- **Identity related**
  - Who is the sender?
  - Who is the receiver?
- **Network Topology related**
  - 1 receiver or many?
- **Flow control related**
  - Guaranteed by the receiver?
  - Sender should wait for reply?
- **Error control and channel management**
  - Node crash……what to do?
  - Receiver not ready….what to do?

Synchronization in IPC

IPC Synchronization Semantics

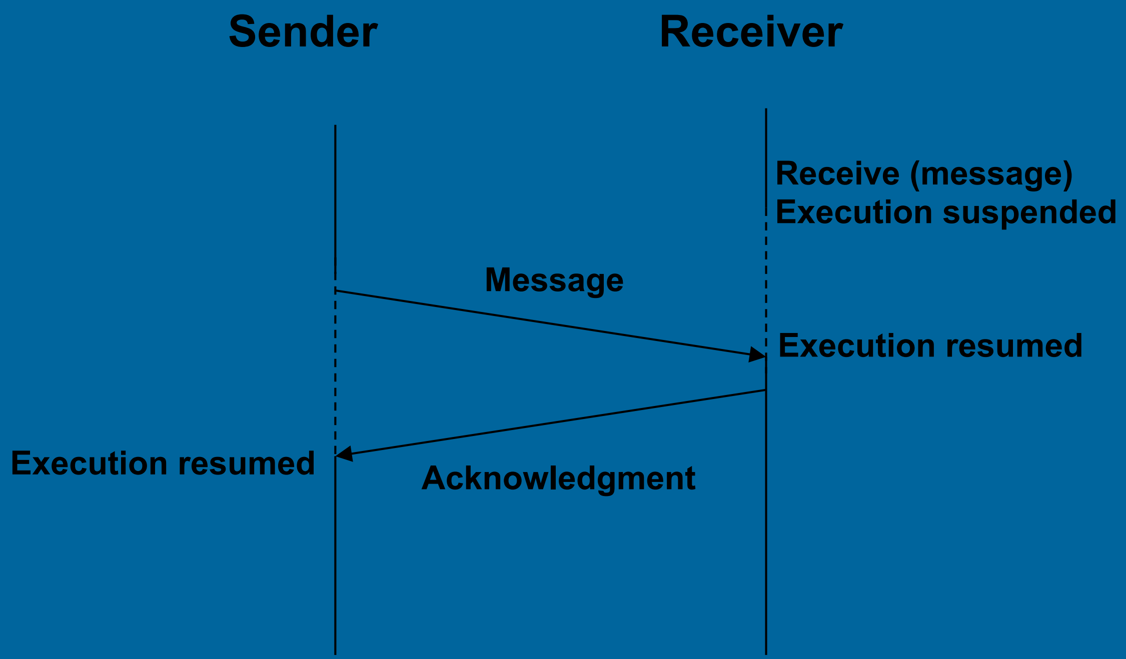
- Blocking
- Non Blocking

- **Send primitive**
  - Blocking
  - Non blocking

- **Receive primitive**
  - Blocking
  - Non Blocking
    - ✓ **Polling**
    - ✓ **interrupt**

Synchronous & Asynchronous Communication

- **When both the send and receive primitives of a communication between two processes use blocking semantics, the communication is said to be Synchronous; otherwise it is asynchronous.**



Synchronous mode with blocking send and receive primitives

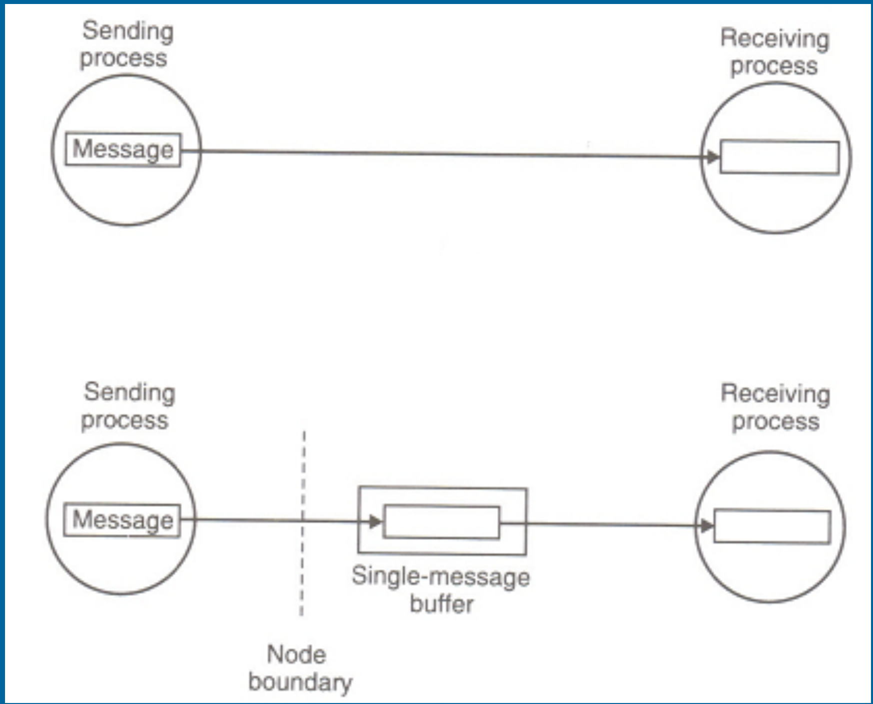
Synchronous VS Asynchronous Communication

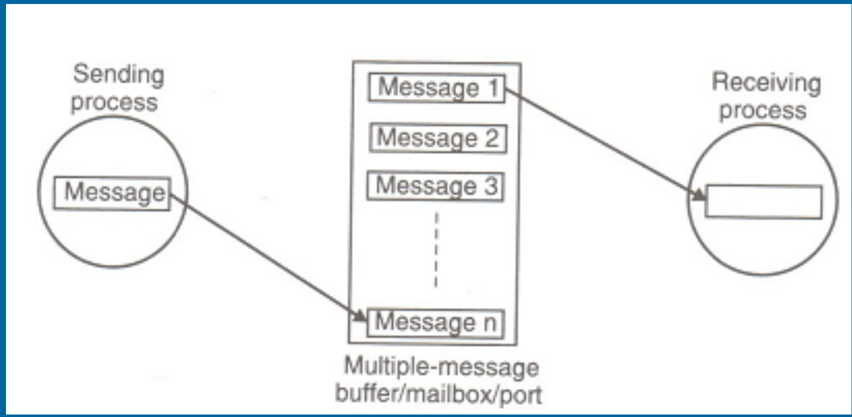
- **Synchronous**
  - Simple and easy to implement
  - Contributes to reliability
  - No backward error recovery needed
- **Asynchronous**
  - High concurrency
  - More flexible than synchronous
  - Lower deadlock risk than in synchronous communication (but beware)

Buffering

- **Synchronous systems**
  - Null buffer
  - Single message buffer
- **Asynchronous systems**
  - Unbounded capacity buffer
  - Finite message (multiple message buffer)

Buffering





Synchronous System

Asynchronous System

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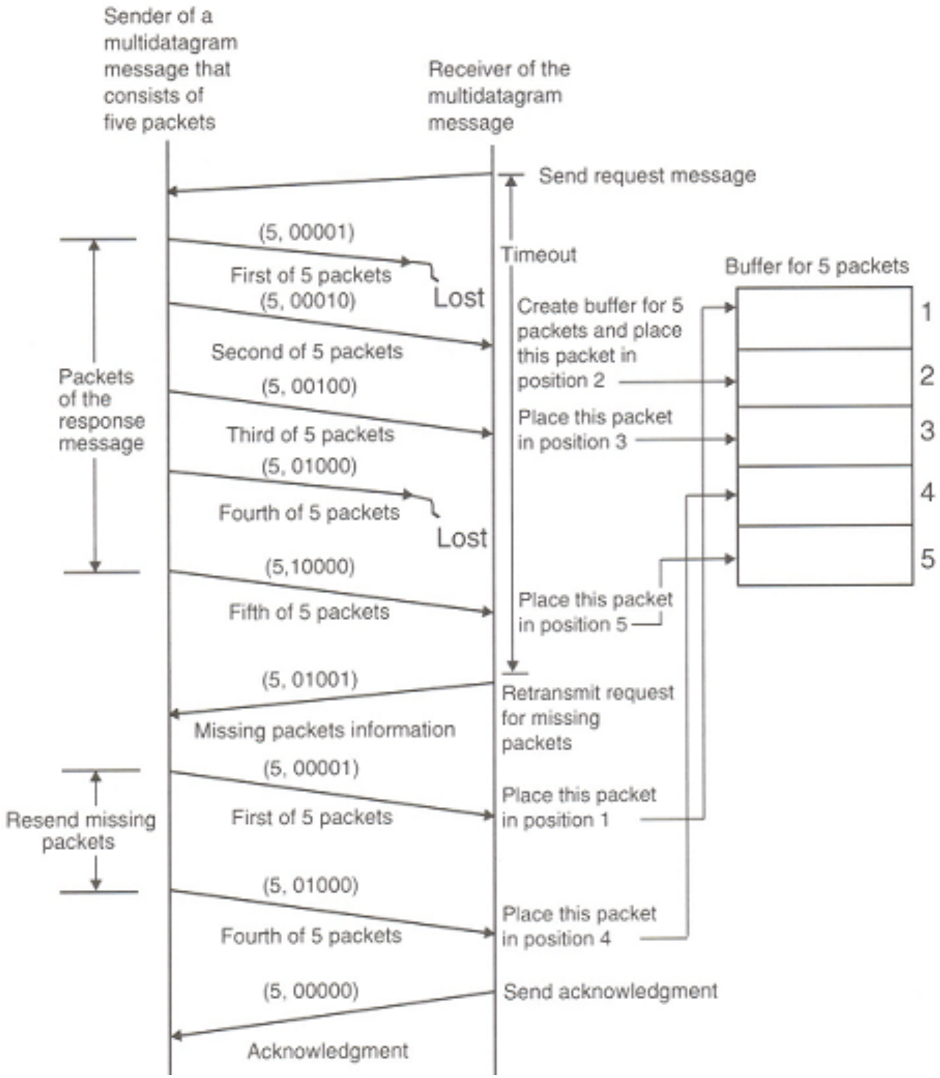
Multi-datagram Messages

- Almost all networks have an upper bound on the size of data that can be transmitted at a time. This is known as MTU (maximum transfer unit).
- Thus a message whose size is greater than MTU has to be fragmented - each fragment is sent in a packet. These packets are known as datagram.
- Thus messages may be single-datagram messages or multi-datagram messages
- Assembling and dissembling is the responsibility of message passing system.

Using Bitmap for Multidatagrams



Encoding Decoding

Encoding/Decoding is needed if

- **Sender and receiver have different architecture**

Even for Homogeneous Encoding/Decoding is needed for

✓ **Using an absolute pointer**

✓ **To know which object is stored in where and how much storage it requires**

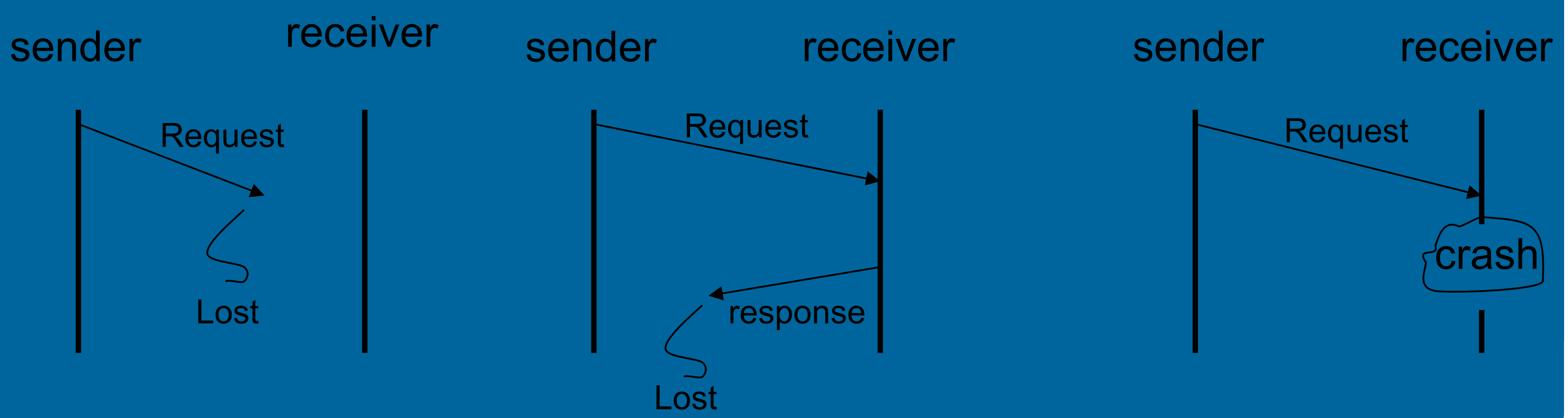
Process Addressing

- **Explicit Addressing**
  - Send(process_ID, message)
  - Receive(process_ID, message)

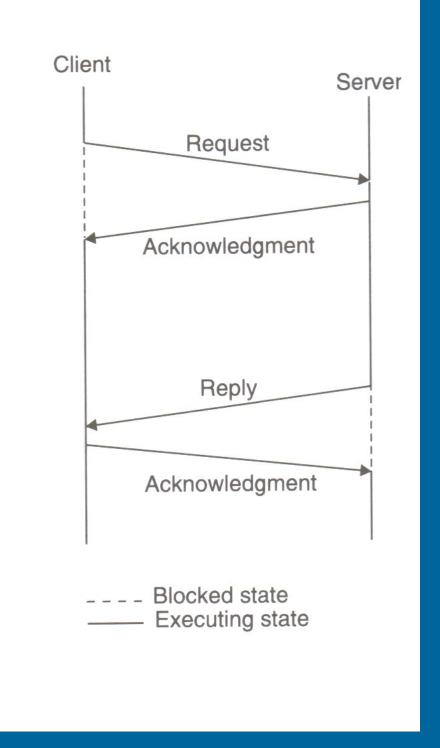
- **Implicit Addressing**
  - Send_any(service_ID, message)
  - Receive_any(process_ID, message)

Failure Handling

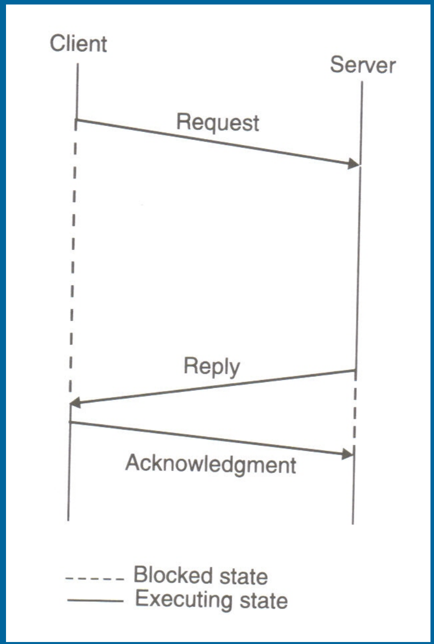
- **Failure classification**
  1. Loss of request message
  2. Loss of response message
  3. Unsuccessful execution of the request



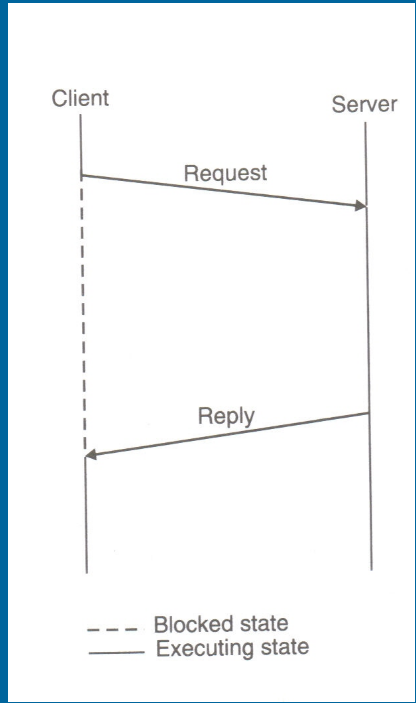
4-message reliable IPC protocol



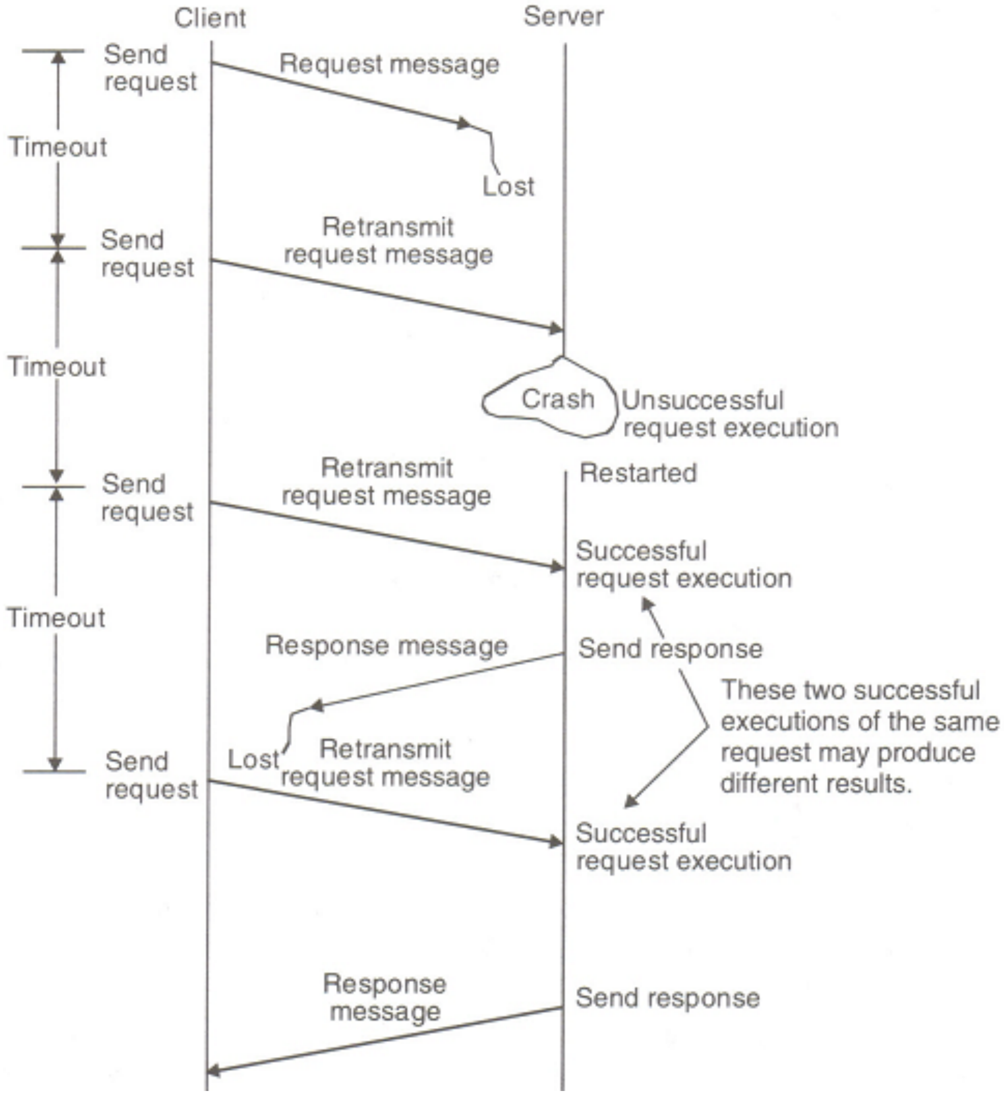
3-message Reliable IPC protocol



2-message Reliable IPC protocol



An Example of Fault Tolerant System



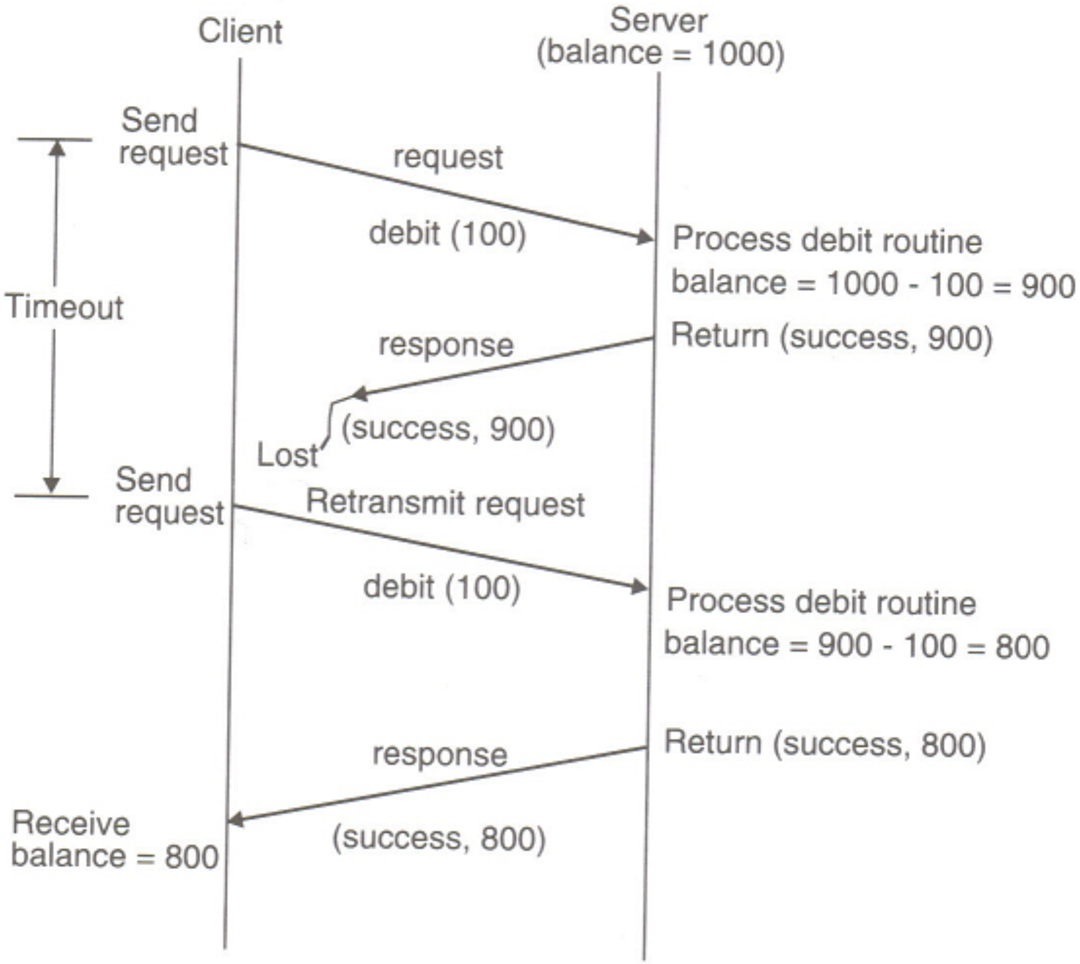
Idempotency

What is the difference between the following two functions?

- **getSqrt(n)**
  { return sqrt(n)
  }

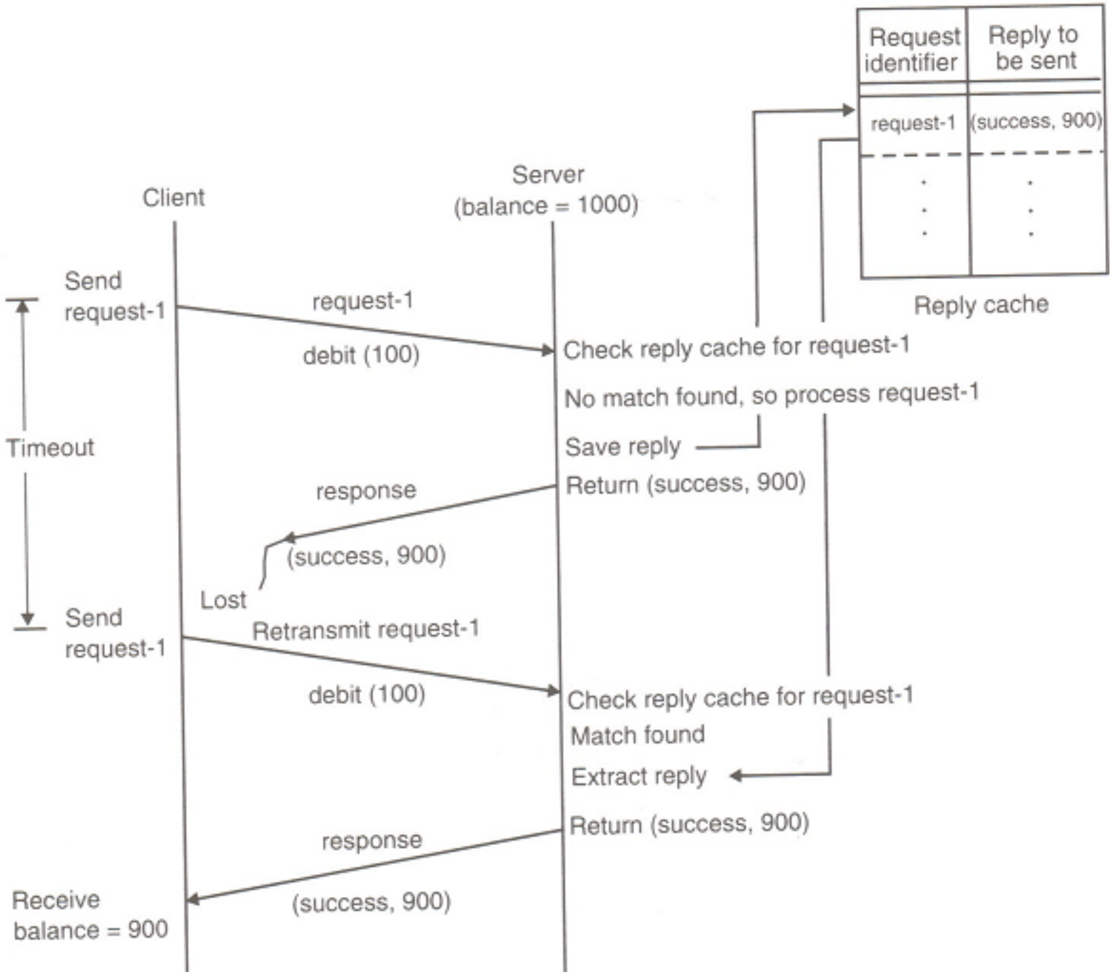
- **Debit (amount)**

A Non-Idempotent Routine



Implementation of Idempotency

- **How to implement Idempotency?**
  - Adding sequence number with the request message
  - Introduction of ‘Reply cache’


Request identifier
Reply to be sent
request-1
(success, 900)
Reply cache
Client
Server
(balance = 1000)
Send
request-1
request-1
debit (100)
Check reply cache for request-1
No match found, so process request-1
Save reply
Timeout
response
Return (success, 900)
(success, 900)
Lost
Send
request-1
Retransmit request-1
debit (100)
Check reply cache for request-1
Match found
Extract reply
response
Return (success, 900)
Receive
balance = 900
(success, 900)

Group Communication

- **Group communication may be**
  - One to many
  - Many to one
  - Many to many

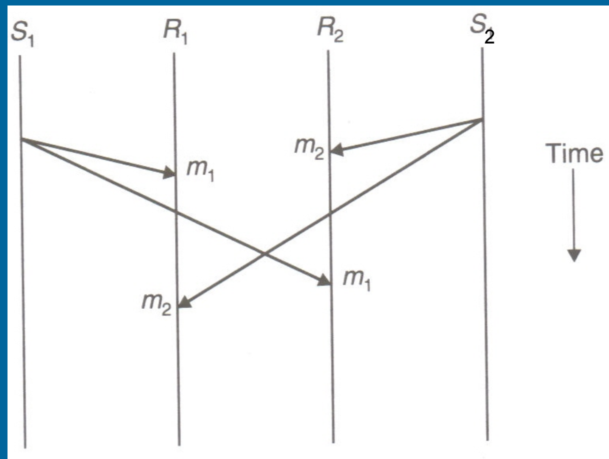
- **One to many**
  - Group management
  - Group addressing
  - Buffered and unbuffered multicast
  - Send-to-all and Bulletin-Board semantics
  - Flexible reliability in multicast communication
  - Atomic multicast

Many to Many communication

- **The issues related to one-to-many and many-to-one communications also applies here**
- **In addition, *ordered message delivery* is an important issue. This is trivial in one-to-many or many-to-one communications.**
- **For example, two server processes are maintaining a single salary database. Two client processes send updates for a salary record. What happen if they reach in different order? (will sequencing of messages help in this case?)**

Semantics for ordered delivery in many-to-many communications

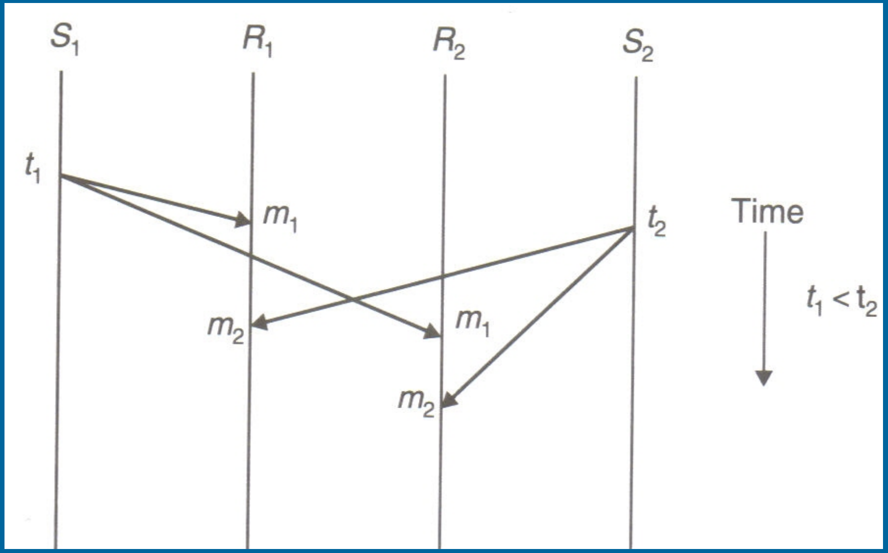
- **No-ordering**



No ordering constraint

Semantics for ordered delivery in many-to-many communications

- **Absolute ordering**
  - All messages are delivered to all receiver processes in the exact order in which they were sent.
  - Using global timestamp as message identifiers with sliding window protocol



Absolute ordering semantic

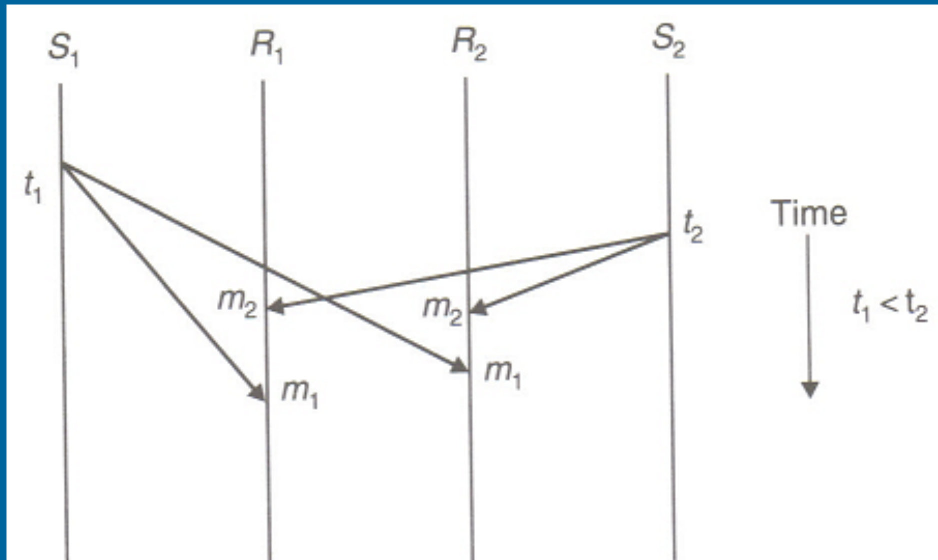
Semantics for ordered delivery in many-to-many communications

- **Consistent ordering**
  - All messages are delivered to all receivers in the same order. However, this order may be different from the order in which messages were sent.

  Implementation
  - Make the communication appear as a combination of many-to-one and one-to-many communication [Chang and Maxemchuk]
  - Kernels of sending machines send messages to a single receiver (known as *sequencer*) that assigns a sequence number to each message and then multicast it.
  - Subject to single point of failure and hence has poor reliability.

  - A distributed algorithm - *ABCAST* in *ISIS* system [Birman and Renesse] (self study)

Semantics for ordered delivery in many-to-many comm.



Consistent ordering semantic

Semantics for ordered delivery in many-to-many comm.

- **Causal ordering**
  - **If the event of sending one message is causally related to the event of sending another message, the two messages are delivered to all receivers in correct order.**
  - **Two message sending events are said to be causally related if they are corelated by the *happened-before* relation.**

[The expression $a \rightarrow b$ is read "*a* happens before *b*" and means that all processes agree that first event *a* occurs, then afterward, event *b* occurs. The happens-before relation can be observed directly in two situations:

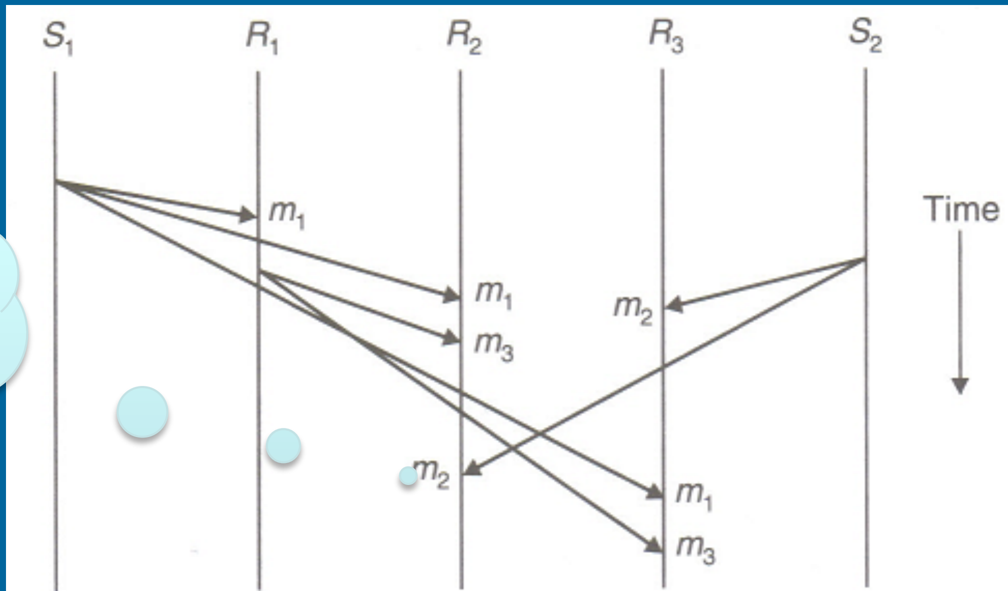
1. If *a* and *b* are events in the same process, and *a* occurs before *b*, then $a \rightarrow b$ is true.
2. If *a* is the event of a message being sent by one process, and *b* is the event of the message being received by another process, then $a \rightarrow b$ is also true.

Happens-before is a transitive relation, so if $a \rightarrow b$ and $b \rightarrow c$, then $a \rightarrow c$.]

Semantics for ordered delivery in many-to-many comm.

- **One example of implementing Causal consistency is *CBCAST* in *ISIS* system [Birman et al].**

2nd round
m2 is
held back



Causal ordering semantic

Remote Procedure Call (RPC)

- The IPC part of a distributed application can be adequately and efficiently handled by using an IPC protocol based on message passing system.
- However, an independently developed IPC protocol is tailored specifically to one application and does not provide a foundation on which to build a variety of distributed applications.
- Therefore, a need was felt for a general IPC protocol that can be used for designing several distributed applications.
- The RPC facility emerged out of this need.

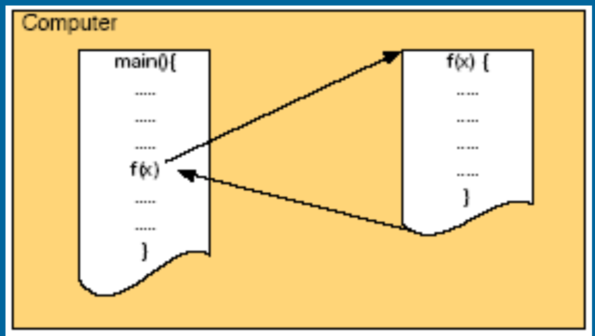
Remote Procedure Call

- **While the RPC is not the universal panacea for all types of distributed applications but for a fairly large number of distributed applications.**
- **The RPC has become a widely accepted IPC mechanism in DS. Its features –**
  - Simple call syntax.
  - Familiar semantics.
  - Specification of a well defined interface.
  - Ease of use.
  - Generality. “In single-machine computations procedure calls are often the most important mechanism for communication between the parts of the algorithm” [Birrell and Nelson].
  - Its efficiency

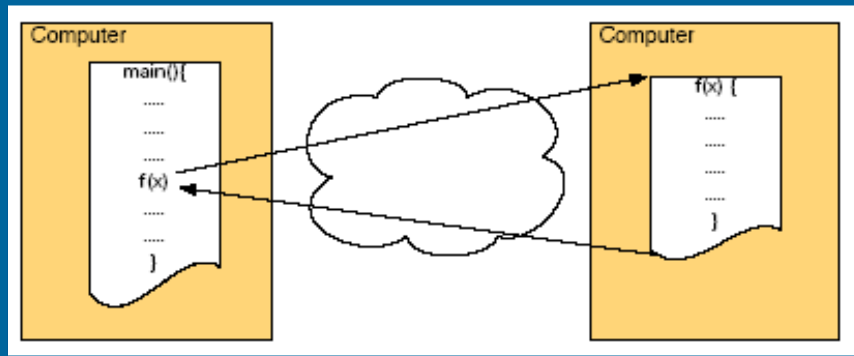
RPC model

- RPC model is similar to “Procedure call” model.
- Procedure call is same as function call or subroutine call
- Local Procedure Call - The caller and the callee are within a single process on a given host.
- Remote Procedure Call (RPC) - A process on the local system invokes a procedure on a remote system. The reason we call this a “procedure call” is because the intent is to make it appear to the programmer that a local procedure call is taking place.

Local and Remote Procedure Call

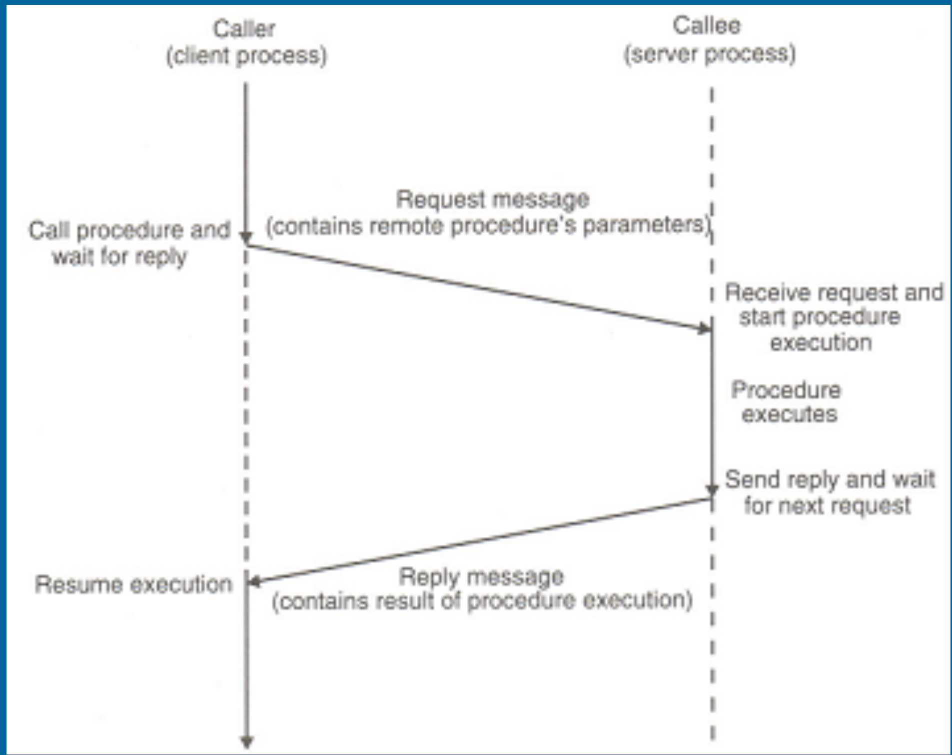


Local Procedure Call



Remote Procedure Call

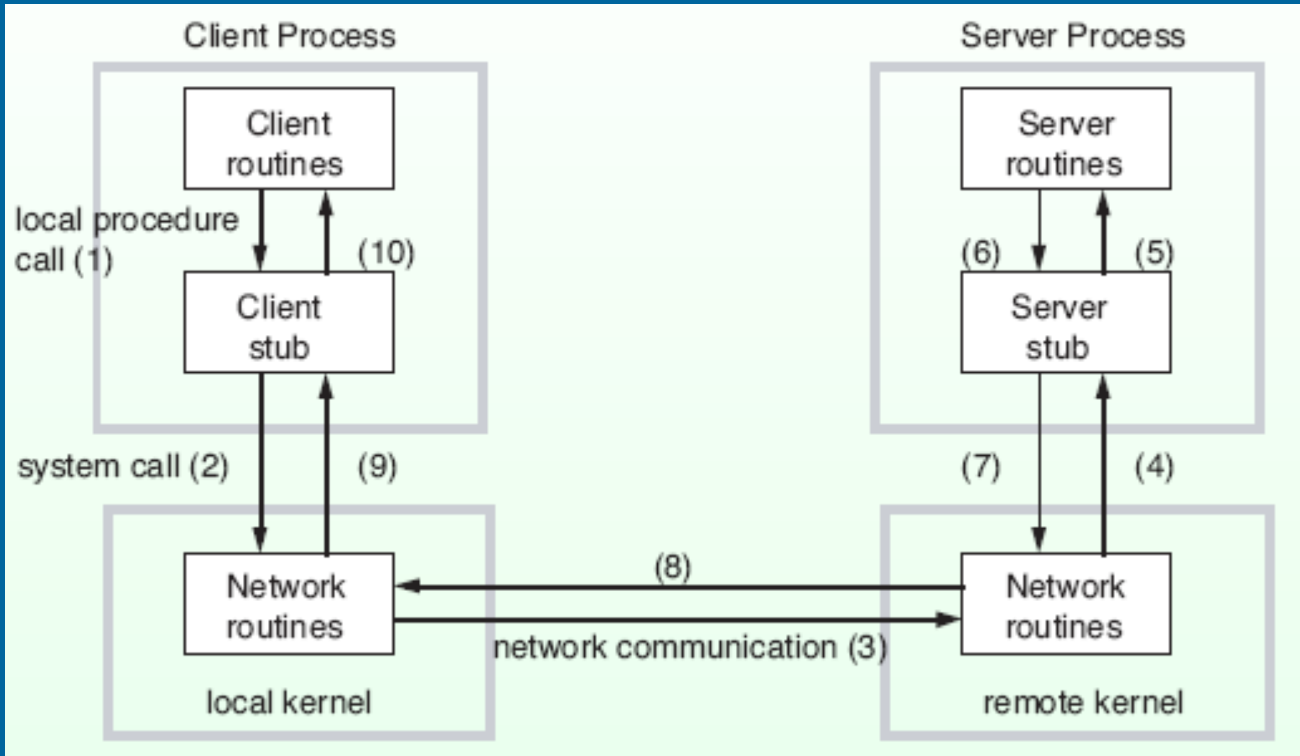
A Typical Model of RPC



Implementing RPC mechanism

- **To achieve the goal of *semantic transparency*, the implementation of an RPC mechanism is based on the concept of *stubs***
- ***Stubs* provide a perfectly normal (local) procedure call abstraction**
- **To hide the distance and functional details of underlying network, an RPC communication package (known as *RPCRuntime)* is used.**
- **Thus RPC implementation involves five elements-**
  - The client
  - The client stub
  - The RPCRuntime
  - The server stub
  - The server

RPC in Detail



Stubs

- Client and server stubs are generated from interface definition of server routines by development tools.

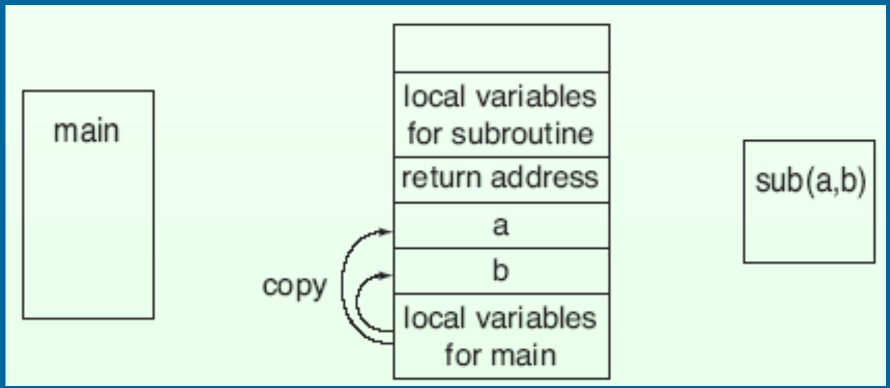
- Interface definition is similar to class definition in C++ and Java.

Parameter Passing Mechanisms

- When a procedure is called, parameters are passed to the procedure as the arguments. There are three methods to pass the parameters.
  - call-by-value
  - call-by-reference
  - call-by-copy/restore

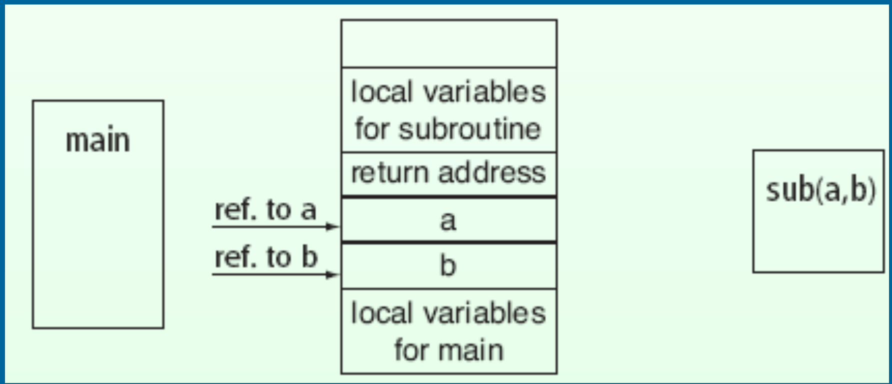
Call by value

- The values of the arguments are copied to the stack and passed to the procedure.
- The called procedure may modify these, but the modifications do not affect the original value at the calling side.



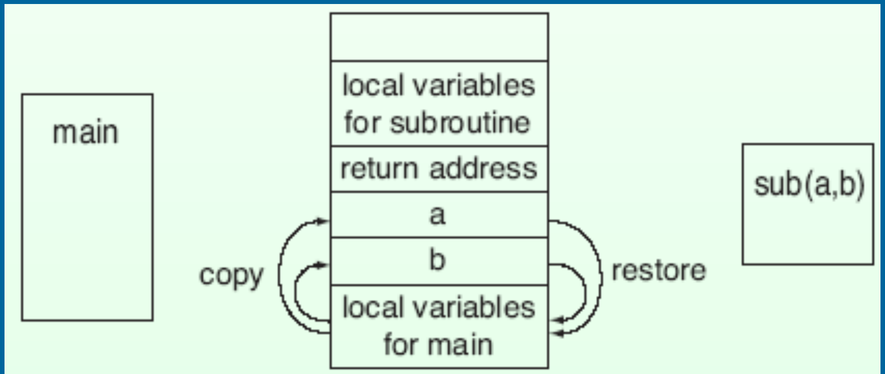
Call-by-Reference

- The memory addresses of the variables corresponding to the arguments are put into the stack and passed to the procedure.
- Since these are memory addresses, the original values at the calling side are changed if modified by the called procedure.



Call-by-Copy/Restore

- **The values of the arguments are copied to the stack and passed to the procedure.**
- **When the processing of the procedure completes, the values are copied back to the original values at the calling side.**
- **If parameter values are changed in the subprogram, the values in the calling program are also affected.**

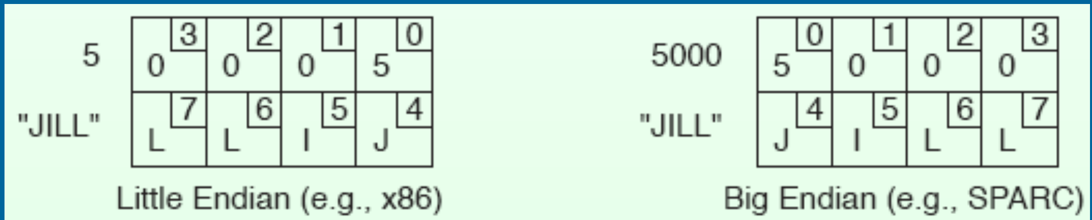


Parameter Passing in RPC

- **Which parameter passing mechanisms are possible?**
  - It is possible to implement all of the three mechanisms if you wish. Usually call-by-value and call-by-copy/restore are used.
  - Call-by-reference is difficult to implement. All data which may be referenced must be copied to the remote host and the reference to the copied data is used.
- **Do we need to convert the values of the arguments into a standard format to transmit over the network?**

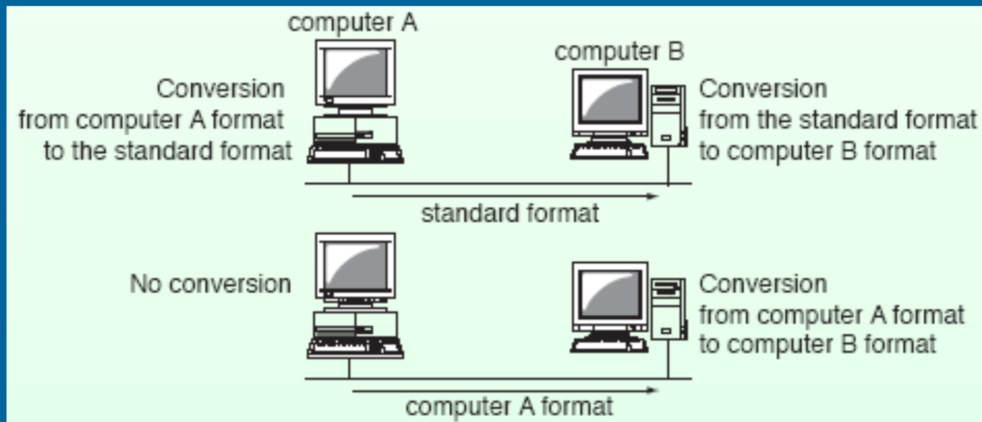
Parameter Passing in RPC

- **Reasons to convert the values of the arguments into a standard format to transmit over the network**
  - Different machines use different character codes. E.g., IBM main frames use EBCDIC, while PCs use ASCII.
  - Representation of numbers may differ from machine to machine.
  - Big endian and little endian



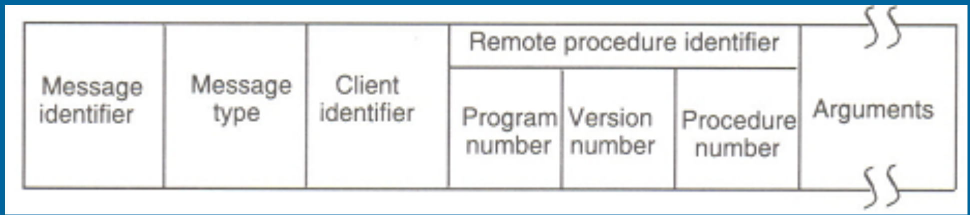
Parameter Passing in RPC

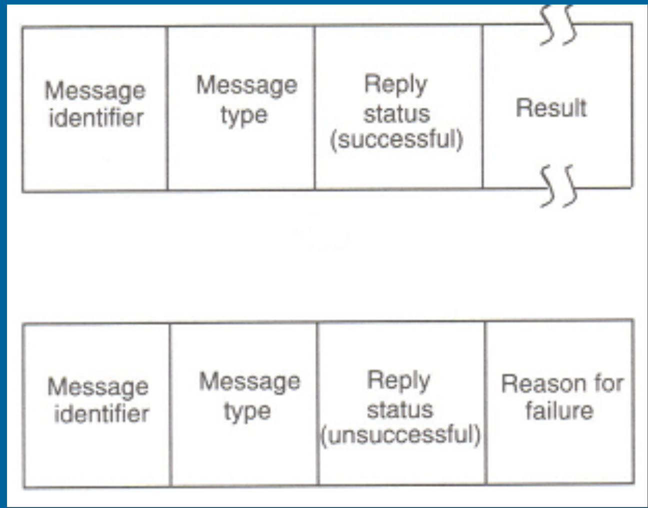
- **If a standard format is not used, two message conversions are necessary.**
  - If format information is attached to the message, only one conversion at the receiver will suffice.
  - However, the receiver must be able to handle many different formats.



RPC Messages

- **Generally two types of messages**
  - Call messages
  - Reply messages





A typical RPC Call message format

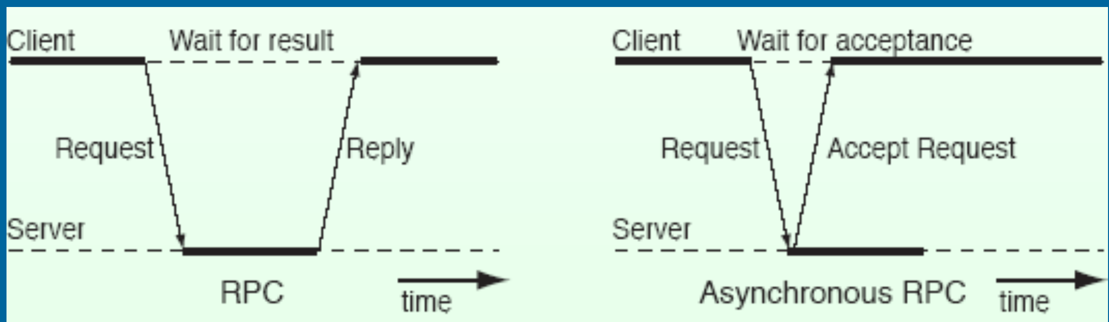
A typical RPC Reply message format

(successful and unsuccessful)

Variations of RPC

Asynchronous RPC

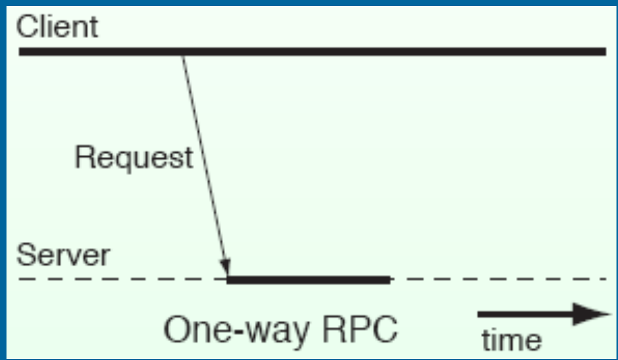
- RPC (When a client requests a remote procedure, the client wait until a reply comes back in RPC.
- If no result is to be returned, unnecessary wait time overhead.
- In asynchronous RPC, the server immediately sends accept message when it receives a request.



Call-Back RPC

One-way RPC

- In one-way RPC, the client immediately continues after sending the request to the server.



Some special types of RPC

- **Callback RPC**
- **Broadcast RPC**
- **Batch-mode RPC**
- **Lightweight RPC**

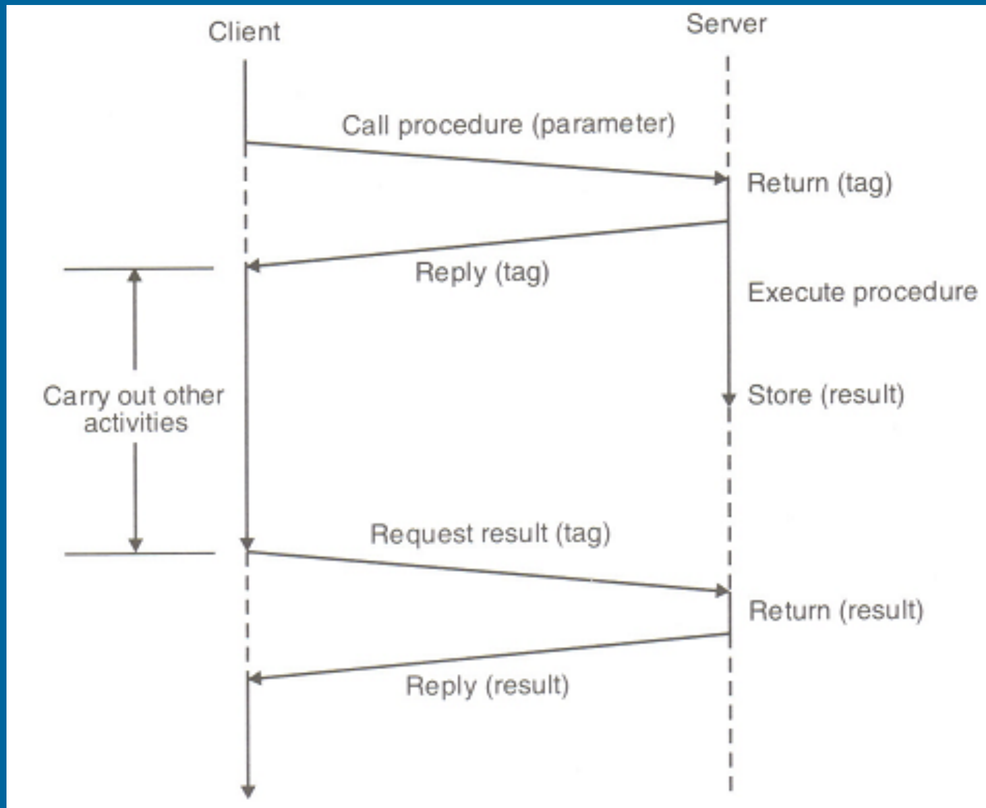
Optimizations for better Performance

- **In Six Different Ways**
  - Concurrent access to multiple servers
  - Serving multiple requests simultaneously
  - Reducing per-call workload of servers
  - Reply caching of idempotent remote procedures
  - Proper selection of timeout values
  - Proper design of RPC protocol specification

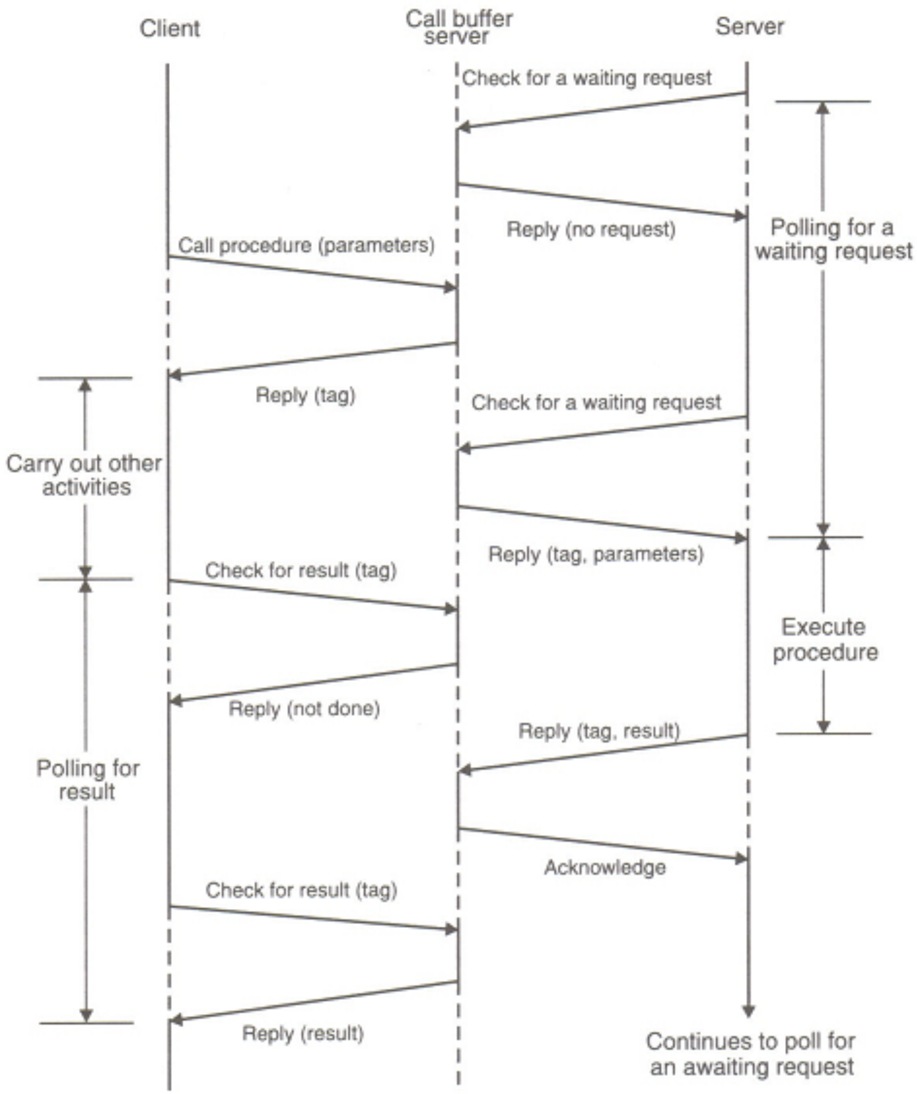
Concurrent Access to Multiple Server

- **One of the following three may be adopted:**
  - Threads
    - > Use of Threads in the implementation of a client process where each thread can independently make remote procedure calls to different servers.
    - > Addressing in underlying protocol should be rich enough to provide correct routing of responses.
  - Early reply approach [Wilbur and Bacarisse]
    - > A call is split into two separate RPC calls- one passing parameters and other requesting the result
    - > Server must hold the result causing congestion or unnecessary overhead.
  - Call buffering approach [Gimson]
    - > Clients and servers do not interact directly but via a call buffer server
    - > A variant of this approach was implemented in MIT (Mercury Communication System)

Early Reply Approach



Call Buffering Approach



Serving Multiple Requests Simultaneously

- **Following types of delays are common-**
  - A server, during the course of a call execution, may wait for a shared resource
  - A server calls a remote function that involves computation or transmission delays

- **So the server may accept and process other requests while waiting to complete a request.**

- **Multiple-threaded server may be a solution.**

Summation (1)

- **What is the purpose of IPC?**
  - information sharing among two or more processes
- **Differences between Synchronous and Asynchronous Communications?**
  - When both the send and receive primitives of a communication between two processes use blocking semantics, the communication is said to be Synchronous; otherwise it is asynchronous
- **List the Types of Failure in IPC**

  Loss of request message, Loss of response message, Unsuccessful execution of the request

Summation (2)

- **How to implement Idempotency?**
  – Adding sequence number with the request message and Introduction of ‘Reply cache’
- **Three main types of Group Communications?**
  – One to many, Many to one, Many to many
- **One of the greatest challenges in Many to Many?**
  > Ordered Delivery
- **Name an all propose IPC protocol?**
  – Remote Procedure Call (RPC)

Summation (3)

- **Name a few ways to optimise RPC?**
  - Concurrent Access to Multiple Servers, Serving Muliple Requests Concurrently, Reducing Call Workload per Server
- **Three different techniques for implementing Concurrent Access to Multiple Servers?**
  - Threads, Early Reply, Call Buffering

References

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