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Training

ANSAwise - Remote Procedure Call in Distributed Systems

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Abstract

Distributed systems usually use remote procedure call (RPC) as a fundamental building block for implementing remote operations.

However, these systems have detailed but important differences in the way RPC operates, and applications programmers need to be aware of these differences.

This module of the ANSAwise training programme discusses simple and advanced use of RPC. It covers RPC semantics, idempotence, failure handling policies, and asynchronous RPC. It discusses the differences between RPC operation in CORBA and DCE.

[This variant of APM.1344 places more stress on CORBA and DCE RPC, and removes discussion of ANSAware RPC. Adding a discussion of Sun's ONC RPC might also be worthwhile, as this is still in moderate use. This variant also describes RPC from its fundamentals, and is intended to replace APM.1344]

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Briefing Note

Distribution:
Supersedes:
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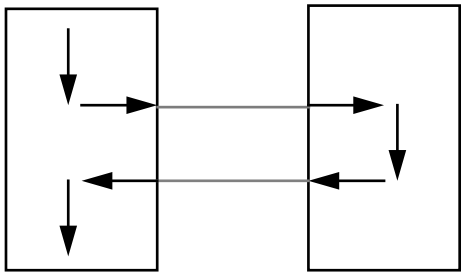
Remote Procedure Call in Distributed Systems

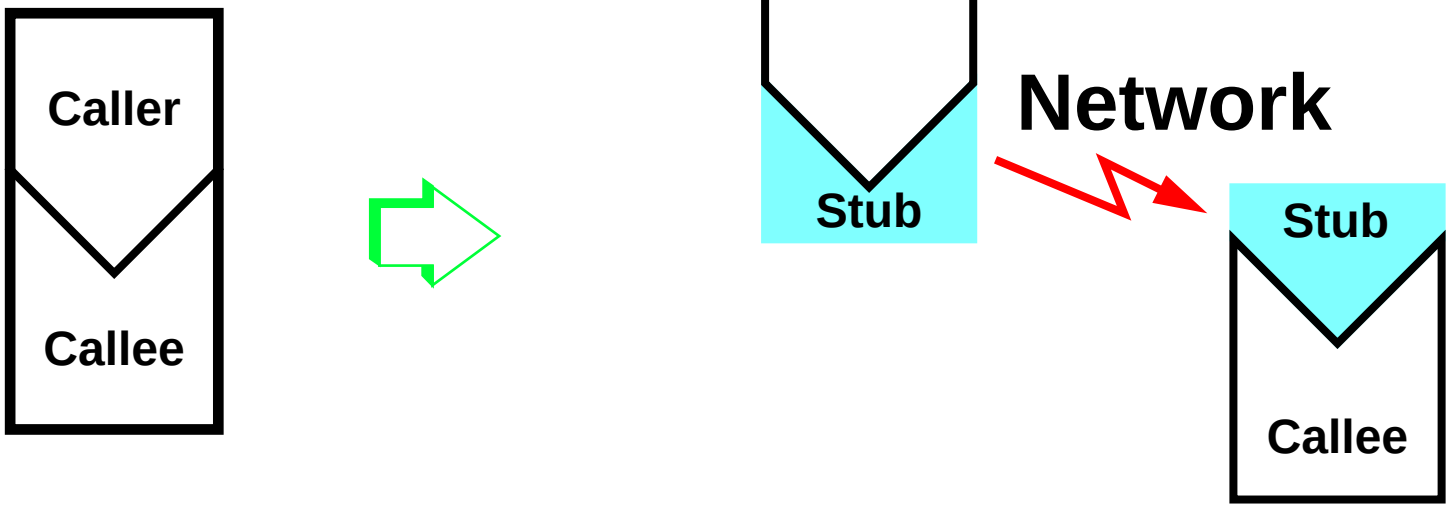


In this session

- **Explain the function of remote procedure call (RPC) in distributed systems**
- **Explain the importance of understanding RPC execution semantics**
- **Examine more sophisticated uses of RPC**
- **Explore the differences between RPC in various distributed environments**

Remote Procedure Call (RPC)

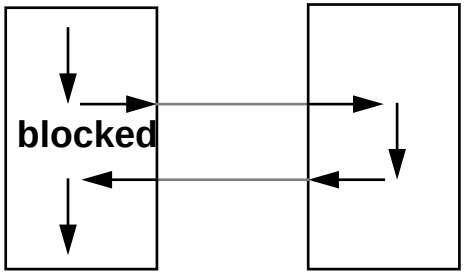
- Local procedure call can be transformed into a remote procedure call



- The caller is the client, the callee is the server

Caller Waits for Callee

- **Remote procedure calls are normally synchronous...**

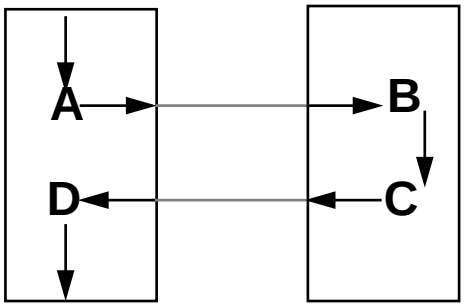


- **... just as in a local procedure call**

- **The difference is how long you may have to wait**

Stubs in RPC

- **The stubs in RPC are responsible for packing and unpacking the call parameters, and the call results**
  - **this is called marshalling (A,C) / unmarshalling (B,D):**



- **Stubs must allow for the fact that client and server may be machines of different types**

Differing data representations

- For example, integers may be represented differently (byte-ordering)

CPU	Ordering
Intel 80x86	b0 b1 b2 b3
Digital PDP-11	b2 b3 b0 b1
Digital VAX-11	b3 b2 b1 b0
Motorola M68K	b3 b2 b1 b0

- ... and there are also different representations for floating-point and other types

RPC and transparency

- Different data representations must be allowed for
- There are two basic possibilities
  - ...a single canonical ‘on-the-wire’ representation
  - ...‘receiver-makes-right’
- Stubs can handle the different data representations transparently
- It is worth considering whether RPC could be transparent...
  - ...so that all remote procedure calls looked like local procedure calls

Remote Procedure Call Isn't Local Procedure Call

- In an ordinary local procedure call you need not be concerned about independent failure of client and server
  - ... in a remote procedure call you must be able to handle this
- Ultimately, it is impossible to hide failures
  - ... therefore, remote procedure call *cannot* be made transparent
- There is no way of avoiding this issue. The conclusion is;

Make local procedure call look like remote procedure call - not the other way round

RPC execution semantics

- This is reflected in the RPC semantics, which may be
  - at-least-once
  - at-most-once: the realistic case
  - exactly-once: the ideal case
- An RPC product may offer a choice of the above
  - different RPC products offer different choices with different defaults
  - .... this affects portability between RPC products

At-least-once RPC semantics

- At-least-once semantics are appropriate for operations that have the same effect when invoked more than once
  - these are called *idempotent*
- For example
  - “add 50 units to stock level” is not idempotent...
  - ... “set stock level to 100 units” is idempotent
- DCE allows you to specify an operation as idempotent
  - it will be executed more efficiently
  - ... but DCE does *not* support at-least-once semantics at all!
- At-least-once has a straightforward implementation
  - ‘retransmit until acknowledged’

At-most-once RPC semantics

- At-most-once RPC semantics are appropriate for non-idempotent operations
- Clients must allow for operation not having occurred
- Sometimes described as best-effort
- Trivial implementation (‘fire and forget’)
  - in practice, retransmit until acknowledged, with duplicate suppression

Exactly-once RPC semantics

- At-least-once + At-most-once = Exactly-once
- Straightforward implementation under normal conditions...
  - ‘wait for acknowledgment’
  - ... in practice, periodic retransmission and duplicate suppression
- ... much harder under failure conditions
  - requires server and message replication, and special group RPC execution and recovery protocols to reduce failure probability
  - still an active area of research; some commercial solutions are available

RPC semantics and failures

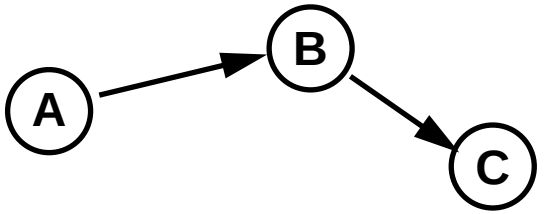
- There are two cases to consider
  - successful case
  - failure (exception) case
- In most systems the default is
  - if successful, exactly-once
  - if failure (exception), at-most-once

Handling RPC failures - policy and transparency

- This is the application's responsibility...
  - ... which it may choose to delegate to the infrastructure in the form of standard policies
  - ... for example, to retry a certain number of times for certain failures
- Failures can be made almost transparent to the application programmer
  - for example, when contacting a service, ANSAware will automatically invoke a relocator if the service cannot be found...
  - ... but this default behaviour can always be overridden
- Failures can never be eliminated

The nested timeout problem

- Suppose there is a chain of invocations...



- ... A client, B client and server, C server
- The A->B timeout must be no less than the B->C timeout
  - or A may incorrectly believe that B has failed
- B must also allow time to retry C, if that is its chosen policy
- This may force timeouts to be unduly large, so failure detection slow

Transforming a non-idempotent operation

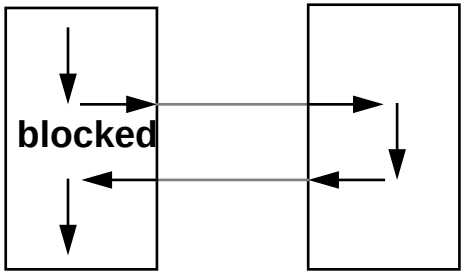
- Consider the non-idempotent operation...
  - “Add 50 units to stock level”
- ...transform this into the pair of idempotent operations
  - “Read old stock level”
  - “Set stock level to old stock level plus 50 units”
- Why is such a transformation almost never practical?
  -
  -
  -
  -

Invocation versus Initiate and Redeem

- There are two basic ways of using an operation
  - invocation (synchronous)
  - initiate and redeem (asynchronous)

Invoking an operation

- **Invoking an operation is synchronous...**

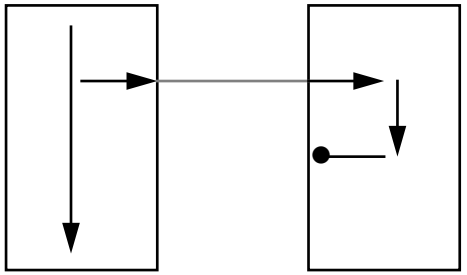


- **...the invoker blocks until the operation is complete, and the result is available**

- **This mimics the behaviour of an ordinary local procedure call**

Initiating an operation

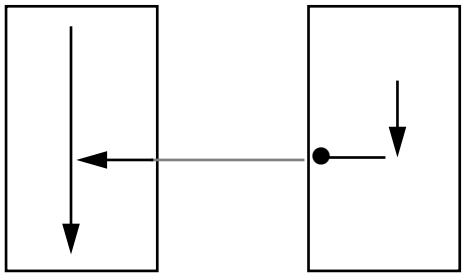
- **Initiating an operation is asynchronous...**



- **...the initiator continues concurrently**

Redeeming an initiate operation

- The initiator is given a voucher
- When the initiator is ready for the result of the operation, it redeems it



- If the operation is not yet complete, the redeem will block
  - just as for an invocation
- Initiate/Redeem is also known as follow-up RPC (FRPC) or deferred synchronous RPC

Using follow-up RPC

- **Use follow-up RPC only if the client can do useful work in the meanwhile**
  - **local I/O and computation**
  - **invoking other remote operations in parallel**
- **Treat follow-up RPC as an engineering optimization**

Simple use of follow-up RPC

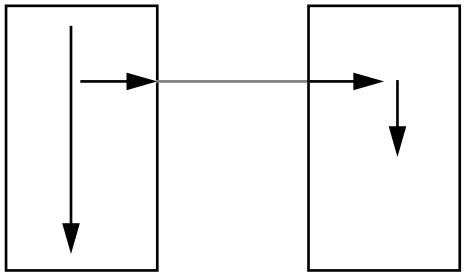
- Many operations are naturally implemented as a series of read operations followed by a series of write operations
  - sometimes, these write operations are independent of each other
- For example a customer change-of-address might involve updates to
  - customer details
  - account manager details
- These updates could be executed as separate follow-up RPCs
  - in parallel with each other

Difficulties with follow-up RPC

- **Error handling is bound to be more complex**
  - **suppose you have initiated 3 operations, and the first of them fails?**
  - **you also need to be careful about race conditions and timeouts**
- **Some implementations do not preserve the order of follow-up RPC correctly**

One-way operations

- One-way operations are like an initiate with no redeem...



- ...obviously, no results can be returned
- Semantics may be restricted
  - for example, at-most-once only
- Some infrastructure failures may still be detected on the client side
  - for example, a local transmission failure
  - the client application must still cope with these errors

Specifying one-way operations

- One-way operations are specified in the interface definition
- In CORBA this is specified using the *oneway* operation attribute
  - the semantics are at-most-once
- In DCE this is specified using the *maybe* IDL attribute
  - the operation is implicitly idempotent
  - the semantics are no-guarantee (0, 1 or more times)

One-way operations as building blocks

- One-way operations are best regarded as a communications mechanism for building application-specific interaction types
  - for example, a 3-phase data commit handshake, or bulk data transfer
- One-way operations give an application ‘raw’ one-way communications
  - ... with access and location transparency
  - ... without the handshake overhead required by stricter RPC semantics
- One-way operations are for the systems programmer
  - not the applications developer
- Streams fulfil the real need

Follow-up RPC versus one-way operations

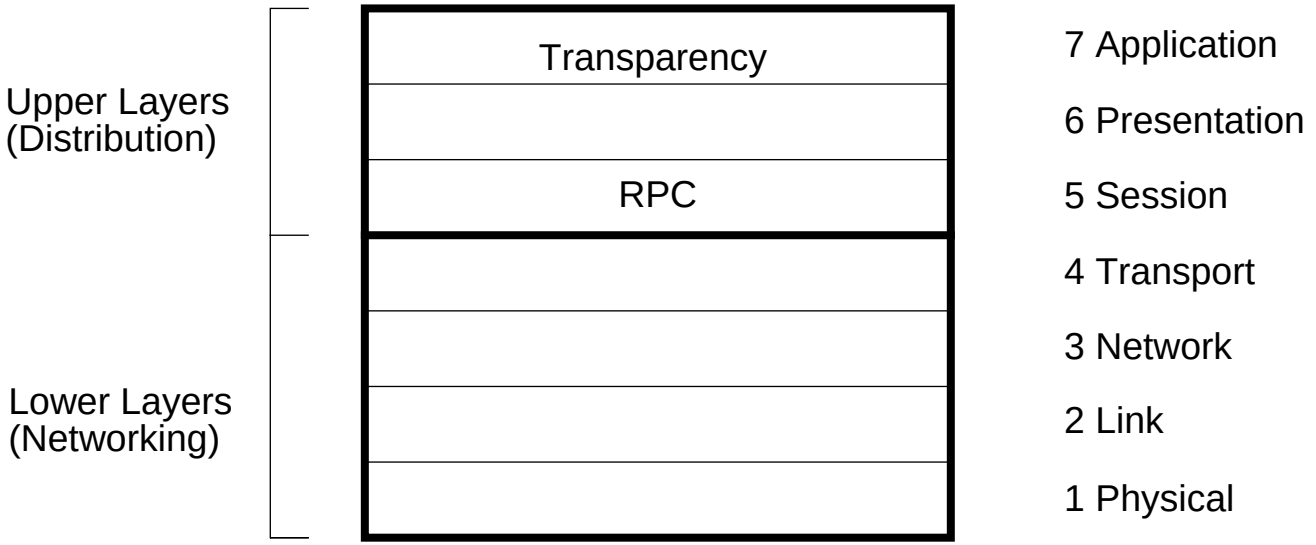
- **Both offer potentially faster performance**
- **Both can be described as ‘asynchronous’**
  - **but are quite different**

Follow-up RPC compared with one-way operations

- **Follow-up RPC**
  - always gets a response (when you redeem)
  - can have results
  - can be used on any operation; it is an implementation choice for the client
- **One-way operation**
  - never gets a response (although failure is still possible)
  - cannot have results
  - are specified for the operation; affects all clients

RPC in the communications protocol stack

- **RPC is the lowest level building block of a distributed system**

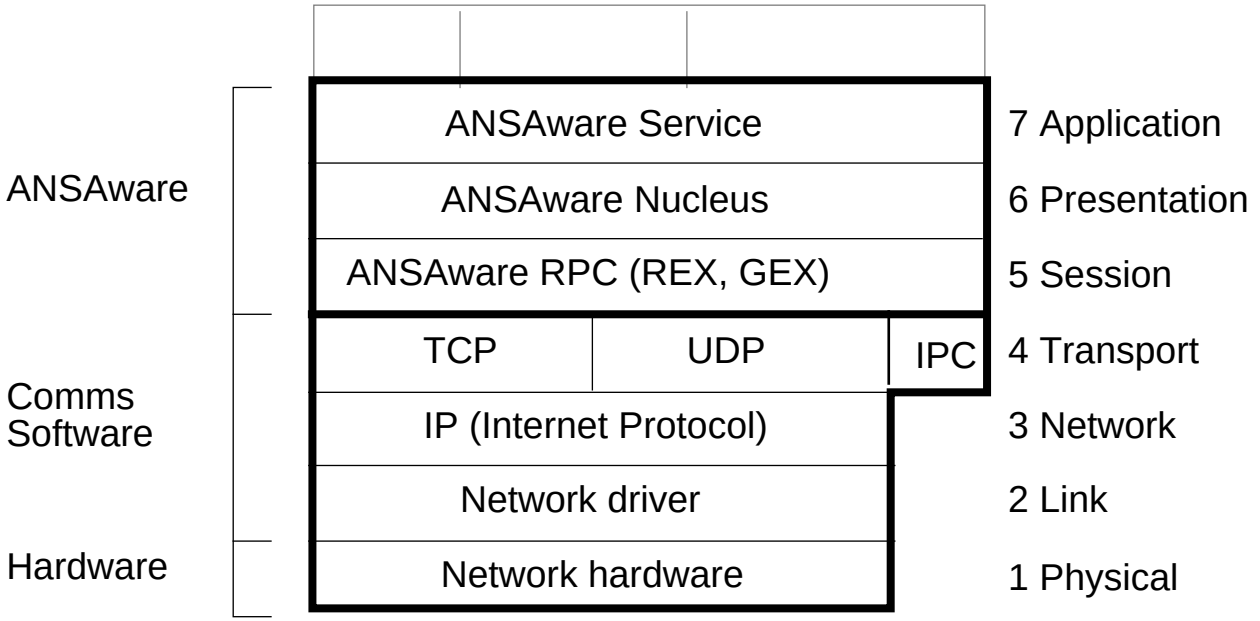


RPC and transport protocols

- RPC can be implemented over
  - connection-oriented transport protocols (e.g TCP)
  - connectionless transport protocols (e.g UDP)
- RPC is a more natural fit to connectionless protocols
  - request/response maps onto a pair of outgoing/incoming datagrams
- But connectionless protocols often
  - are “unreliable” (delivery not guaranteed)
  - have a maximum size (determined by the underlying network)
- The RPC layer must then provide its own delivery guarantees, and handle its own fragmentation
  - even so, performance may well be better over a connectionless protocol

Multiple transport protocols

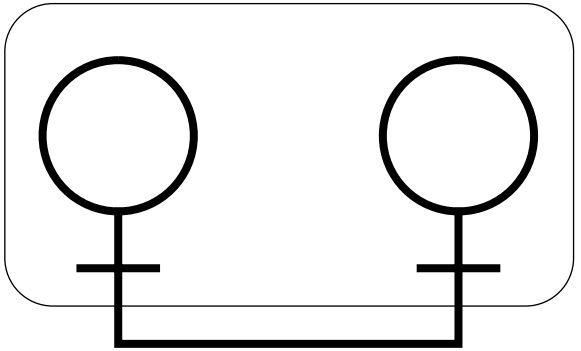
- **Systems can support multiple transport protocols simultaneously...**



- **... including a lightweight local RPC protocol (here, IPC)**

Lightweight local RPC

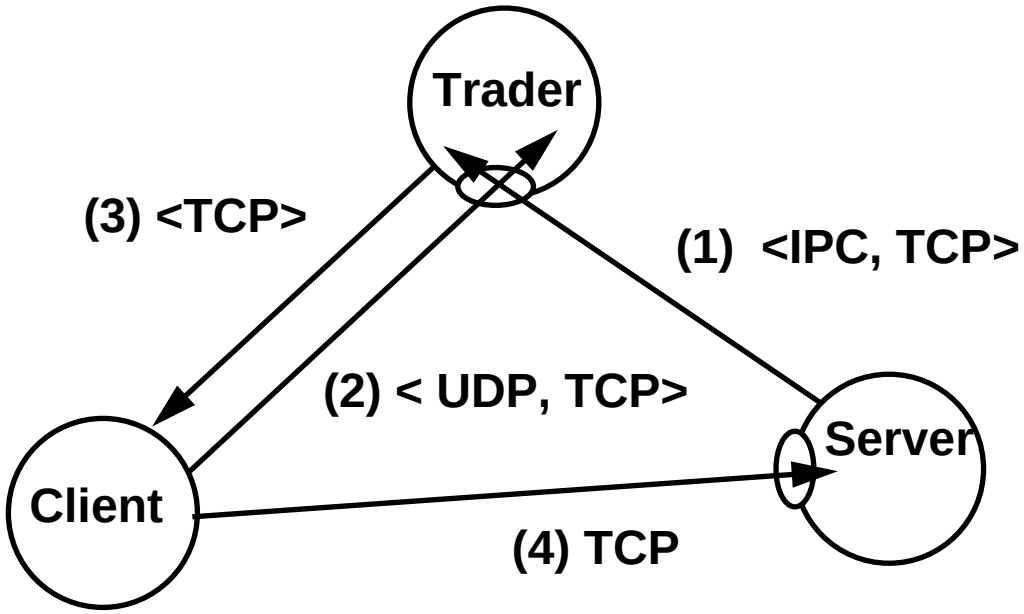
- Calls between co-located objects (on the same machine) can be optimized



- ... avoiding network traffic
  - ... avoiding data copying
  - ... avoiding marshalling overheads

Trading and multiple transport protocols

- A service can state which transport protocols apply to an offer...



- ... allowing a common protocol to be selected (here, TCP)

Multiple RPC protocols - interoperability

- Suppose you have both CORBA and DCE...
  - ...how can a CORBA client access a DCE server and vice-versa?
- It would be necessary to federate their RPC protocols
  - ... but RPC interoperability alone is not enough for service interoperability
  - ... many other issues have to be resolved

Performance of DCE RPC

- Roundtrip DCE RPC timings by University of Michigan group (Khandker, Honeyman, Teorey) using IBM RS/6000 and direct system calls:
  - 1392 bytes request packet size
  - NULL response
- ... this gives timings of
  - 8.351 milliseconds
- ... or, put another way
  - about 120 RPCs/second (single-threaded client and server)
  - 167 kbytes/second (11% of Ethernet capacity)

Performance of Orbix 1.3 RPC

- Request/response RPC with server on SparcClassic and client running under HP-UX 9.0:
  - 100 bytes request packet size
  - 2 milliseconds server computation
  - 100 bytes response packet size
- ... this gives timings of
  - 4.686 milliseconds (passing primitive types)
  - 4.658 milliseconds (passing a structure)
- ... or, put another way
  - about 215 RPCs/second (single-threaded client and server)
  - 43 kbytes/second (2.9% of Ethernet capacity)

Basic performance of RPC

- With the configuration...
  - Ethernet (10 Mbit/s)
  - 10 MIPS CPU
- ... 1992 measurements indicate for a Null RPC (no arguments, no results, no computation at server)
  - 2 to 4 milliseconds (typical implementation)
  - 0.3 milliseconds (best known implementation)
- ... this is how long it takes to ‘do nothing’!

Realistic performance of RPC

- Instead of a null RPC, assume a more realistic...
  - 100 bytes request packet size
  - 2 milliseconds server computation
  - 100 bytes response packet size
- ... this equates to
  - 6 milliseconds (typical implementation)
  - 2.5 milliseconds (best known implementation)
- ... or, put another way
  - 150 RPCs/second (typical implementation, single-threaded client)
  - 400 RPCs/second (best known implementation)
  - 30 kbytes/second (2% of Ethernet) (typical)
  - 80 kbytes/second (6% of Ethernet) (best)

Comparison with file transfer

- **The same machine on the same network performing file transfer of the same packet size...**
  - **using the standard Novell NetWare PERFORM3 benchmark program**
  - **200 kbytes/second (best)**
- **... with bigger packet size (2 kbytes)**
  - **500 kbytes/second (best)**
  - **two clients can *(and do)* saturate Ethernet (1000 kbytes/second)**

Why is RPC performance limited?

- File transfer is faster because it typically uses
  - specific file-transfer protocols
  - windowed network protocols
  - larger packet size matching network packet size
  - protocol stack optimized for LAN file transfer performance
  - hand-optimized Ethernet drivers
- RPC is slower because it uses
  - general-purpose RPC protocols
  - call/response interactions
  - packet sizes typically much smaller than optimal network packet sizes

How important is RPC performance?

- Look again at the figures for a typical implementation...
  - 6 milliseconds for a remote procedure call
  - 2 milliseconds for the equivalent local procedure call (pure computation)
- ... is a factor of 3 significant in your application?

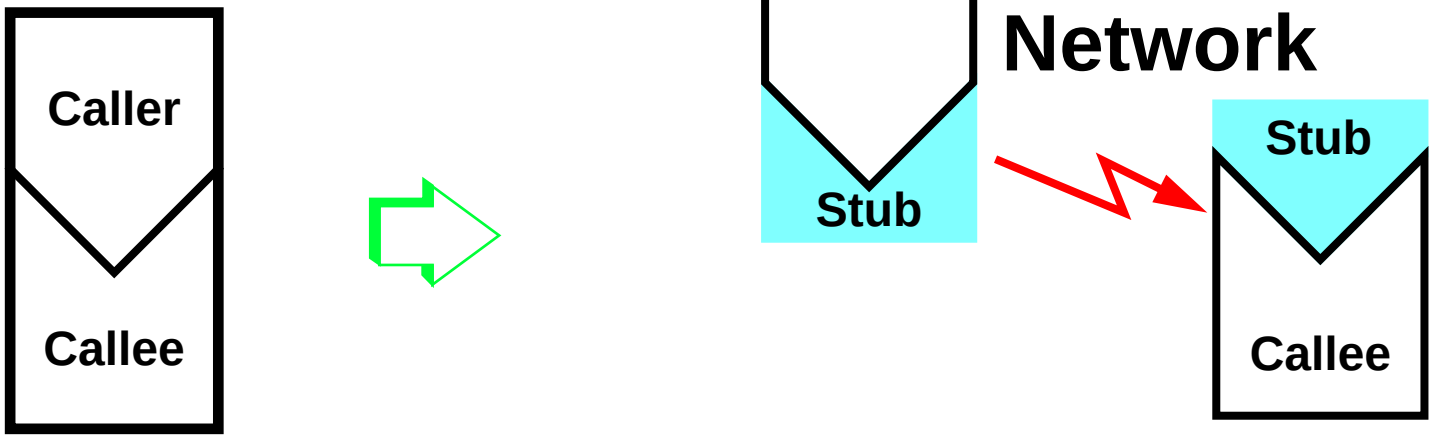
Real-life factors in RPC performance

- If you wish to make your own measurements, all these need to be considered
  - Size of request (marshalling and buffering overhead)
  - Network bandwidth (unlikely to be a limiting factor for LANs)
  - Network occupancy
  - Speed of local and remote machines
  - Concurrency and other load on remote machines
  - Transport protocol selected
  - Other overheads (e.g. authentication)
  - Actually servicing the request!

Engineering control for ordinary procedure calls

- Suppose you are writing an ordinary non-distributed program...
- ...for a conventional procedure call, your compiler may offer you
  - a choice of calling conventions, for compatibility with other programming languages
  - the option of generating inline code
- Carefully used, valuable techniques for performance engineering

Engineering control for remote procedure calls



- You may require engineering control over the stubs, for example
  - to control marshalling of parameters and results
  - to control implicit binding
  - to control error handling policy

Engineering control over stubs

- In DCE, this is done using the Attribute Configuration Language
  - for example, the *nocode* attribute eliminates client-side stub code for operations that the client does not use
- In CORBA, this is implementation-dependent

Other advanced RPC features

- Group RPC for replication
  - often using multicast protocols
- Secure RPC for integrity and confidentiality
  - supporting authentication and authorization...
  - ... a particular strength of DCE
- Transactional RPC for dependability
- ...support for all these features is patchy

General guidance - specifying interfaces

- When specifying an operation, determine whether it is logically idempotent or not
  - but do not alter the interface to make it idempotent
- Avoid using one-way operations, unless you have a very clear reason
- Use the default RPC semantics (at-most-once under failure)
  - and have a standard application policy for handling failures/exceptions

General guidance - configuration

- Choose one RPC protocol for all your applications
- Ensure that appropriate transport protocols are available
  - including a transparent optimized local RPC for the co-located case
- Ensure that the programming language mappings you need are available
  - check both client and server machines
  - also check compiler and operating system versions
- Beware of operating system-specific restrictions on RPC
  - for example in non-multi-tasking systems such as DOS/Windows 3.x, or MacOS

General guidance - performance

- Decide whether performance is an issue for your application
- Consider benchmarking a simple RPC-based application in your own configuration
  - holding constant as many factors as possible
- Do not expect RPC performance to match measured file transfer performance in the same configuration
- Consider selective use of follow-up RPC
  - once the application is working!
- Aim for fast-enough performance for successful invocations
  - reliable-enough handling for failed invocations

General guidance - keeping it simple

- Choose one RPC protocol
- Confirm its performance is adequate
- Use its defaults
- Specify your interfaces allowing for failure conditions

Summary

- **For more information on RPC**
  - **see Chapter 5 of *Distributed Systems Concepts and Design* by Coulouris, Dollimore, and Kindberg (Addison-Wesley)...**
  - **...also see *Power Programming with RPC* by John Bloomer (O'Reilly and Associates)**