Distributed Systems

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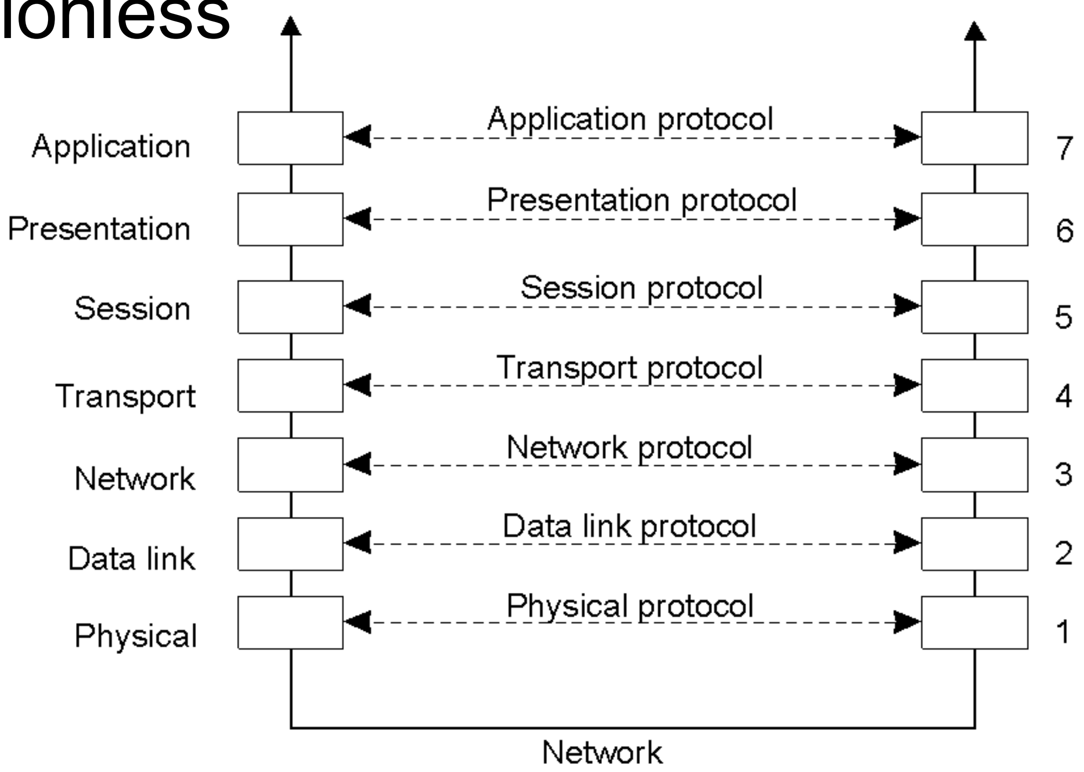
Chapter 2: Communication

- Issues in communication
- Message-oriented Communication
- Remote Procedure Calls
  - Transparency but poor for passing references
- Remote Method Invocation
  - RMIs are essentially RPCs but specific to remote objects
  - System wide references passed as parameters
- Stream-oriented Communication

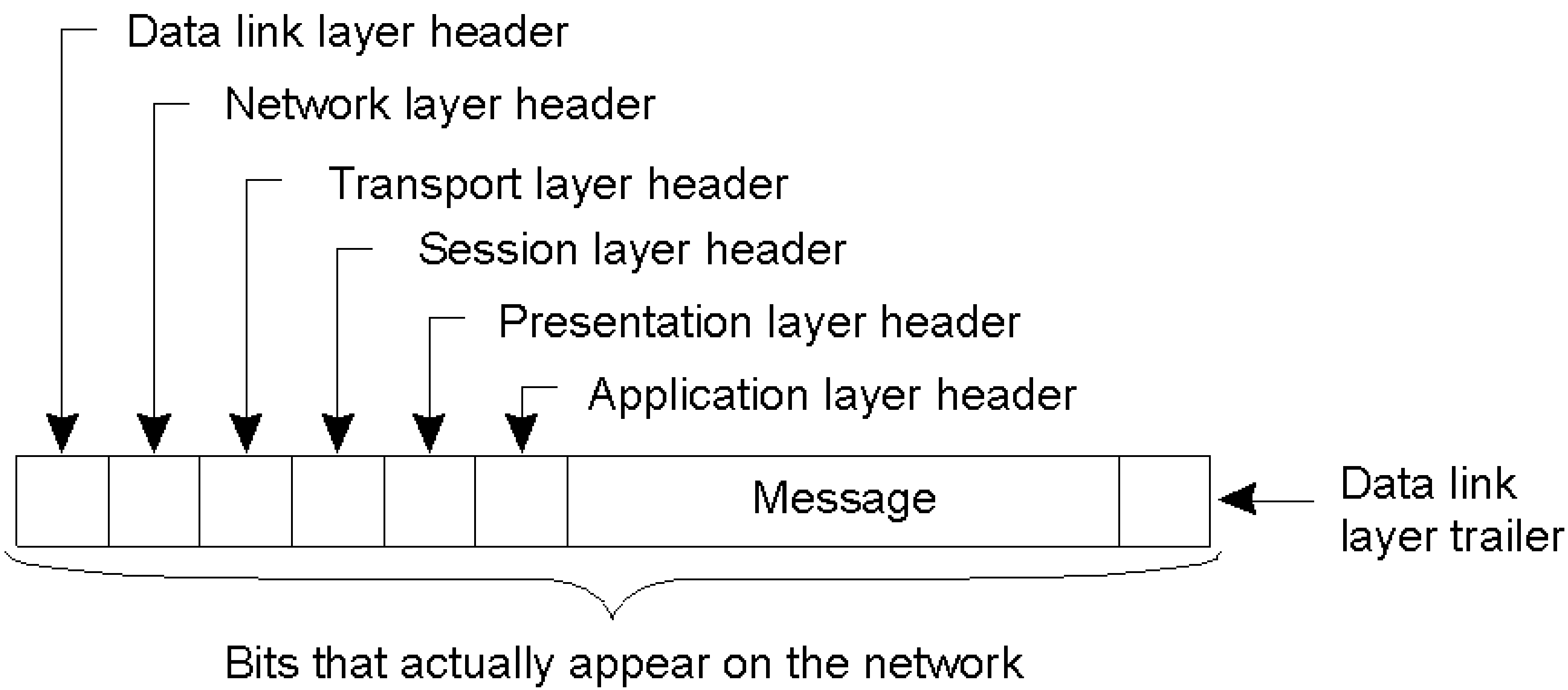
Communication Protocols

- Protocols are agreements/rules on communication
- Protocols could be connection-oriented or connectionless

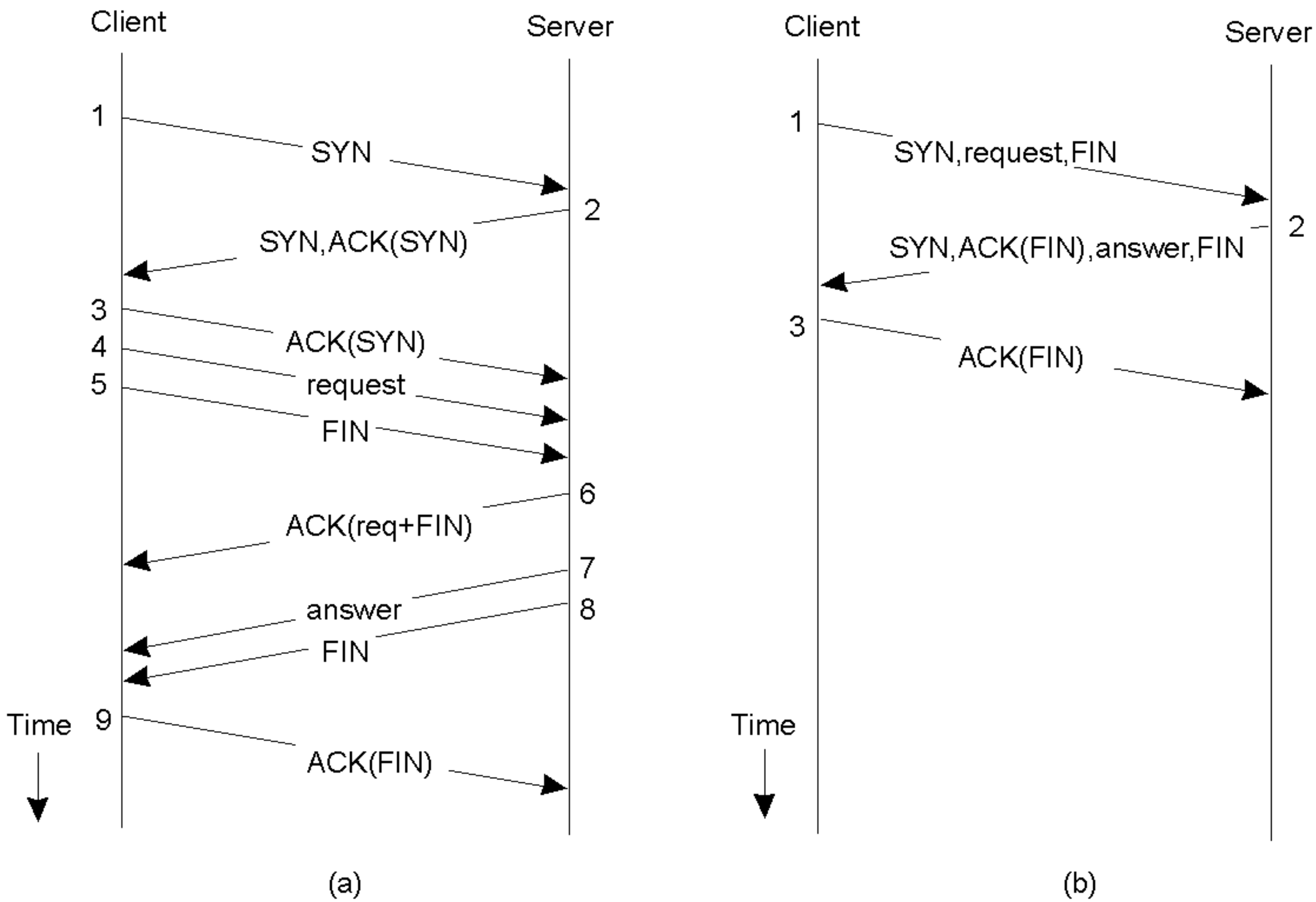


Layered Protocols

- A typical message as it appears on the network.

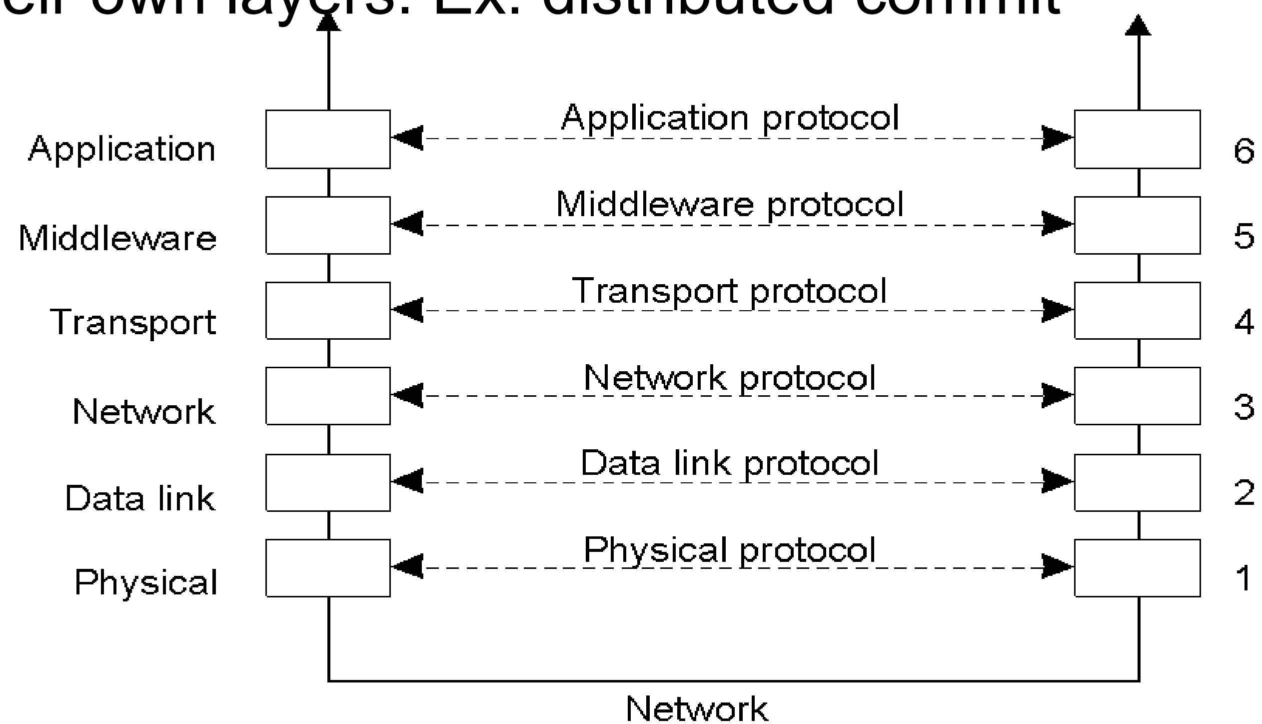


Client-Server TCP



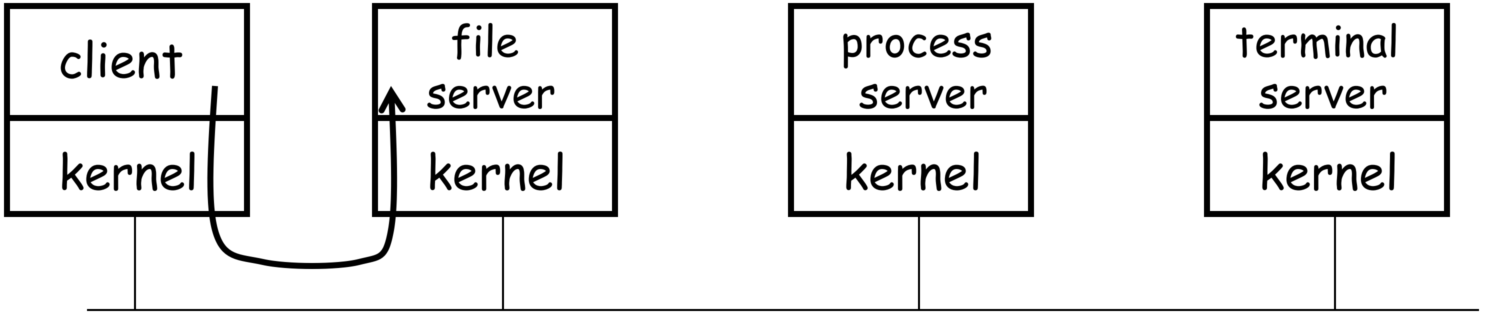
Middleware Protocols

- Middleware: layer that resides between an OS and an application
  - May implement general-purpose protocols that warrant their own layers. Ex: distributed commit



Client-Server Communication Model

- Structure: group of servers offering service to clients
- Based on a request/response paradigm
- Techniques:
  - Socket, remote procedure calls (RPC), Remote Method Invocation (RMI)

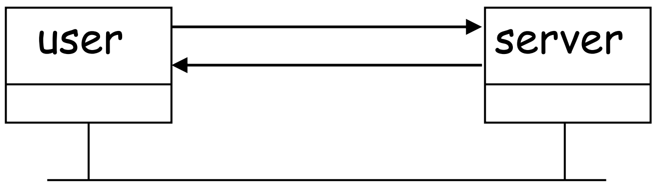


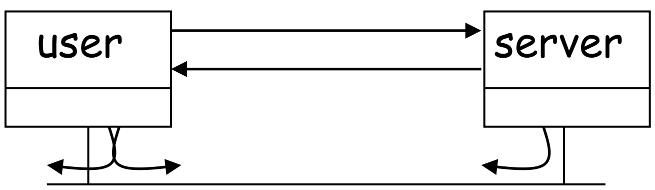
Issues in Client-Server Communication

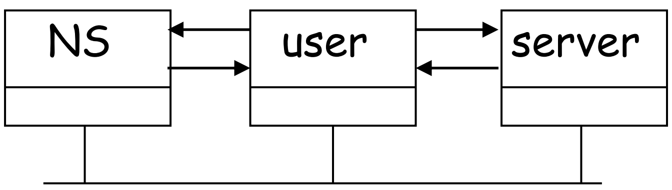
- Addressing
- Blocking versus non-blocking
- Buffered versus unbuffered
- Reliable versus unreliable
- Server architecture: concurrent versus sequential
- Scalability

Addressing Issues

- *Question:* how is the server located?
- Hard-wired address
  - Machine address and process address are known a priori
- Broadcast-based
  - Server chooses address from a sparse address space
  - Client broadcasts request
  - Can cache response for future
- Locate address via name server





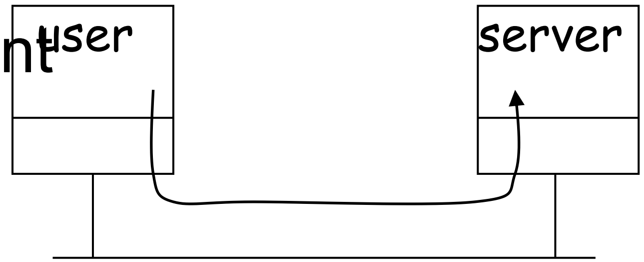


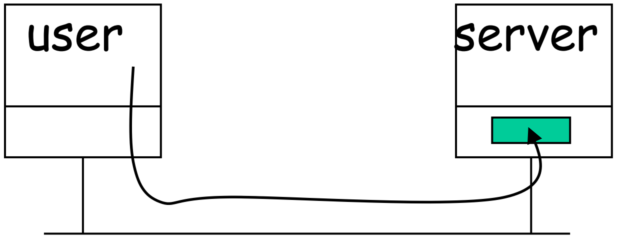
Blocking versus Non-blocking

- Blocking communication (synchronous)
  - Send blocks until message is actually sent
  - Receive blocks until message is actually received
- Non-blocking communication (asynchronous)
  - Send returns immediately
  - Return does not block either
- Examples

Buffering Issues

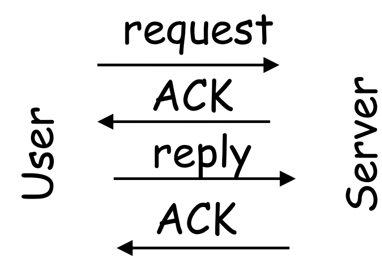
- Unbuffered communication
  - Server must call receive before client can call send
- Buffered communication
  - Client send to a mailbox
  - Server receives from a mailbox



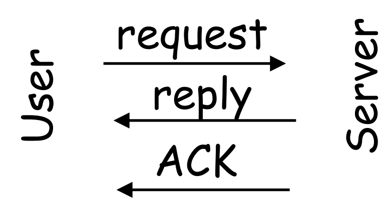


Reliability

- Unreliable channel
  - – Need acknowledgements (ACKs)
  - – Applications handle ACKs
  - – ACKs for both request and reply



- Reliable channel
  - – Reply acts as ACK for request
  - – Explicit ACK for response



- Reliable communication on unreliable channels
  - – Transport protocol handles lost messages

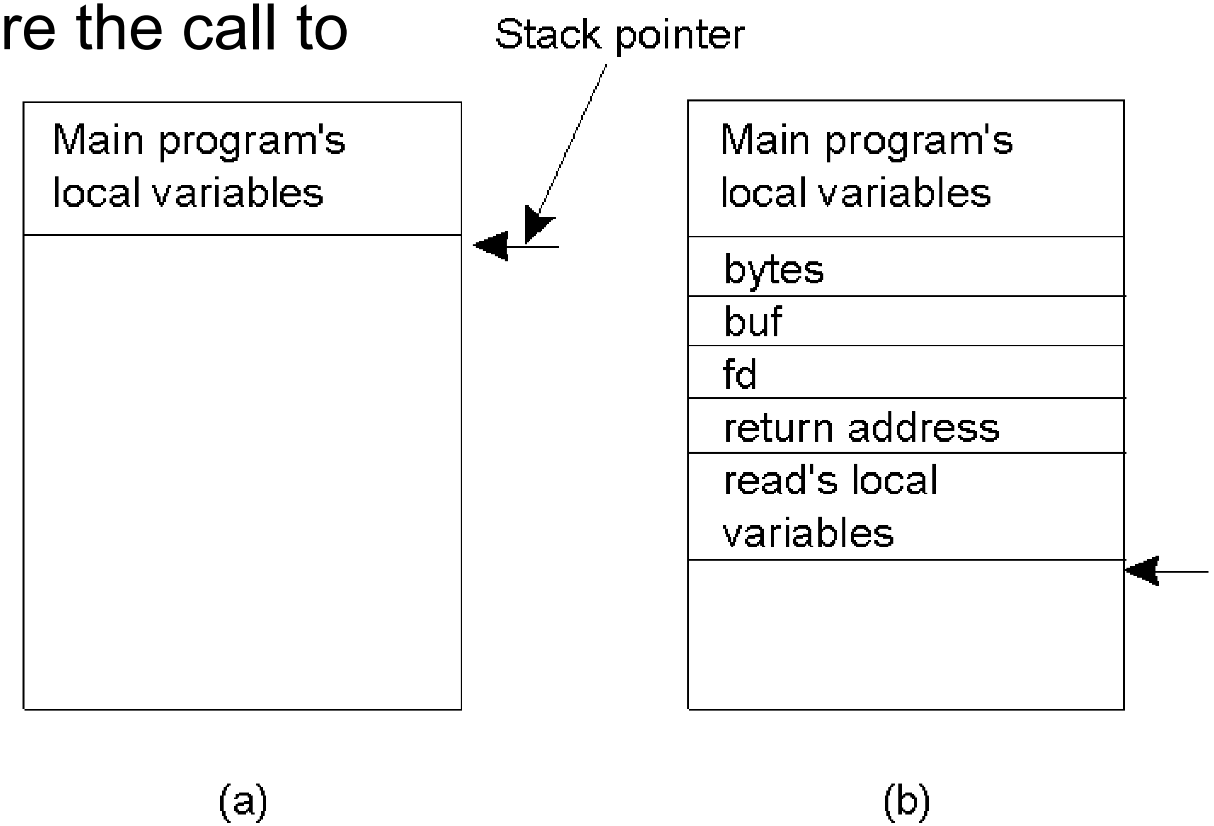
Remote Procedure Calls

- Goal: Make distributed computing look like centralized computing
- Allow remote services to be called as procedures
  – Transparency with regard to location, implementation, language
- Issues
  – How to pass parameters
  – Bindings
  – Semantics in face of errors
- Two classes: integrated into prog, language and separate

Conventional Procedure Call

a) Parameter passing in a local procedure call: the stack before the call to read

b) The stack while the called procedure is active

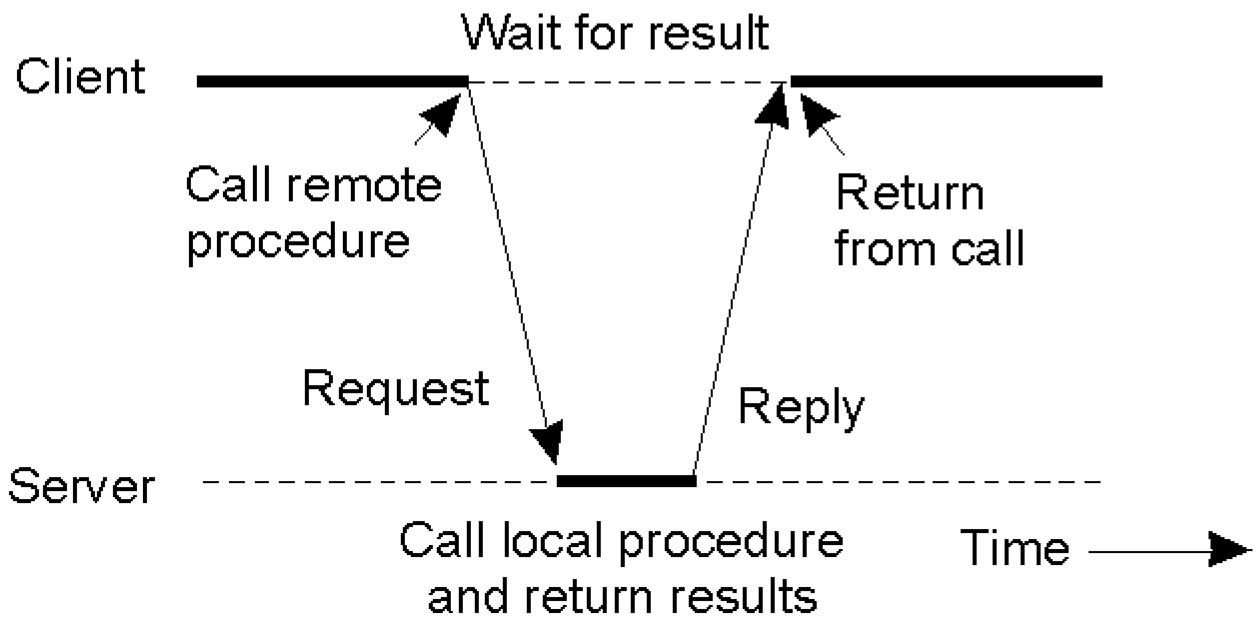


Parameter Passing

- Local procedure parameter passing
  - Call-by-value
  - Call-by-reference: arrays, complex data structures
- Remote procedure calls simulate this through:
  - Stubs – proxies
  - Flattening – marshalling
- Related issue: global variables are not allowed in RPCs

Client and Server Stubs

- Principle of RPC between a client and server program.



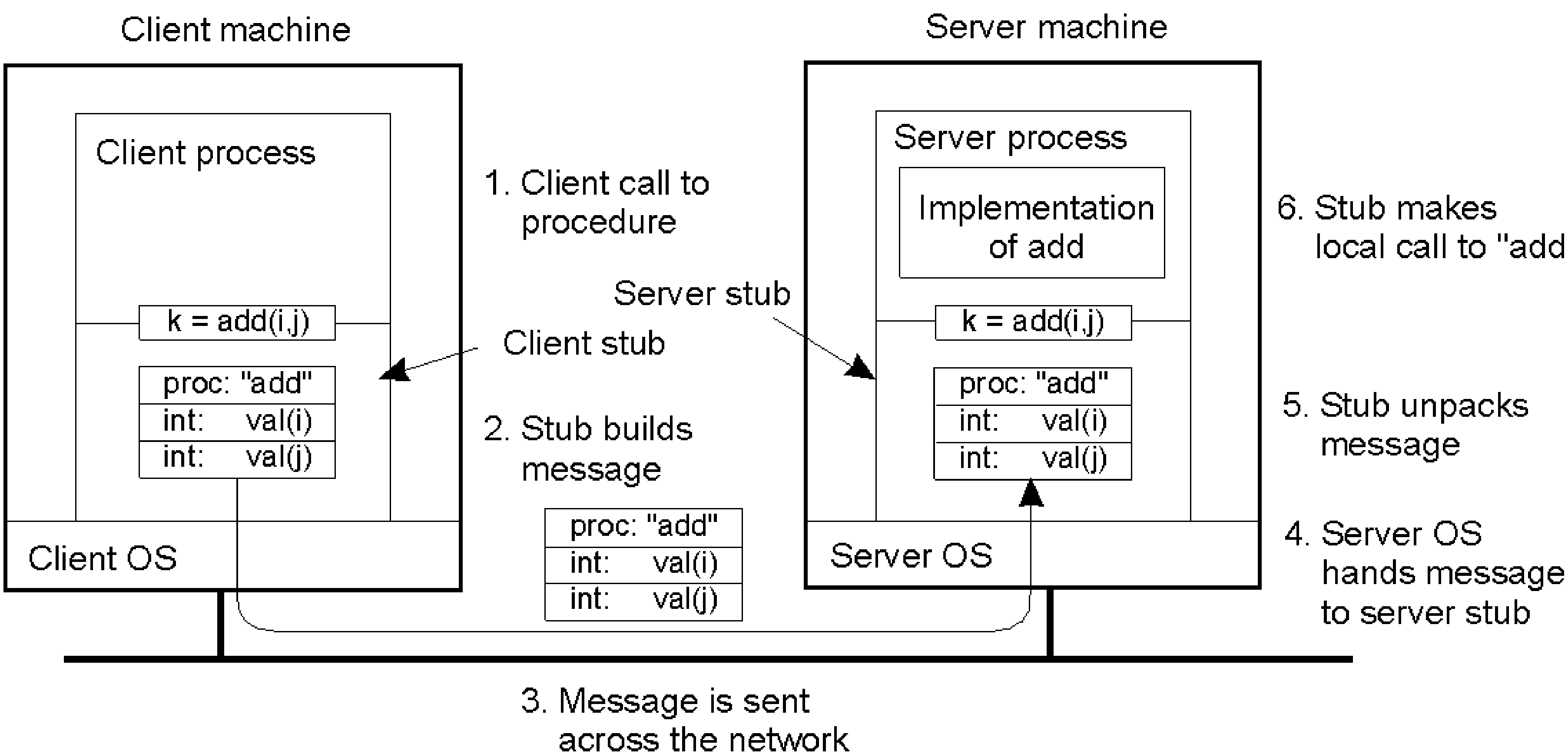
Stubs

- Client makes procedure call (just like a local procedure call) to the client stub
- Server is written as a standard procedure
- Stubs take care of packaging arguments and sending messages
- Packaging parameters is called *marshalling*
- Stub compiler generates stub automatically from specs in an Interface Definition Language (IDL)
  - Simplifies programmer task

Steps of a Remote Procedure Call

1. Client procedure calls client stub in normal way
2. Client stub builds message, calls local OS
3. Client's OS sends message to remote OS
4. Remote OS gives message to server stub
5. Server stub unpacks parameters, calls server
6. Server does work, returns result to the stub
7. Server stub packs it in message, calls local OS
8. Server's OS sends message to client's OS
9. Client's OS gives message to client stub
10. Stub unpacks result, returns to client

Example of an RPC



Marshalling

- Problem: different machines have different data formats
  - Intel: little endian, SPARC: big endian
- Solution: use a standard representation
  - Example: external data representation (XDR)
- Problem: how do we pass pointers?
  - If it points to a well-defined data structure, pass a copy and the server stub passes a pointer to the local copy
- What about data structures containing pointers?
  - Prohibit
  - Chase pointers over network
- Marshalling: transform parameters/results into a byte stream

Binding

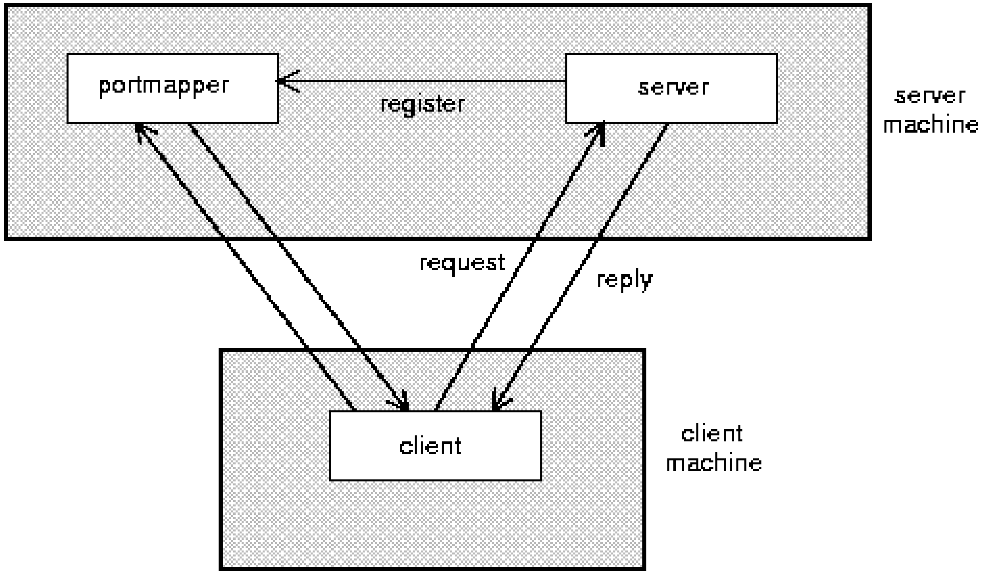
- Problem: how does a client locate a server?
  - Use Bindings
- Server
  - Export server interface during initialization
  - Send name, version no, unique identifier, handle (address) to binder
- Client
  - First RPC: send message to binder to import server interface
  - Binder: check to see if server has exported interface
    - » Return handle and unique identifier to client

Case Study: SUNRPC

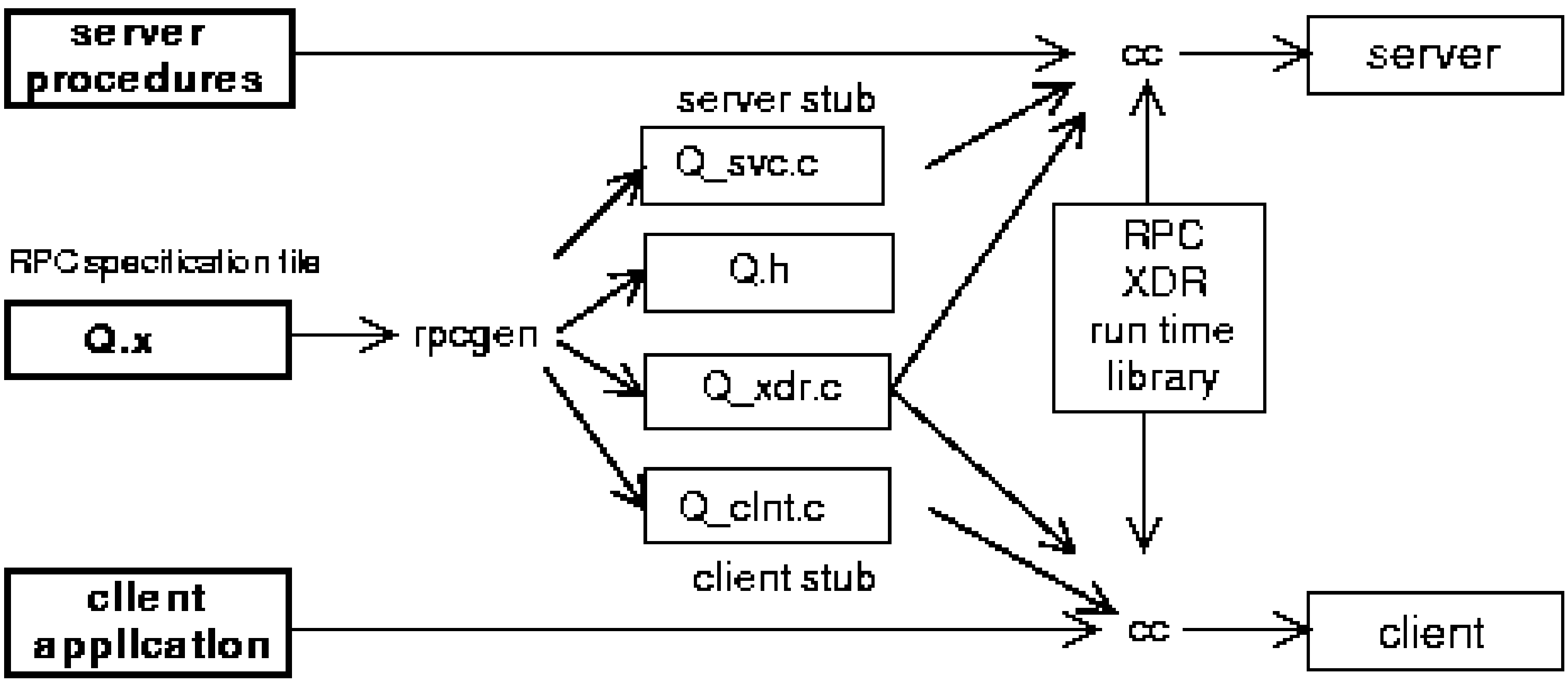
- One of the most widely used RPC systems
- Developed for use with NFS
- Built on top of UDP or TCP
  - TCP: stream is divided into records
  - UDP: max packet size < 8912 bytes
  - UDP: timeout plus limited number of retransmissions
  - TCP: return error if connection is terminated by server
- Multiple arguments marshaled into a single structure
- At-least-once semantics if reply received, at-least-zero semantics if no reply. With UDP tries at-most-once
- Use SUN's eXternal Data Representation (XDR)
  - Big endian order for 32 bit integers, handle arbitrarily large data structures

Binder: Port Mapper

- Server start-up: create port
- Server stub calls *svc_register* to register prog. #, version # with local port mapper
- Port mapper stores prog #, version #, and port
- Client start-up: call *clnt_create* to locate server port
- Upon return, client can call procedures at the server



Rpcgen: generating stubs



- Q_xdr.c: do XDR conversion
- Detailed example: later in this course

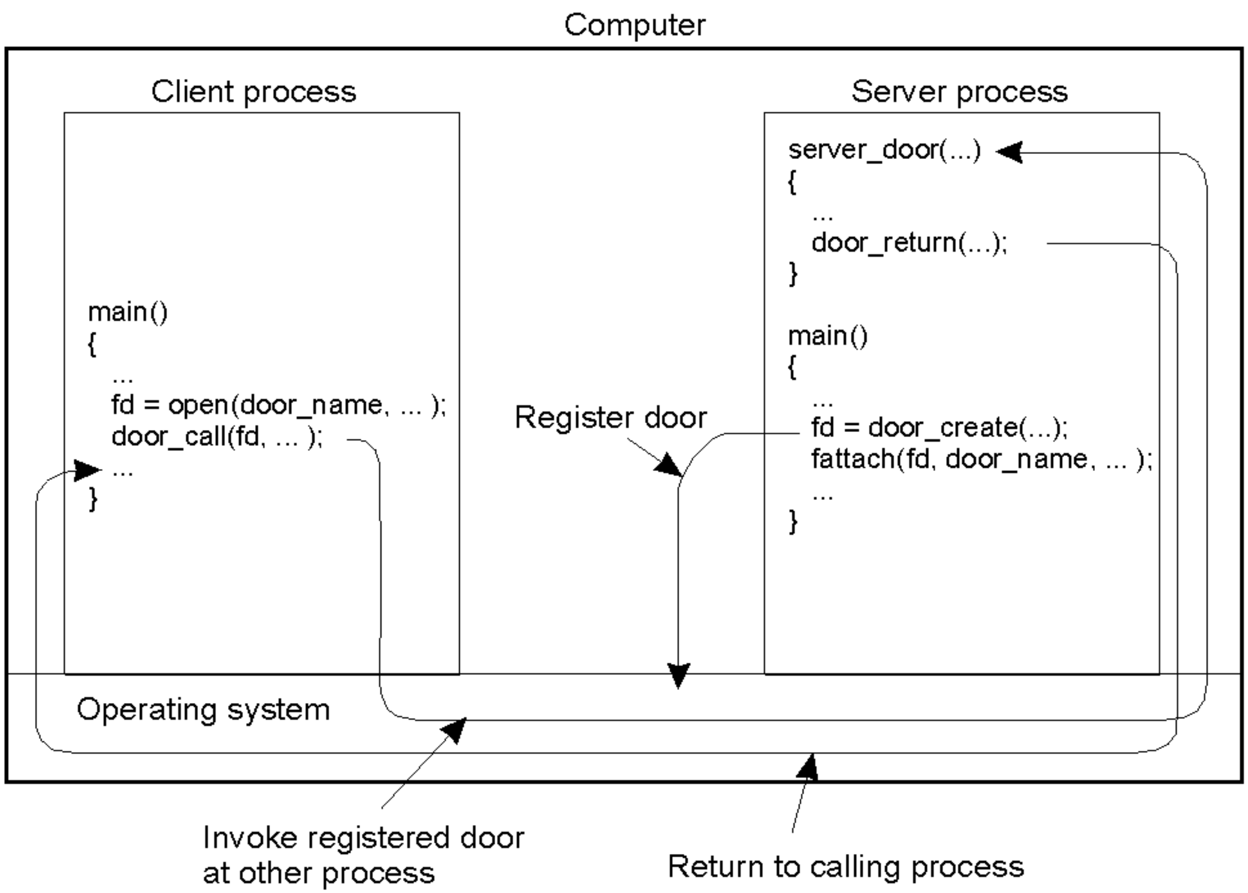
Lightweight RPCs

- Many RPCs occur between client and server on same machine
  - Need to optimize RPCs for this special case => use a lightweight RPC mechanism (LRPC)
- Server *S* exports interface to remote procedures
- Client *C* on same machine imports interface
- OS kernel creates data structures including an argument stack shared between *S* and *C*

Lightweight RPCs

- RPC execution
  - Push arguments onto stack
  - Trap to kernel
  - Kernel changes mem map of client to server address space
  - Client thread executes procedure (OS upcall)
  - Thread traps to kernel upon completion
  - Kernel changes the address space back and returns control to client
- Called “doors” in Solaris

Doors

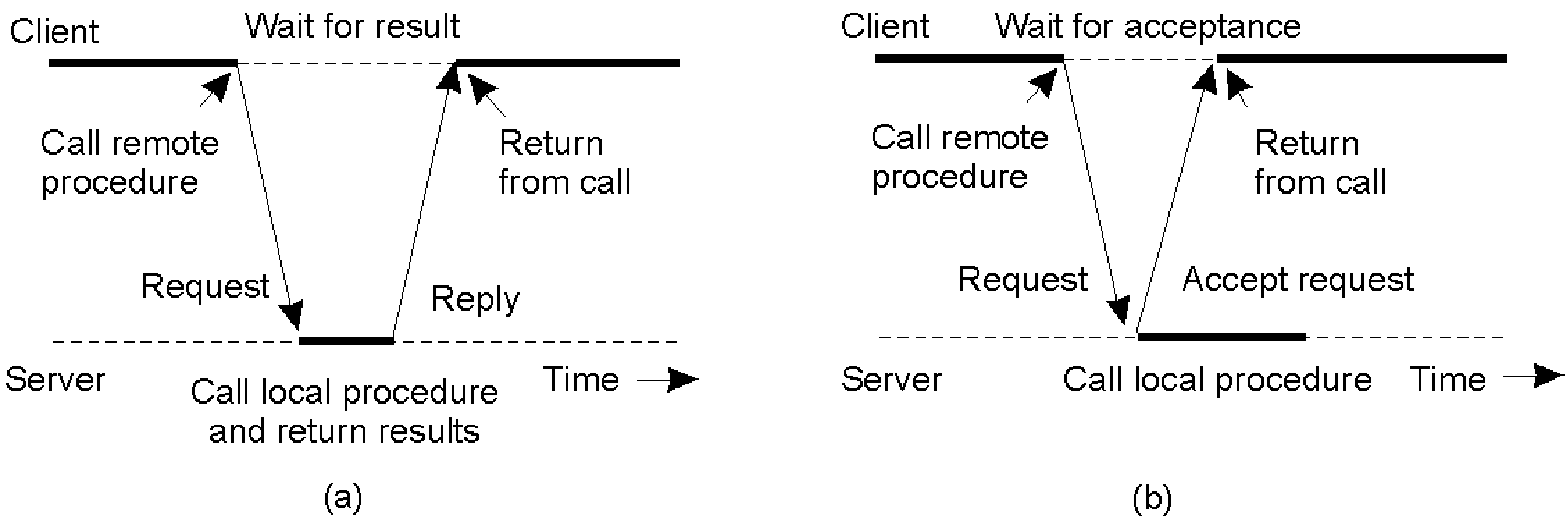


- Which RPC to use? - run-time bit allows stub to choose between LRPC and RPC

Other RPC Models

- Asynchronous RPC
  - Request-reply behavior often not needed
  - Server can reply as soon as request is received and execute procedure later
- Deferred-synchronous RPC
  - Use two asynchronous RPCs
  - Client needs a reply but can’t wait for it; server sends reply via another asynchronous RPC
- One-way RPC
  - Client does not even wait for an ACK from the server
  - Limitation: reliability not guaranteed (Client does not know if procedure was executed by the server).

Asynchronous RPC

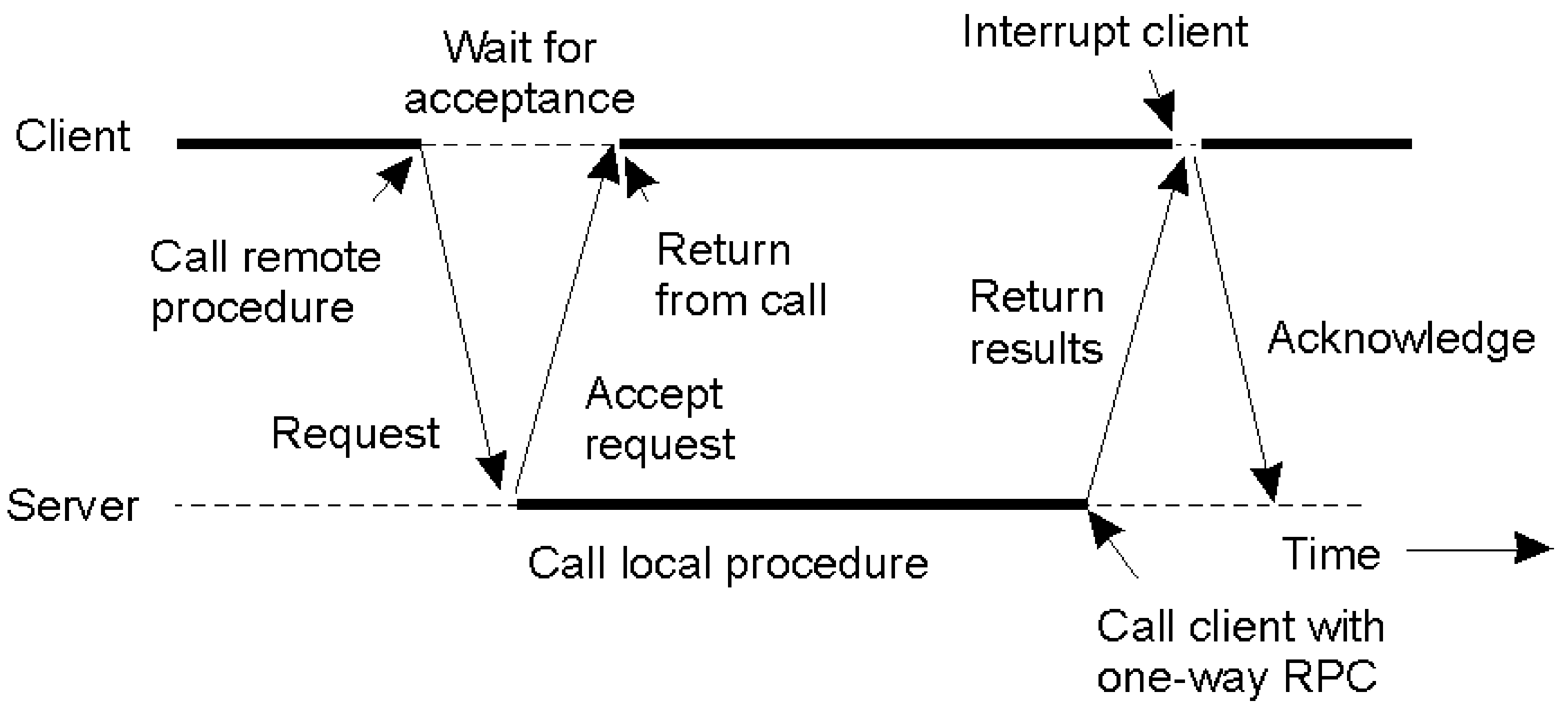


a) The interconnection between client and server in a traditional RPC

b) The interaction using asynchronous RPC

Deferred Synchronous RPC

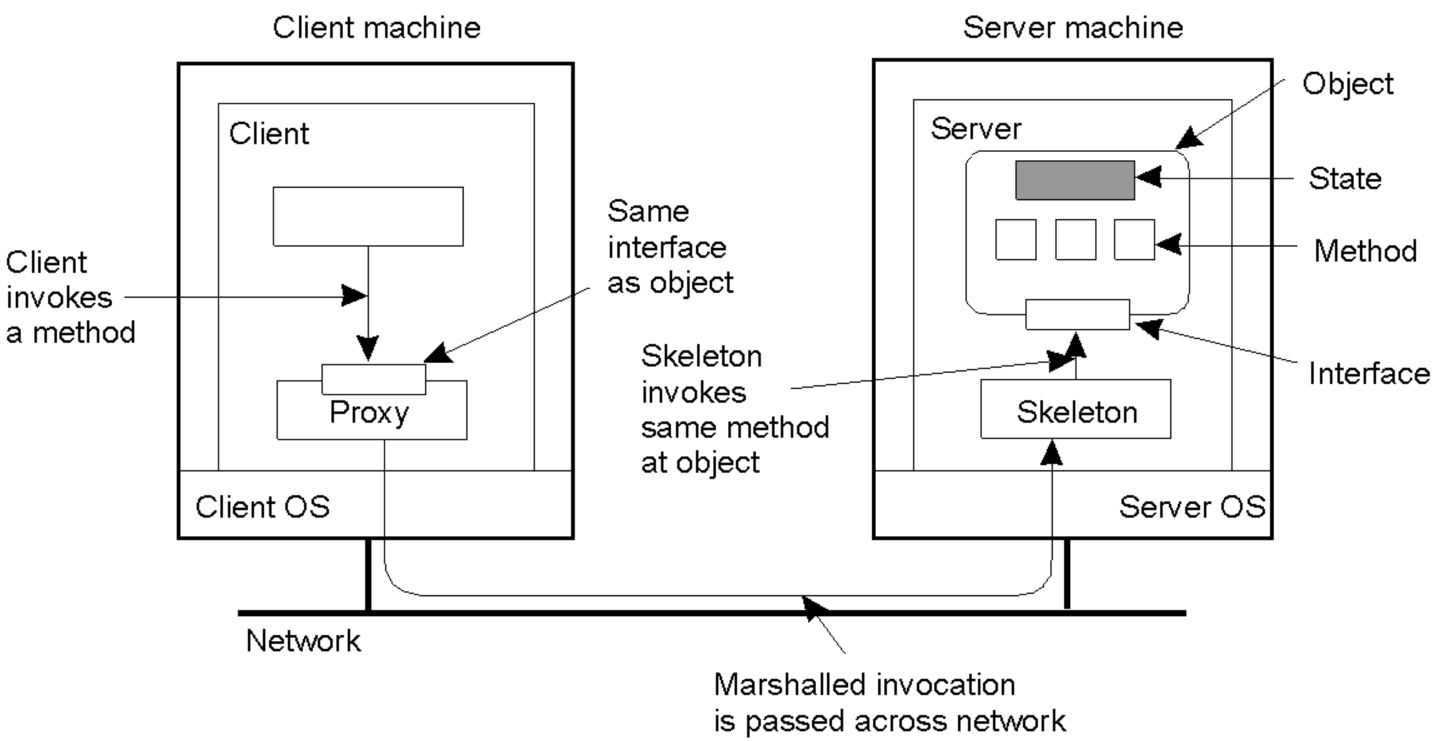
- A client and server interacting through two asynchronous RPCs



Remote Method Invocation (RMI)

- RPCs applied to *objects,* i.e., instances of a class
  - *Class:* object-oriented abstraction; module with data and operations
  - Separation between interface and implementation
  - Interface resides on one machine, implementation on another
- RMIs support system-wide object references
  - Parameters can be object references

Distributed Objects



- When a client binds to a distributed object, load the interface ("proxy") into client address space
  - Proxy analogous to stubs
- Server stub is referred to as a skeleton

Proxies and Skeletons

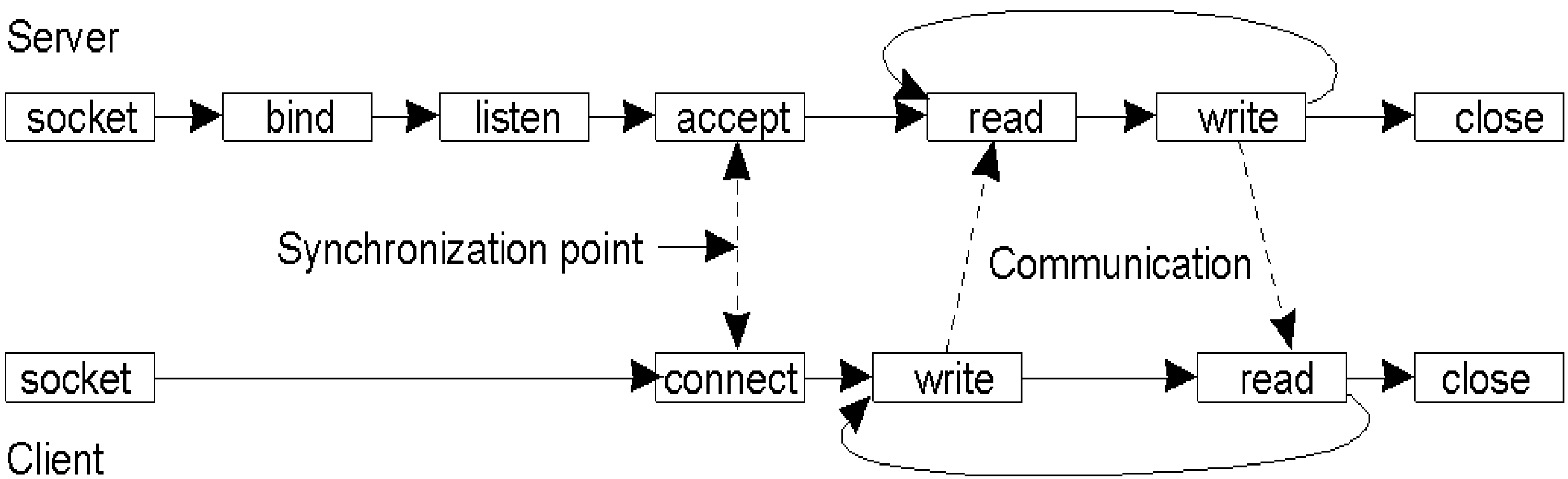
- Proxy: client stub
  - Maintains server ID, endpoint, object ID
  - Sets up and tears down connection with the server
  - [Java:] does serialization of local object parameters
  - In practice, can be downloaded/constructed on the fly (why can't this be done for RPCs in general?)
- Skeleton: server stub
  - Does deserialization and passes parameters to server and sends result to proxy

Java RMI

- Server
  - Defines interface and implements interface methods
  - Server program
    - » Creates server object and registers object with “remote object” registry
- Client
  - Looks up server in remote object registry
  - Uses normal method call syntax for remote methos
- Java tools
  - Rmiregistry: server-side name server
  - Rmic: uses server interface to create client and server stubs

Message-oriented Transient Communication

- Many distributed systems built on top of simple message-oriented model
  - Example: Berkeley sockets



Berkeley Socket Primitives

Primitive	Meaning
Socket	Create a new communication endpoint
Bind	Attach a local address to a socket
Listen	Announce willingness to accept connections
Accept	Block caller until a connection request arrives
Connect	Actively attempt to establish a connection
Send	Send some data over the connection
Receive	Receive some data over the connection
Close	Release the connection