Concepts of Distributed Systems 2006/2007

Communication

Johan Lukkien

Programme

- Introduction & overview
- Communication
- Distributed OS & Processes
- Synchronization
- Security
- Consistency & replication

- Naming
- Fault Tolerance

Communication

- Some concepts and definitions
- Layered protocols
- Remote Procedure Calls
- Remote Method Invocation
- Message oriented communication
- Stream oriented

Johan J. Lukkien, j.j.lukkien@tue.nl
TU/e Informatica, System Architecture and Networking

Communication modes

- Synchronization
  - Synchronous: send and receive are coupled
  - Buffered: bounded send surplus
  - Asynchronous: sender never blocked
- Message existence
  - Persistent: subsystem will deliver messages
  - Transient: message life depends on life of sender, receiver, subsystem
- Timing
  - Time-independent
  - Time-dependent (real-time)
    - soft real-time, hard real-time

Connections

- Connection oriented
  - setup & destroy
  - control: reliability, flow, congestion
- Connection-less
  - each message single-shot
- Sources and destinations
  - many to one
  - one to many
    - with addressing (multicast) or without (broadcast)
  - many to many

Routes and forwarding

- Packet-switched
  - each packet is dealt with (routed) separately
  - difficult to guarantee end-to-end quality
    - usually: over-dimensioning
  - much more efficient use of resources

- Circuit-switched
  - information is forwarded along a reserved, end-to-end route
  - admits quality guarantees
  - fits connection oriented message transfer

Definition: protocol

- **Protocol:** *A formal set of rules that dictates how information exchange as well as interaction between objects (can be devices, execution threads, etc.) should take place.*

  The rules specify
  - *the format of the messages exchanged;*
  - *a number of different protocol states and what messages are allowed to be sent in each state; these states determine, among others, the order of the messages.*
  - *timing constraints and other non-functional properties, if any.*

Definition: service

- **Service**: *a contractually specified overall functionality (semantics) of an entity.*
- **Service quality**: *non-functional properties of a service (e.g. speed, reliability, ...).*
- **Service interface (API)**: *actions ("primitives") and responses that make the service available; these responses can be autonomous ("events", "call-backs"). In addition, a specification that*
  - *describes their effect on state variables and parameters, as well as their results;*
  - *describes rules as how and in what sequence to call them;*
  - *describes the functional and non-functional properties of sequences of calls.*

  (i.e., the interaction protocol)

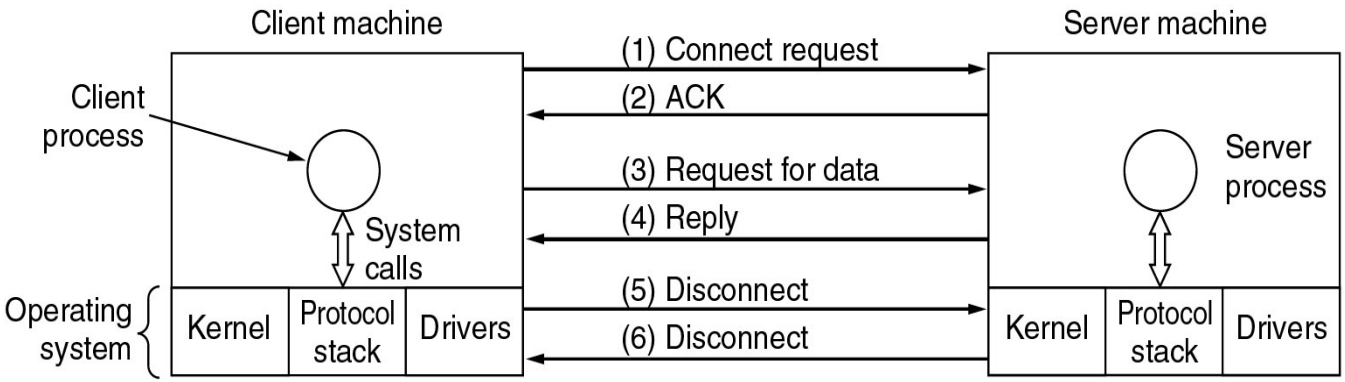
Service examples

- Typically, the communication modes
- Quality dimensions
  - reliable, acknowledged, guaranteed bandwidth, low latency

	Service	Example
Connection-oriented	Reliable message stream	Sequence of pages
	Reliable byte stream	Remote login
	Unreliable connection	Digitized voice
Connection-less	Unreliable datagram	Electronic junk mail
	Acknowledged datagram	Registered mail
	Request-reply	Database query

Example: primitives for connection oriented service

Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection



Definition: carrier, binding

- A protocol can be realized directly in hardware. If not, the messages of a protocol are given to another protocol, called the *carrier*.

- The functionality and properties that a protocol provides is called the *provided service*. The provided service is often specified by an API for the protocol.

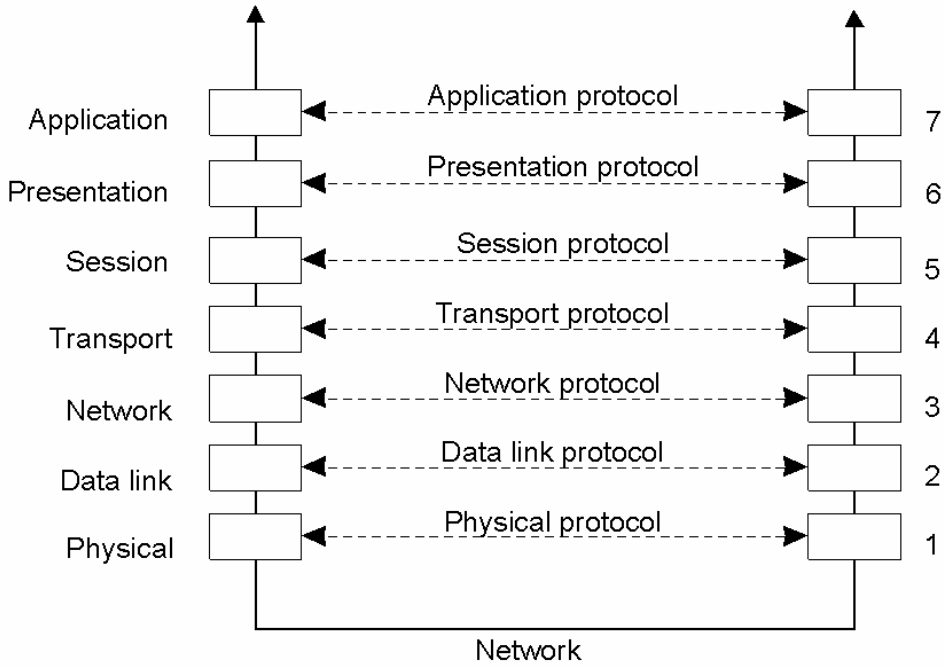
- A protocol requires services from its carrier and any carrier providing these services can be used. The rules that specify how a protocol is mapped onto a carrier is called a *binding*.

Communication

- Some concepts and definitions
- Layered protocols
- Remote Procedure Calls
- Remote Method Invocation
- Message oriented communication
- Stream oriented

OSI('83): Basic reference networking model

- Layers communicate with peers and with neighbors (provided & required services)
- OSI protocols:
  - not used
- OSI reference:
  - widely accepted

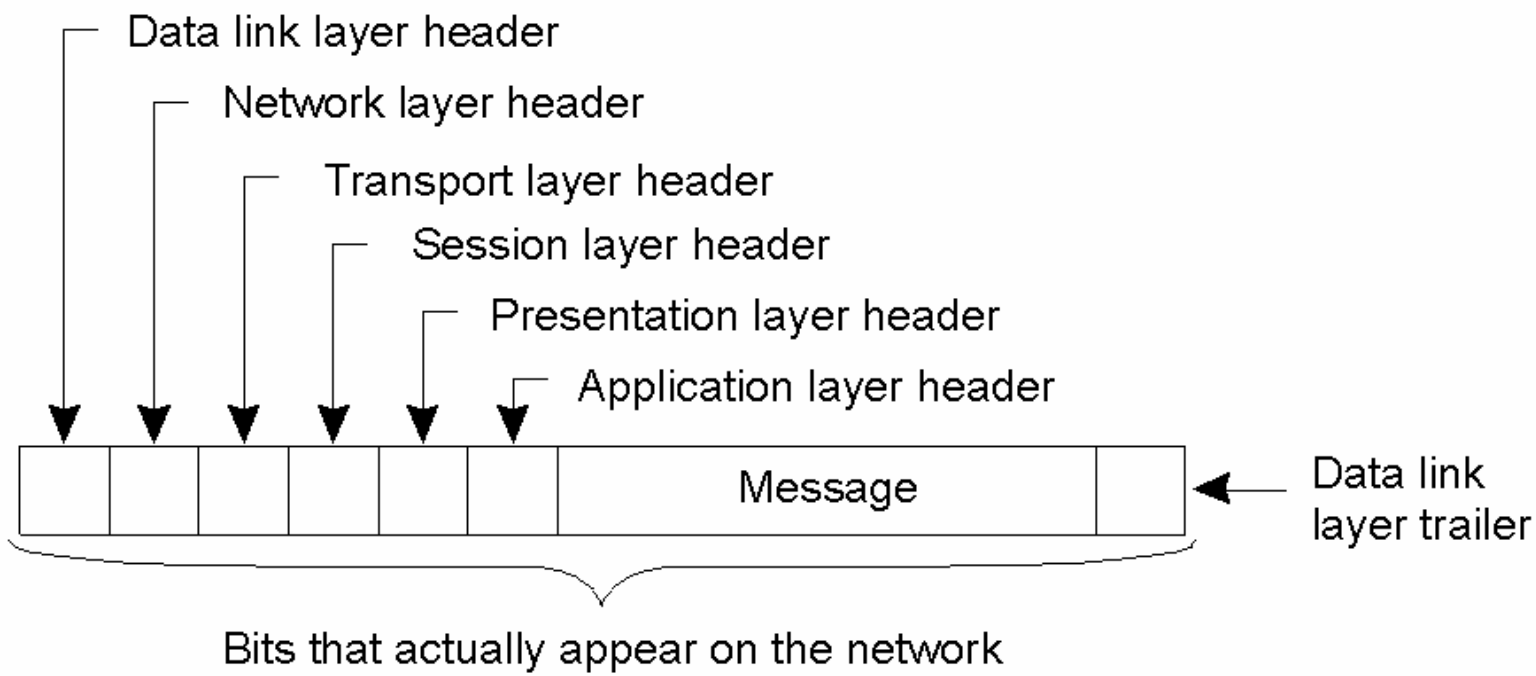


Some stacks and the OSI model

Protocol Stacks in Relationship to the OSI Model

OSI Layer	Apple Computer	Banyan Systems	DEC DECnet	IBM SNA	Microsoft Networking	Novell NetWare	TCP/IP Internet	Xerox XNS	OSI Protocols
Application Layer 7	Application Programs and Protocols for file transfer, electronic mail, etc.								
Presentation Layer 6	AppleTalk Filing Protocol (AFP)	Remote Procedural Calls (Net RPC)	Network Management Network Application	Transaction Services Presentation Services	Server Message Block (SMB)	NetWare Core Protocols (NCP	(Telnet, FTP, SMTP, etc.)	Control and Process Interaction	ISO 8823
Session Layer 5	AppleTalk Session Protocol (ASP)		Session	Data Flow Control	Network Basic Input/Output System (NetBIOS)	Network Basic Input/Output System (NetBIOS)			ISO 8327
Transport Layer 4	AppleTalk Transaction Protocol (ATP)	VINES InterProcess Communications (VIPC)	End Communications	Transmission Control	Network Basic Extended User Interface (NetBEUI)	Sequenced Packet Exchange (SPX)	Transmission Control Protocol (TCP), User Datagram Protocol (UDP)	Sequenced Packet Protocol (SPP)	ISO 8073 TP0-4
Network Layer 3	Datagram Delivery Protocol (DDP)	VINES Internet Protocol (VIP)	Routing	Path Control		Internet Packet Exchange (IPX)	Internet Protocol (IP)	Internet Datagram Protocol (IDP)	ISO 8473 (CLNP)
Data Link Layer 2	Network Interface Cards: Ethernet, Token-Ring, ARCNET, StarLAN, LocalTalk, FDDI, ATM, etc. NIC Drivers: Open Datalink Interface (ODI), Network Independent Interface Specification (NDIS)								
Physical Layer 1	Transmission Media: Twisted Pair, Coax, Fiber Optic, Wireless Media, etc.								

Layered Protocols and message layout



Issues, to be resolved by the layers

- Error detection, correction
- Flow control
- Addressing
- Multiplexing
- Naming
- Congestion control
- Mobility
- Routing
- Fragmentation
- Security
- ....

Lower layer tasks

- Physical: put bits and bytes on media
  - voltage levels, radio signals, direction
- Data Link (simplified):
  - transport frames
    - frame separation, error recovery (check-sum....), flow control (sequence numbers, on/off, ...)
  - medium access, local addressing (MAC)
- Network: network-(world-) wide packet routing
  - IP !
  - the lowest level in many distributed system

Conversation in Data Link Layer

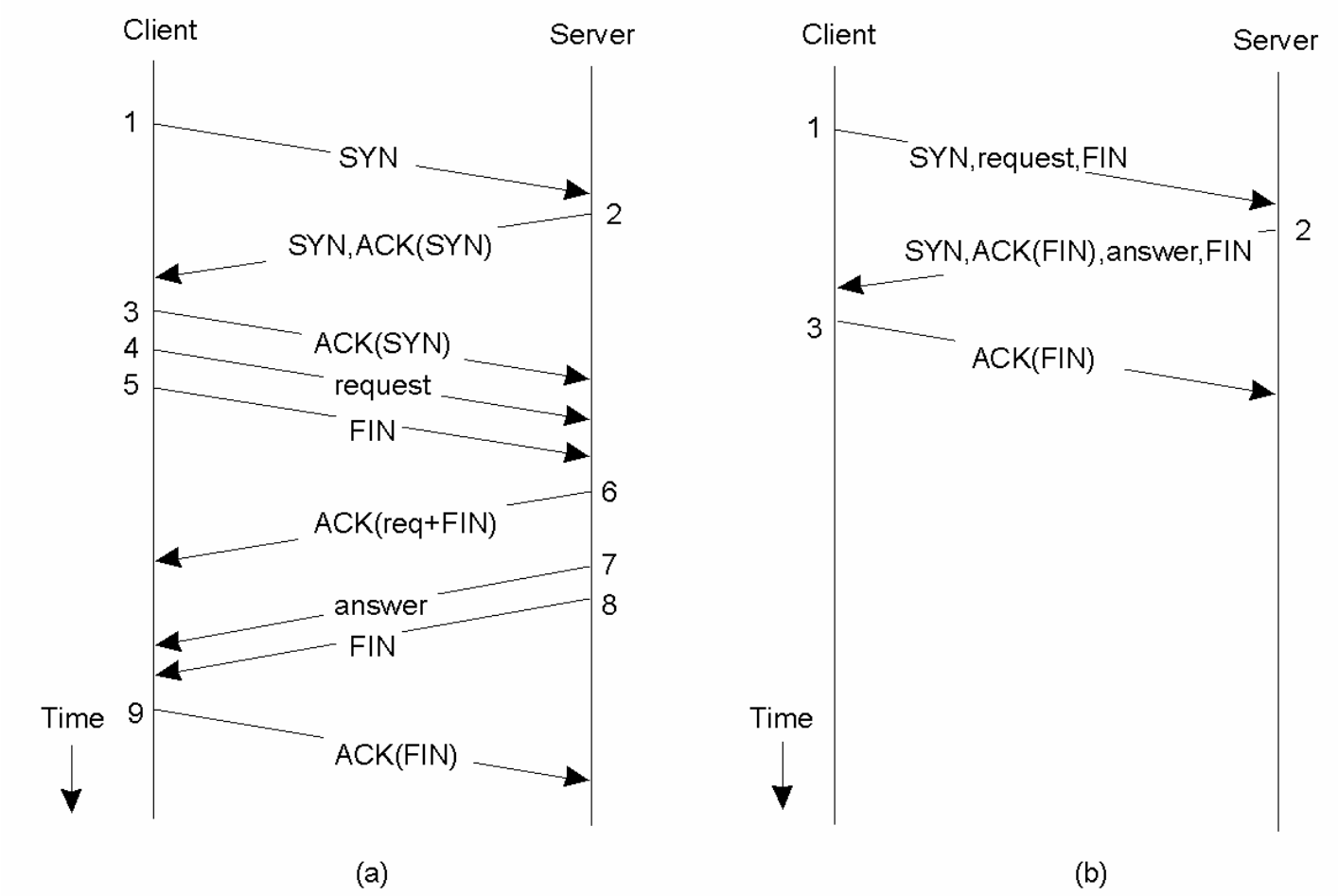
Time	A	B	Event
0	Data 0		A sends data message 0
1		Data 0	B gets 0, sees bad checksum
2	Data 1	Control 0	A sends data message 1 B complains about the checksum
3	Control 0	Data 1	Both messages arrive correctly
4	Data 0	Control 1	A retransmits data message 0 B says: "I want 0, not 1"
5	Control 1	Data 0	Both messages arrive correctly
6	Data 0		A retransmits data message 0 again
7		Data 0	B finally gets message 0

Transport layer

- End-to-end communication
  - recover lost packets, re-order
    - sliding-window protocols
  - adjust speed to network performance, congestion
    - e.g. TCP-compliance
  - multiplexing
    - several ports

- On the Internet
  - TCP: transmission control protocol (connection oriented, stream)
  - UDP: user datagram protocol
  - RTP: real-time protocol (RTP/UDP)

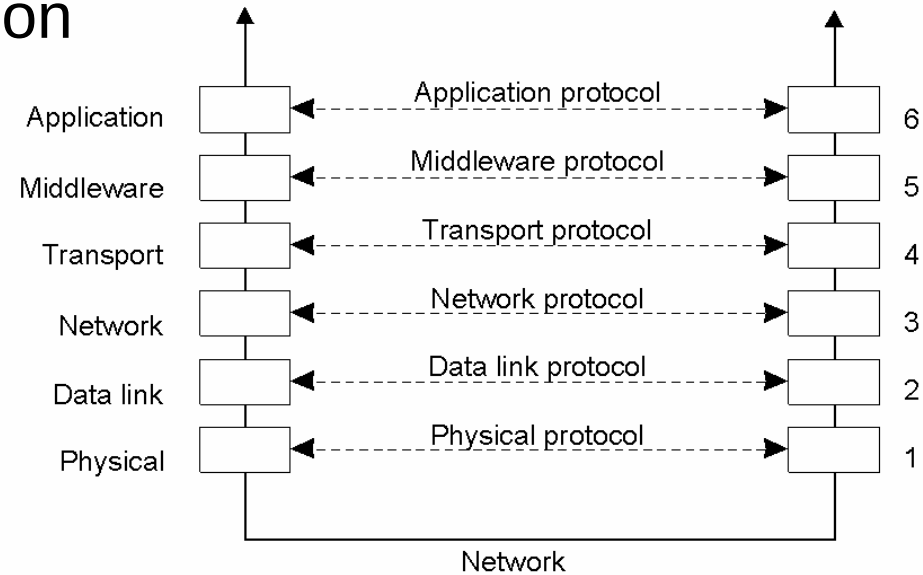
TCP and transactions (T/TCP)



Higher layer protocols

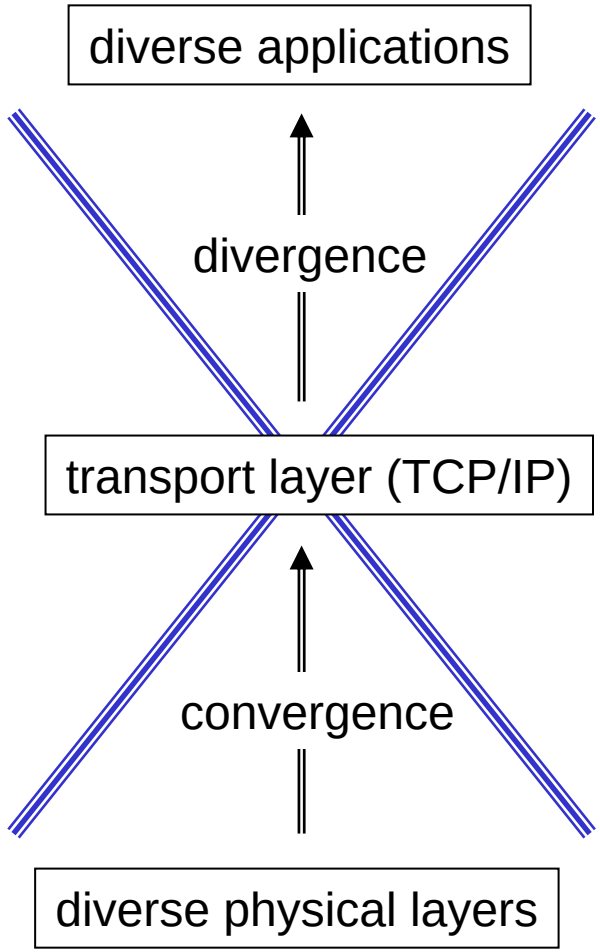
- Often, application specific
  - ftp, http, nntp, smtp, ...
- Usually, the API non-existent

- Integration of common protocols can provide a rich set of application-independent functionalities



The protocol triangle

- IP/everything tendency
  - goal in the layering: connect everything
  - TCP/IP as basic interoperability
- Application needs are diverse
  - use transport layer for private purpose (interest in *meaning* of the bits)
  - no direct need to support standards



Question

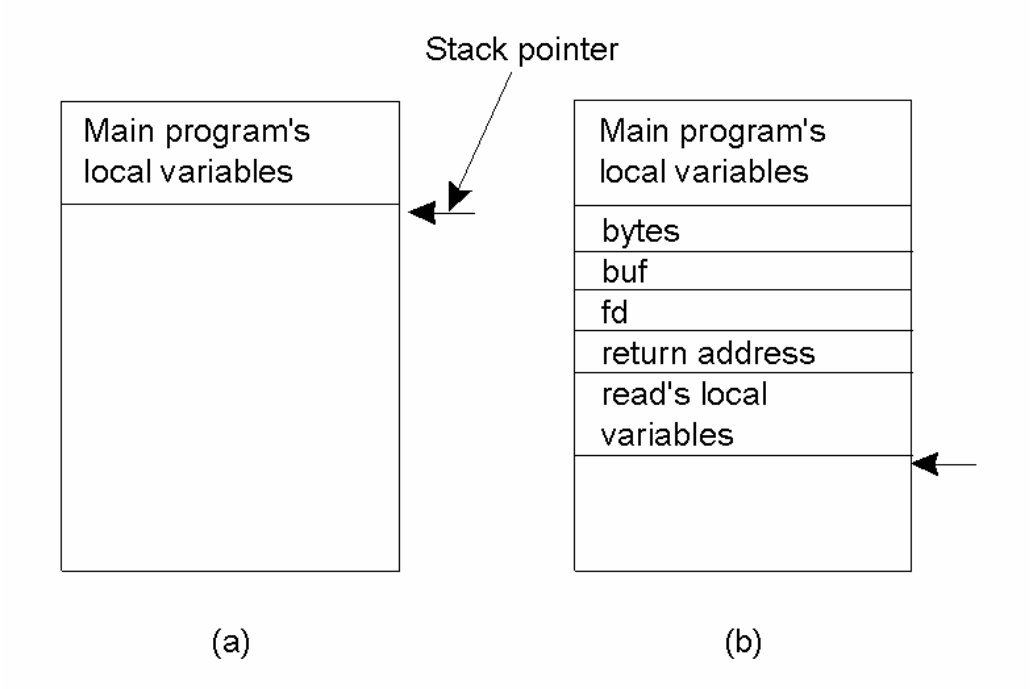
- Suppose that you want to have a multicast communication. Where should this be addressed?
  - Network layer: multicast addressing
    - efficient: packets go where they should
    - e.g. IP multicast
  - Transport layer: message replication from the start
  - Middleware: overlay network
    - limits communication
    - physical distance may be smaller than logical distance
    - penalty for high-level handling

Communication

- Some concepts and definitions
- Layered protocols
- Remote Procedure Calls
- Remote Method Invocation
- Message oriented communication
- Stream oriented

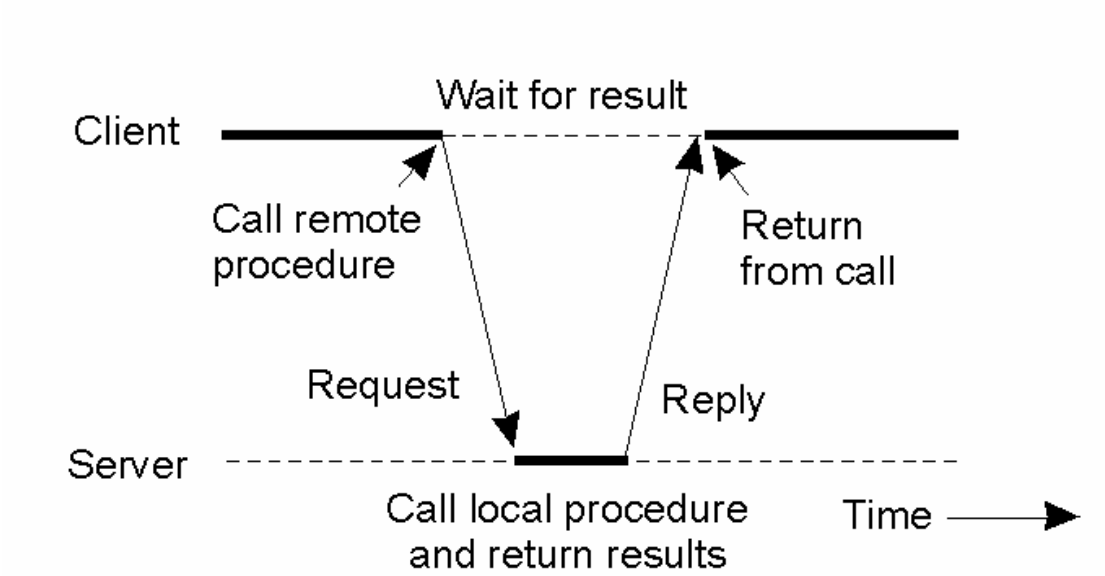
Conventional Procedure Call

- *read(int fd, unsigned char *buf, int bytes)*



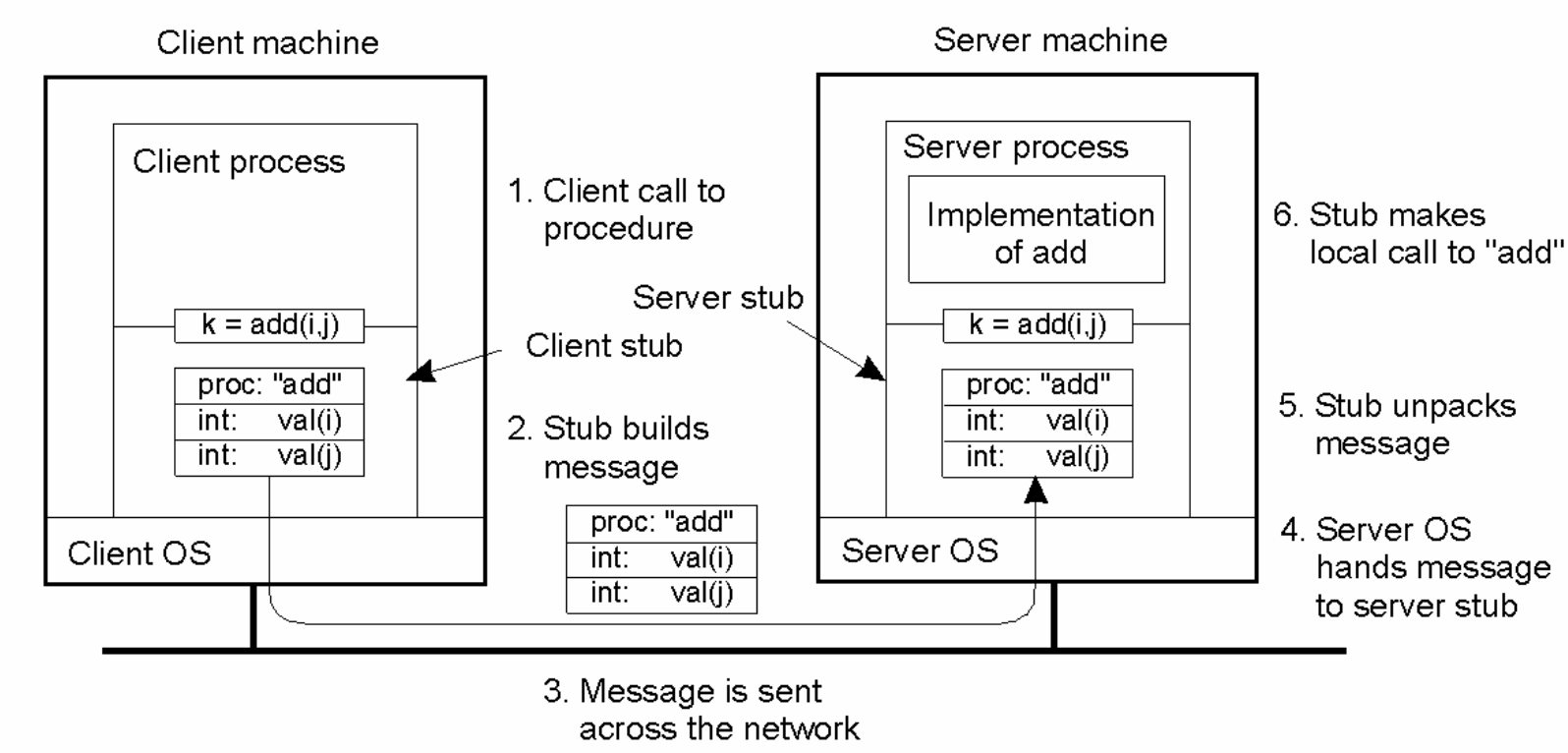
- Natural unit of encapsulation for concurrency
  - combines functionality and message passing!

Remote Procedure Call



- Issues
  - ‘translation’ of regular call into message passing
  - packing parameters and results
    - call by value, reference

Steps in calling an RPC

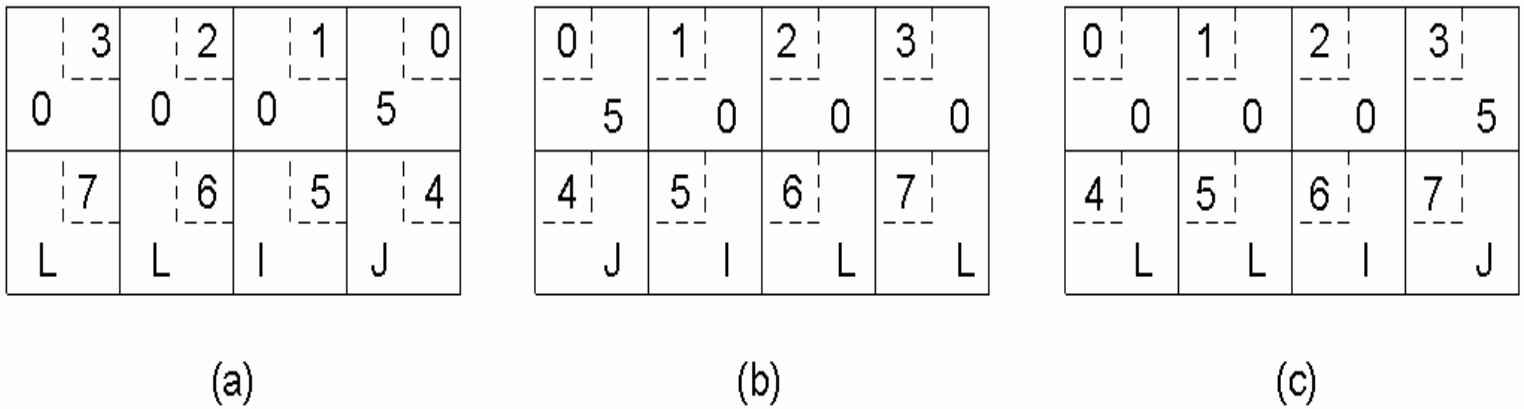


- Remark: *k* can be ignored in the call
  - or it should be treated as a reference parameter

Steps in calling an RPC

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

Need for Marshaling



a) Original message on the Pentium

b) The message after receipt on the SPARC

c) The message after being inverted. The little numbers in boxes indicate the address of each byte

Parameter Specification and Stub Generation

a) A procedure
b) The corresponding message.

```
foobar( char x; float y; int z[5] )
{
   ....
}
```

(a)

foobar's local variables	
	x
y	
5	
z[0]	
z[1]	
z[2]	
z[3]	
z[4]	

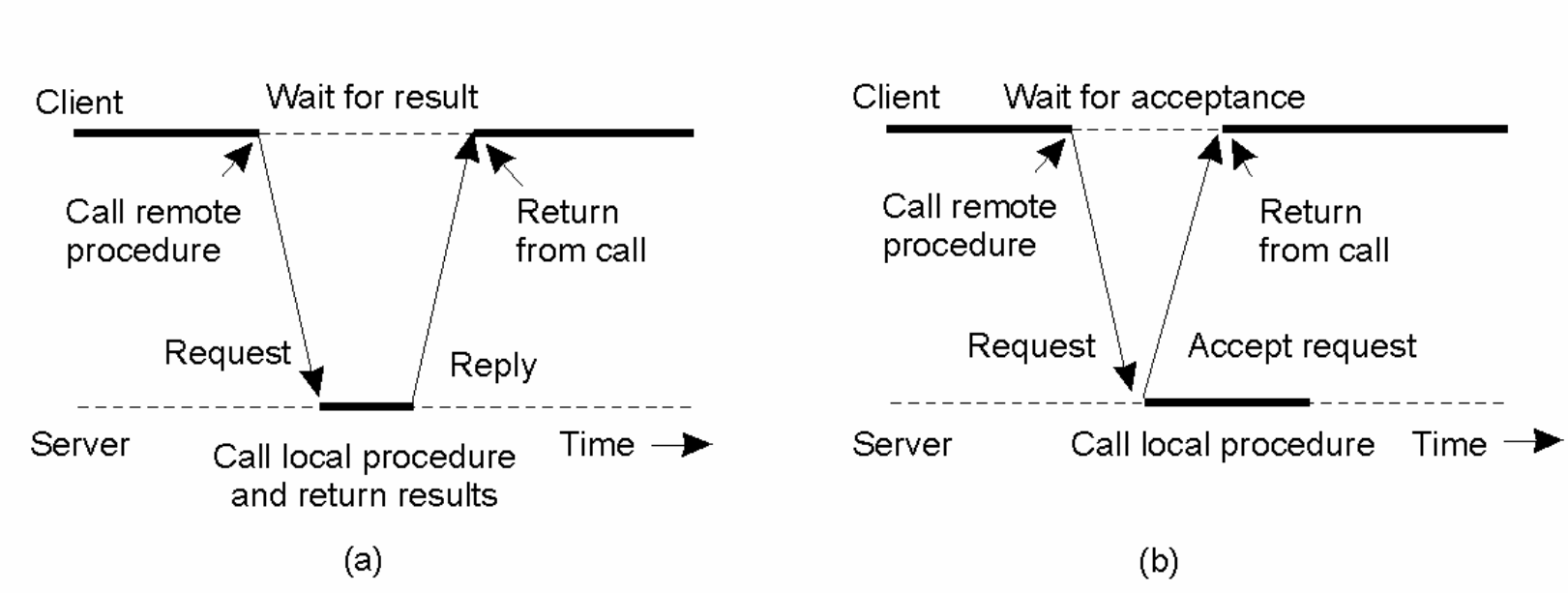
(b)

RPC parameter passing

- Usually, value/result semantics
  - no assumptions *during* the call
  - no reference parameters, no statics
  - ...lack of transparency

- Include reference parameters
  - need remote reference mechanism
  - ....just another RPC?
  - or values of references parameters should be passed as well
    - concurrency? value/result?

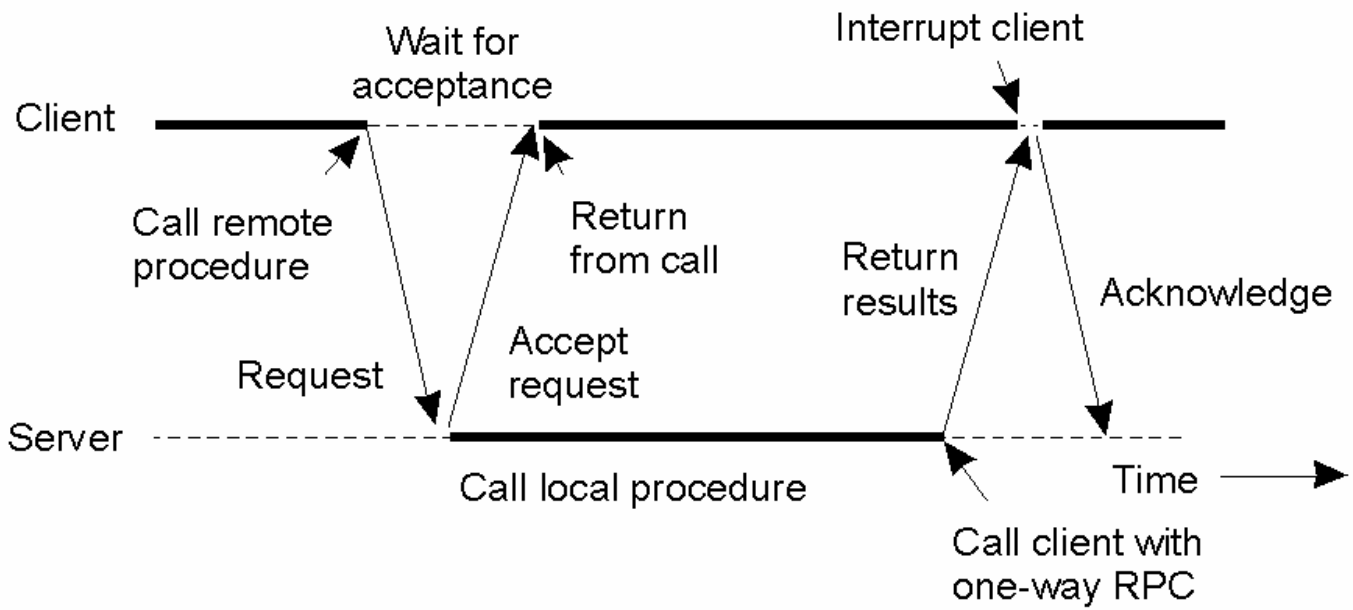
Asynchronous RPC (1)



a) Traditional RPC
b) Asynchronous RPC

Deferred synchronous RPC

- Basically, two asynchronous RPC's



Developing with RPC's

- Stubs and descriptions generated automatically
- Just focus on application development

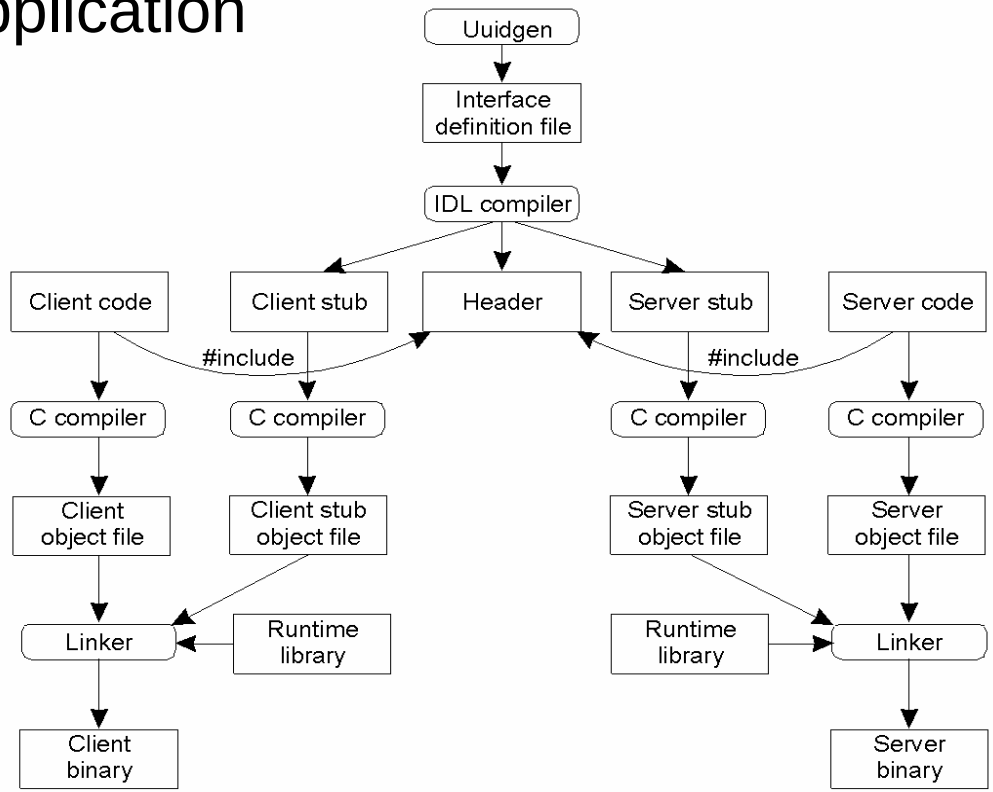
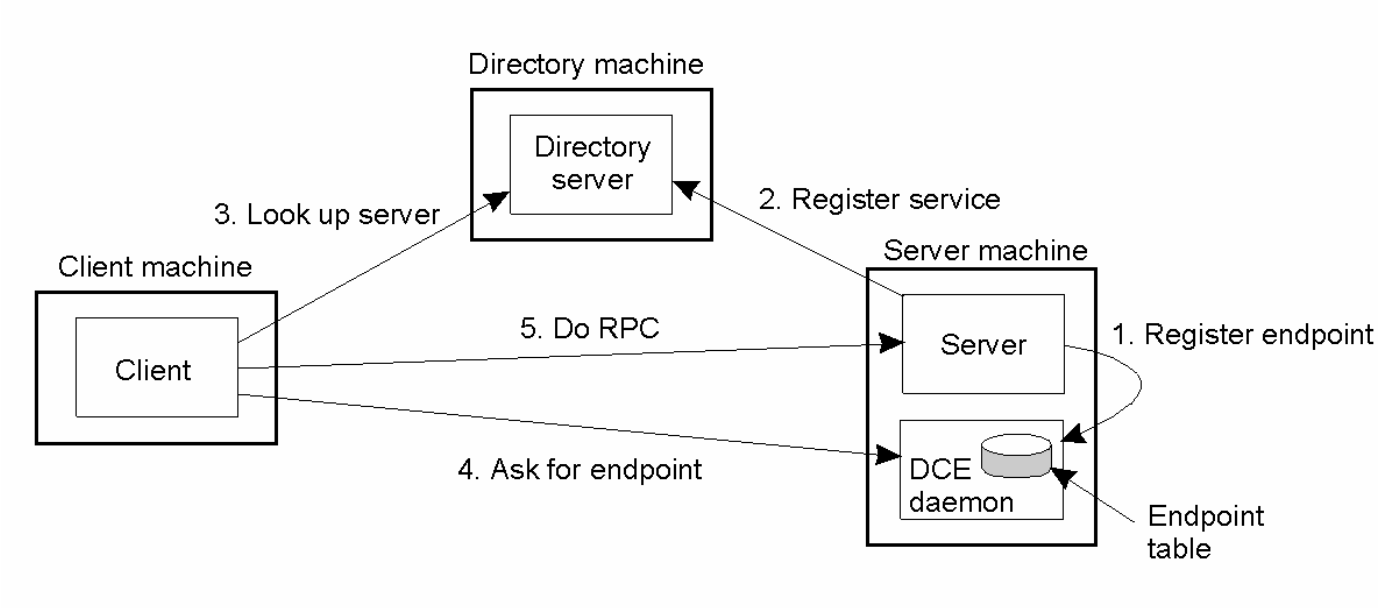


Figure: DCE process

Example: DCE

- Distributed Computing Environment



- Needs discovery facilities
  - endpoint: place to send messages
  - at directory: server's address

Communication

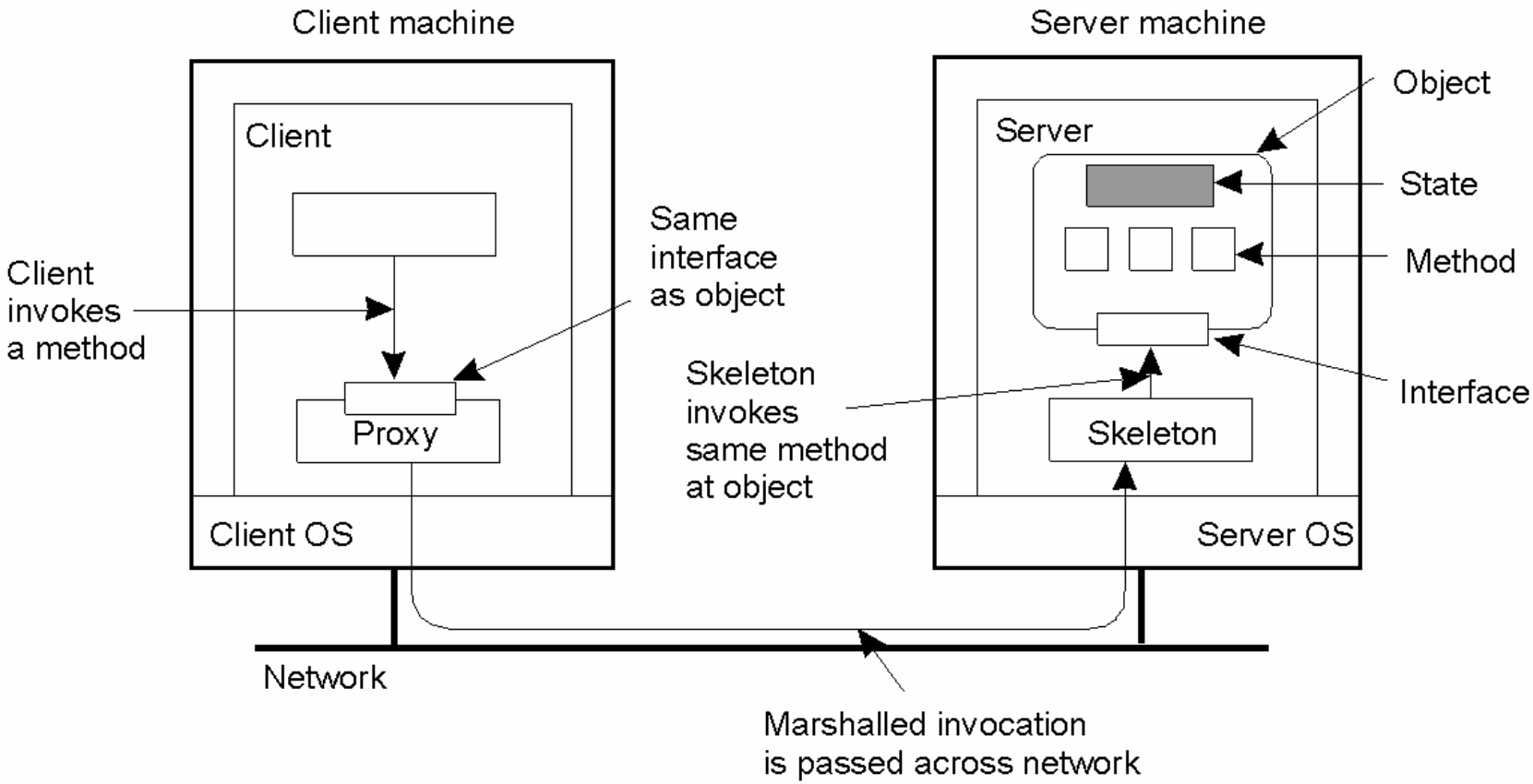
- Some concepts and definitions
- Layered protocols
- Remote Procedure Calls
- Remote Method Invocation
- Message oriented communication
- Stream oriented

Distributed Objects

- Compile-time – static, closed approach
  - language fixed
  - automatically generated stubs, proxies etc.
- Run-time – dynamic, open
  - any language, any application can be an object
  - need “object adapters” to find/bind interface
  - focus on “access protocol”

- Transient
  - die with server (e.g., the shopping cart)
- Persistent
  - remain (passively) available

Using Remote Objects



often: process/thread per object

Binding a Client to an Object

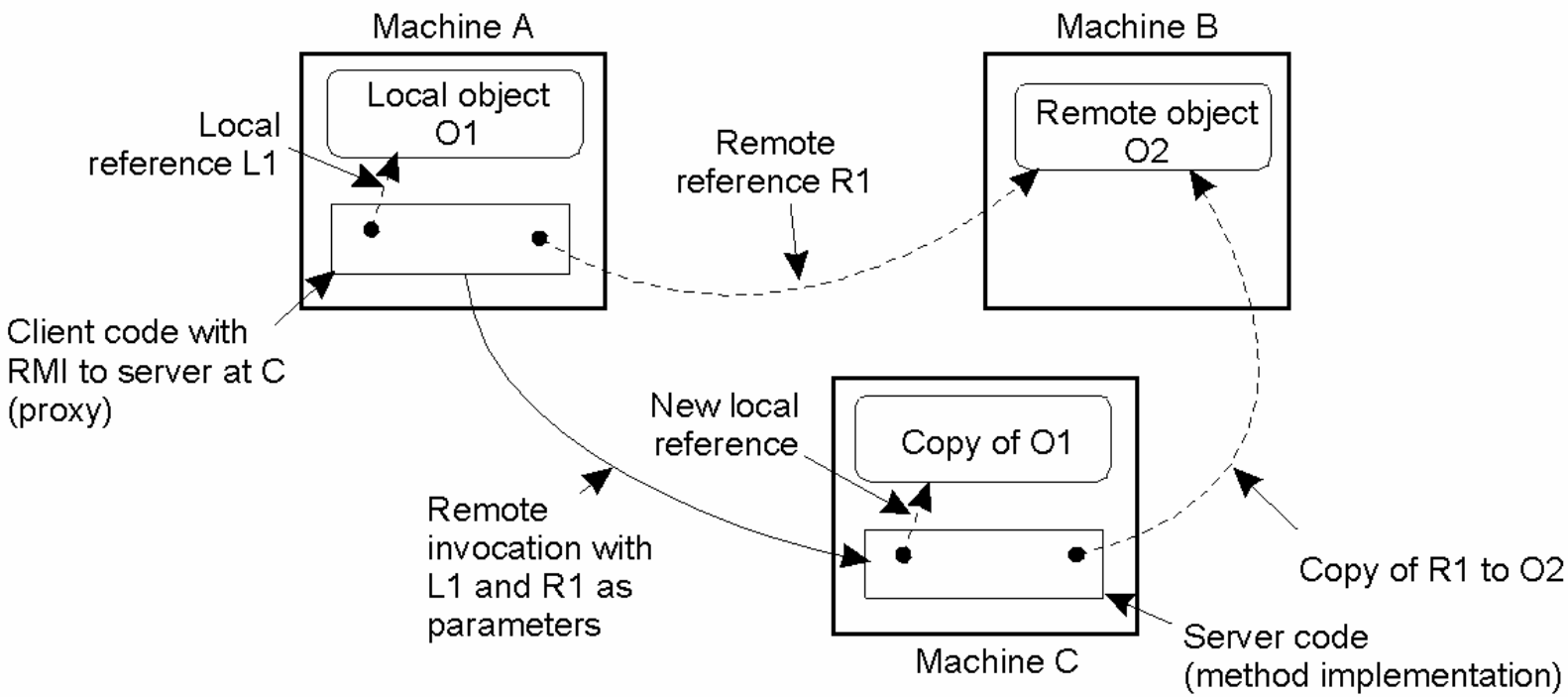
- Binding: ‘get a reference to work’
  - download stub code (platform?) or create proxy
  - bind explicitly or implicitly
    - followed by static or dynamic invocation
      - dynamic: ***invoke*** *(object ref, method name, parameters) [no knowledge at language level]*
  - identification by pair (server, object)

- Can use object references easily in this way
  - object server becomes client for object references sent as parameters

- Value parameters
  - need to serialize object
  - difficult across platforms

Parameter Passing

- *RMI (C, obj.method (L1, R1))*



Communication

- Some concepts and definitions
- Layered protocols
- Remote Procedure Calls
- Remote Method Invocation
- Message oriented communication
- Stream oriented

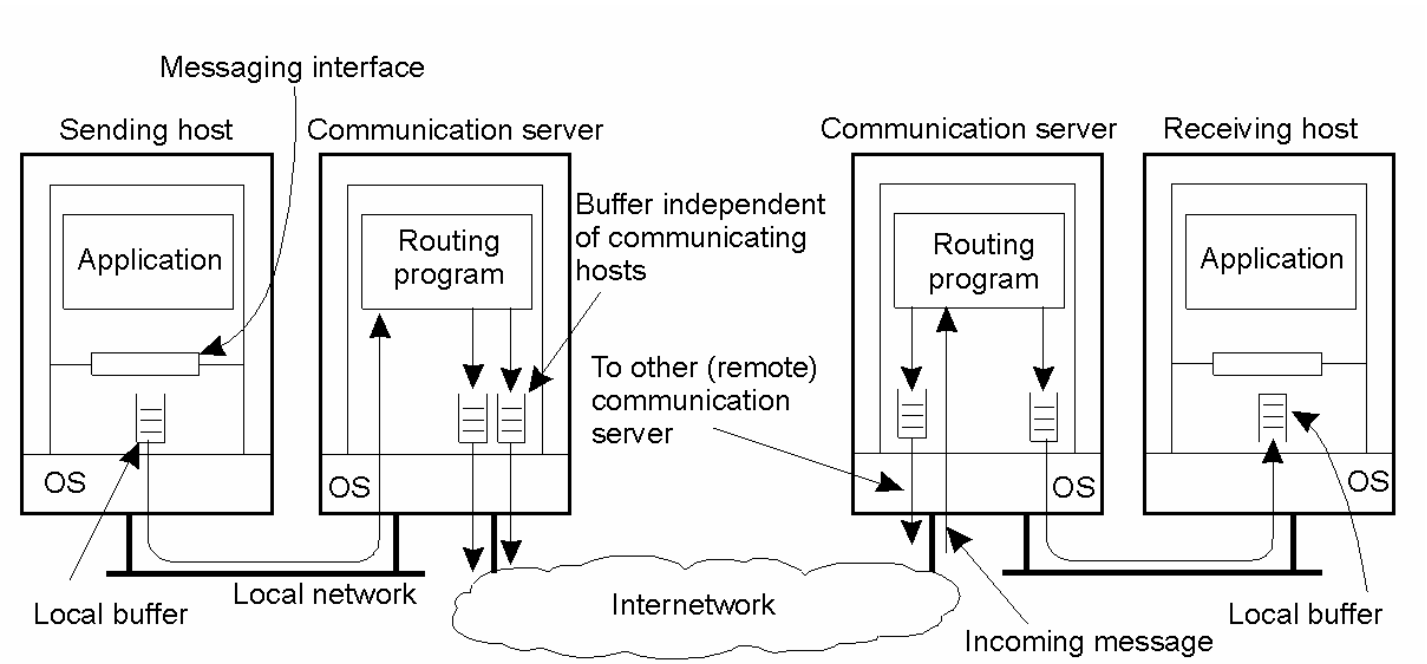
Observations

- RPC & RMI rather synchronous
  - in time: wait for reply
  - in space: shared data is known
    - though not all machines need all objects; better than a single database
  - functionality and communication coupled

- Look for communication models with better decoupling
  - message oriented – communication and functionality separated
    - more abstract? or more basic?

General networked organization

- Communication subsystem (e.g. email)
  - Asynchronous/synchronous
  - Transient/persistent

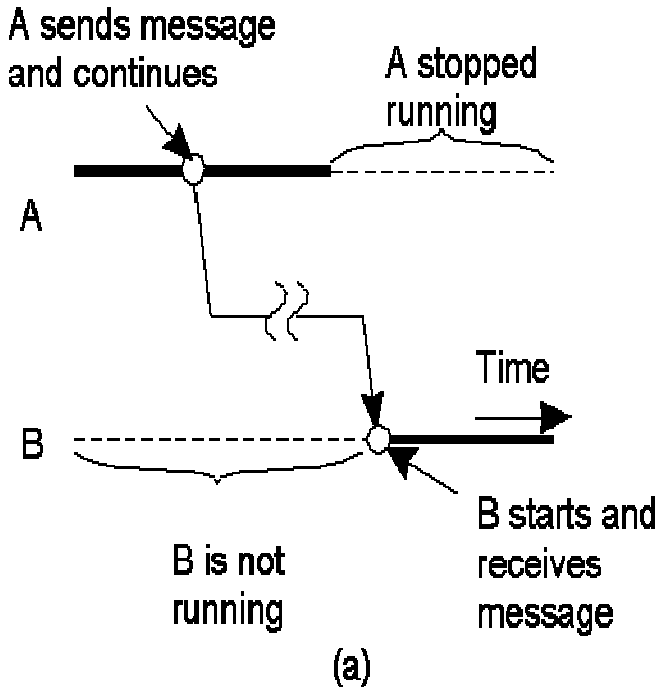


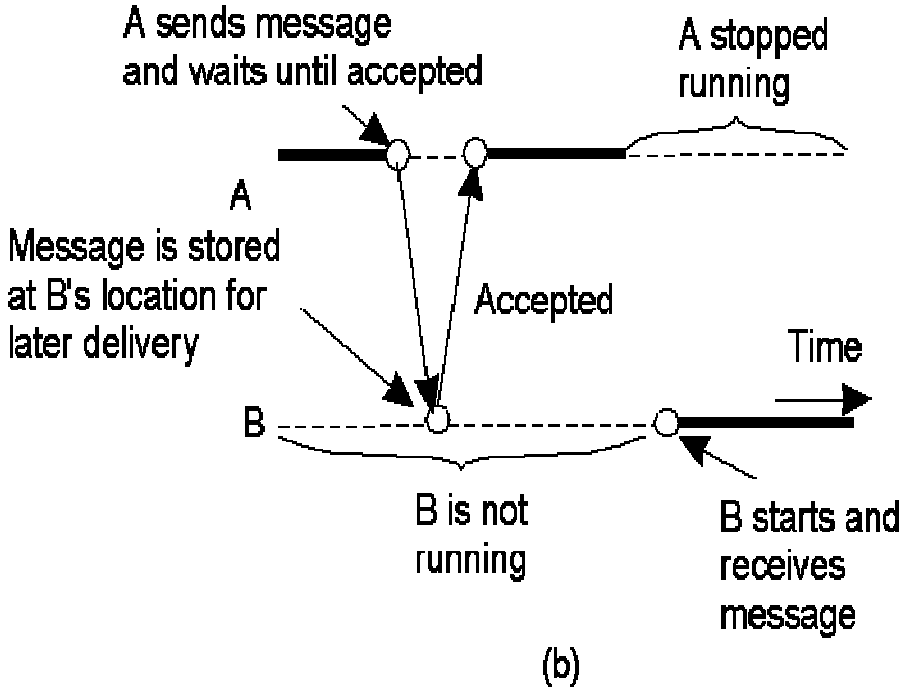
Combinations

a) Persistent asynchronous communication

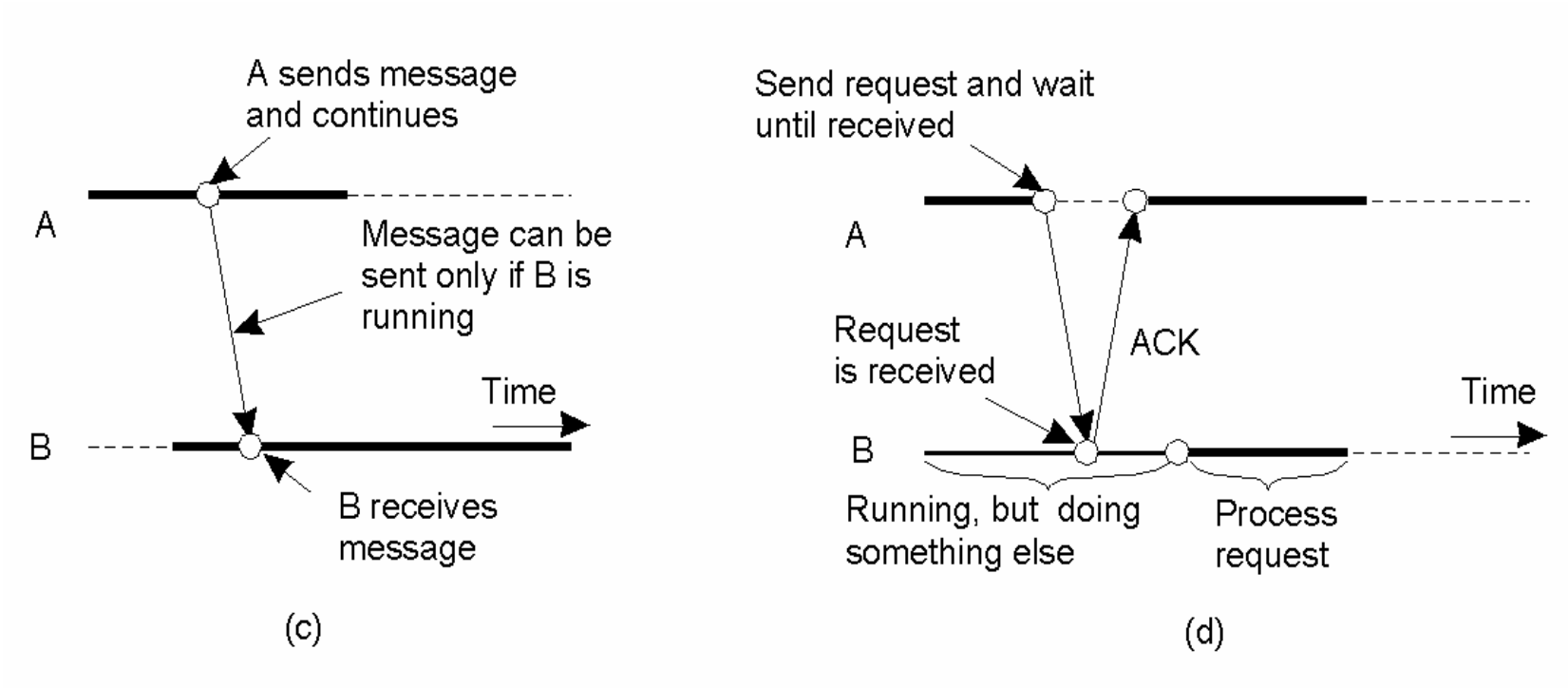
b) Persistent synchronous communication

- though debatable whether B should accept first





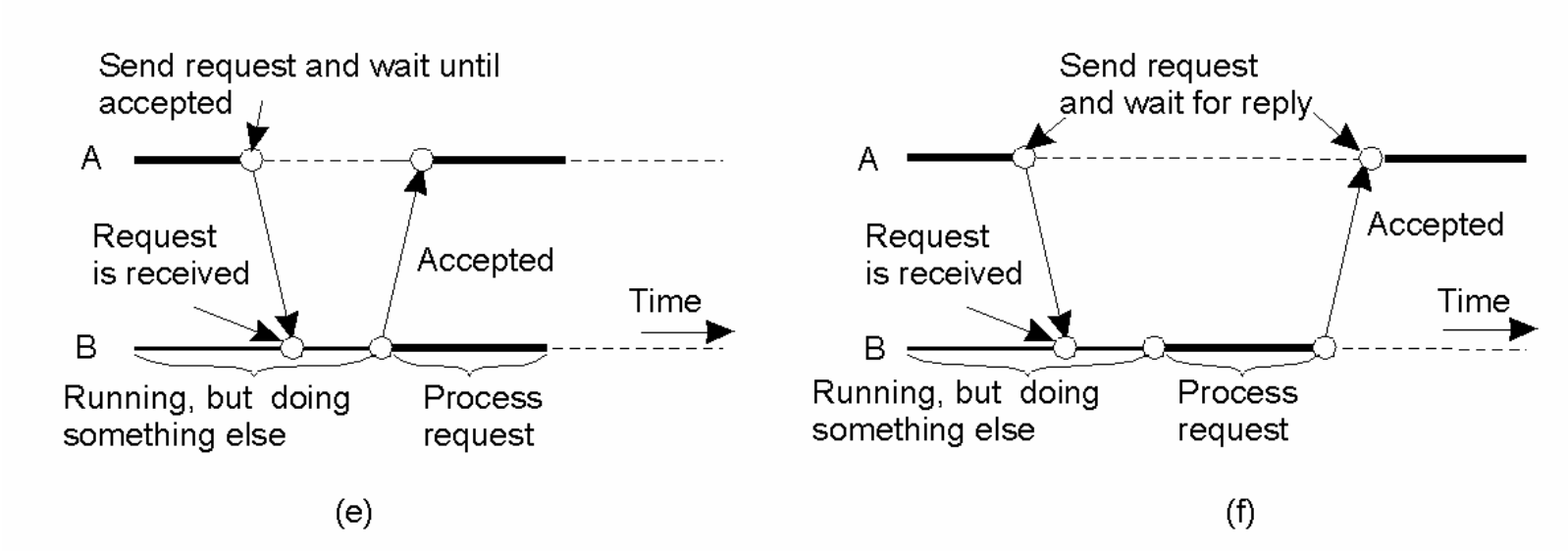
Other combinations



c) Transient asynchronous communication

d) Receipt-based transient synchronous communication

Combinations (cnt'd)



e) Delivery-based transient synchronous communication at message delivery

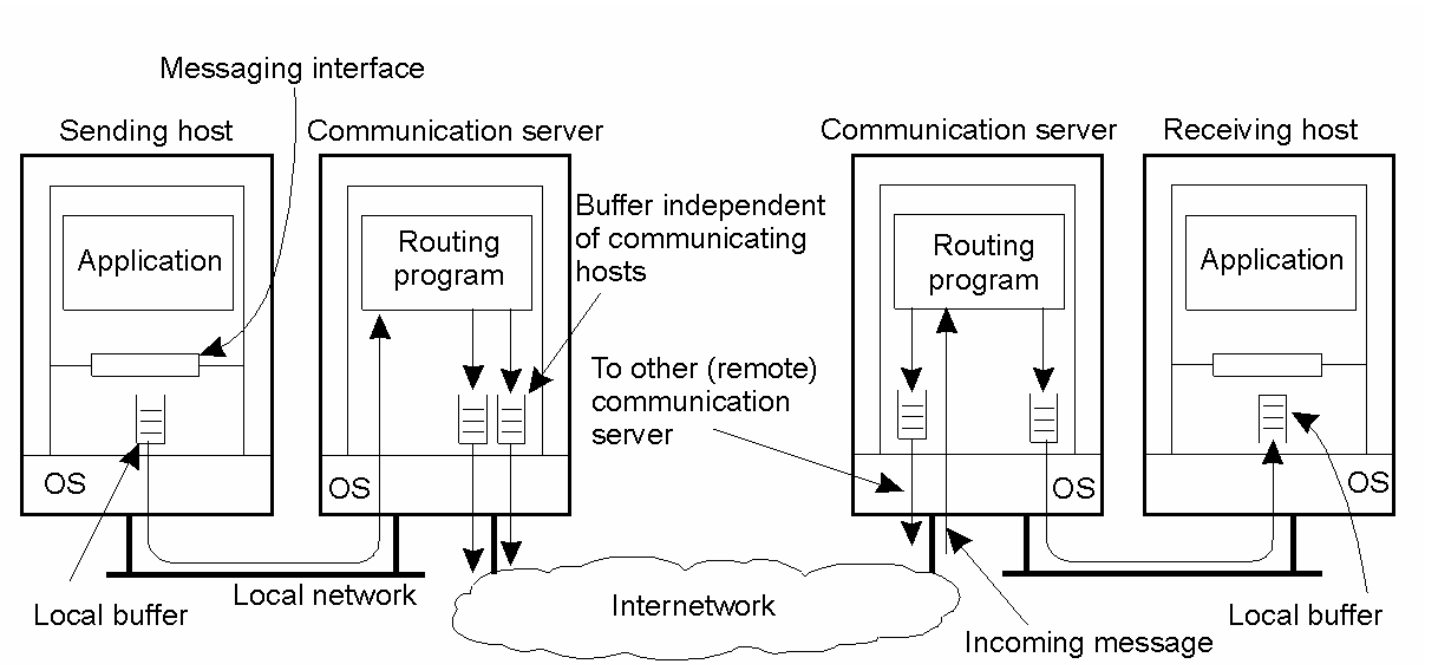
f) Response-based transient synchronous communication

Question

- Example of
  a) email
  b) email with notification
  c) datagram services (e.g. UDP)
  d) asynchronous RPC
  e) asynchronous RPC
  f) synchronous RPC

Message oriented systems

- Typical: asynchronous
- Small: transient
- Scaling: persistent



Examples

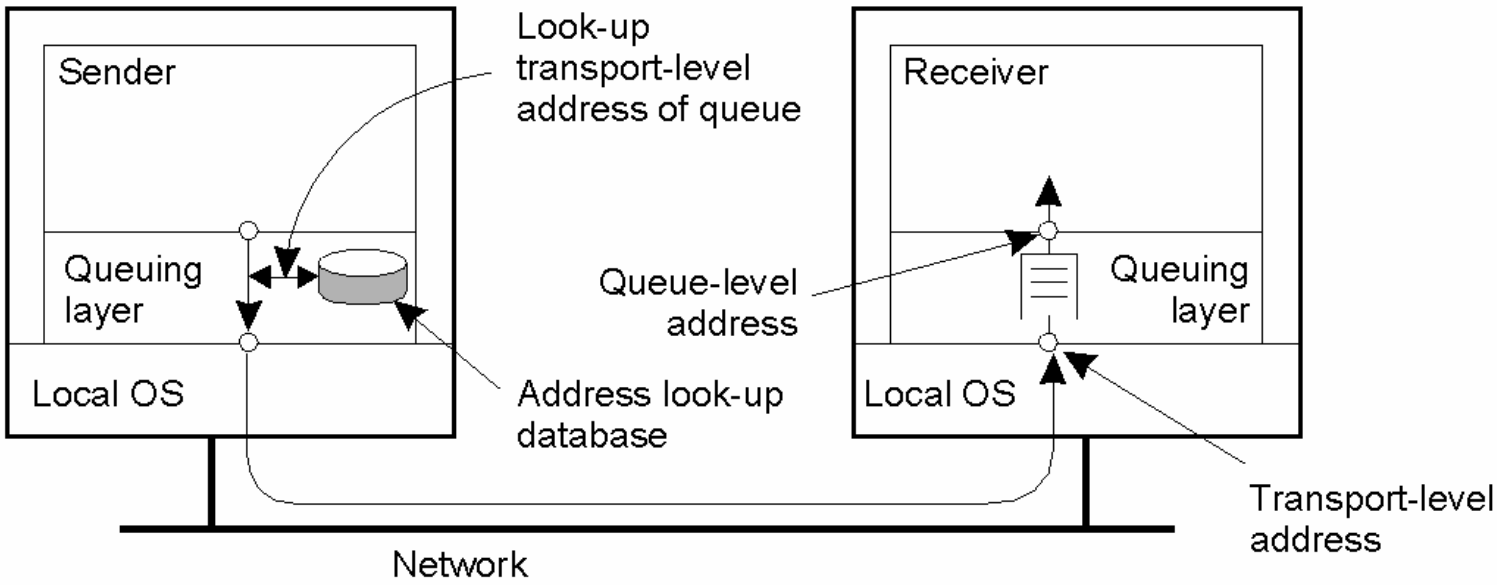
- Message queueing systems
  - persistent, asynchronous
  - e.g. IBM MQseries (Tanenbaum & van Steen)
- Java Message Service
  - transient?, asynchronous
- MPI: message passing interface
  - high-performance computing
  - transient, optional: (a)synchronous

The Message-Passing Interface

Primitive	Meaning
MPI_bsend	Append outgoing message to a local send buffer
MPI_send	Send a message and wait until copied to local or remote buffer
MPI_ssend	Send a message and wait until receipt starts
MPI_sendrecv	Send a message and wait for reply
MPI_isend	Pass reference to outgoing message, and continue
MPI_issend	Pass reference to outgoing message, and wait until receipt starts
MPI_recv	Receive a message; block if there are none
MPI_irecv	Check if there is an incoming message, but do not block

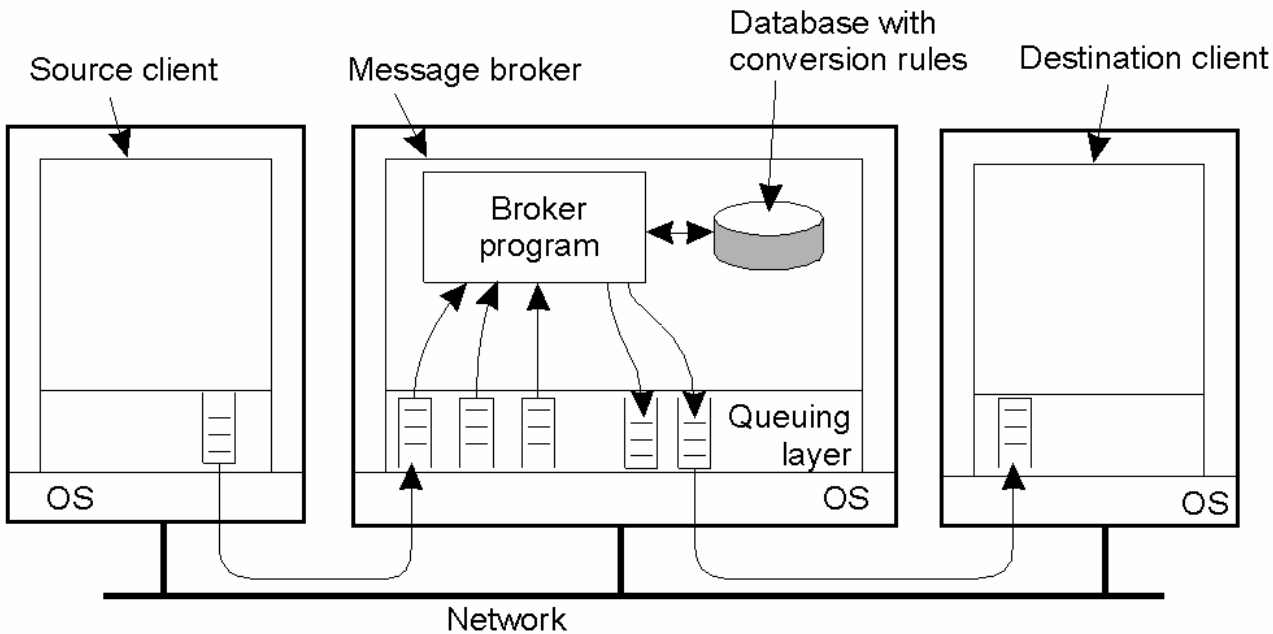
General Architecture of queuing systems

- Use logical names for source and destination queues
  - queue manager in overlay network (relay/routing)
  - need to map names to addresses



Message Brokers

- Conversion may be needed: no common format
- Broker: intermediate between source and destination

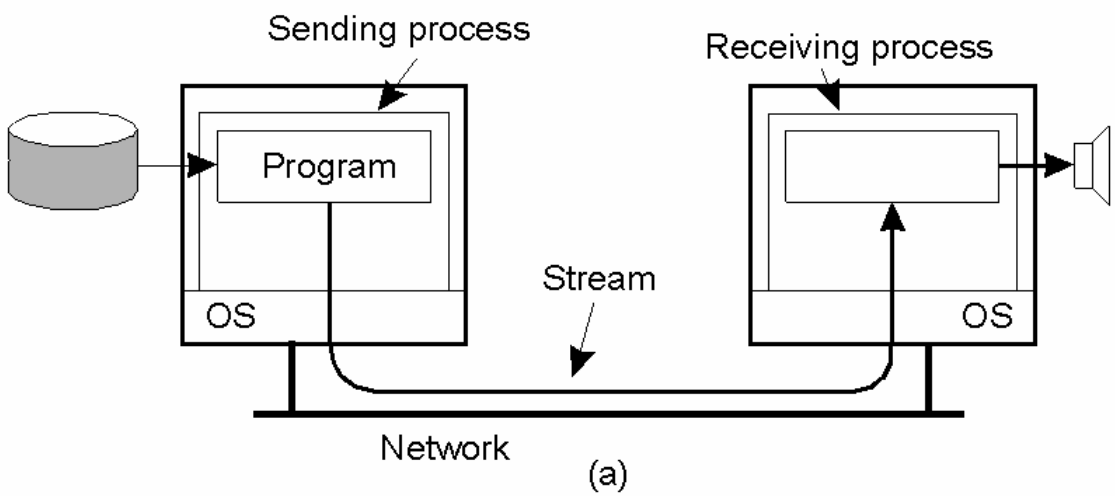


Communication

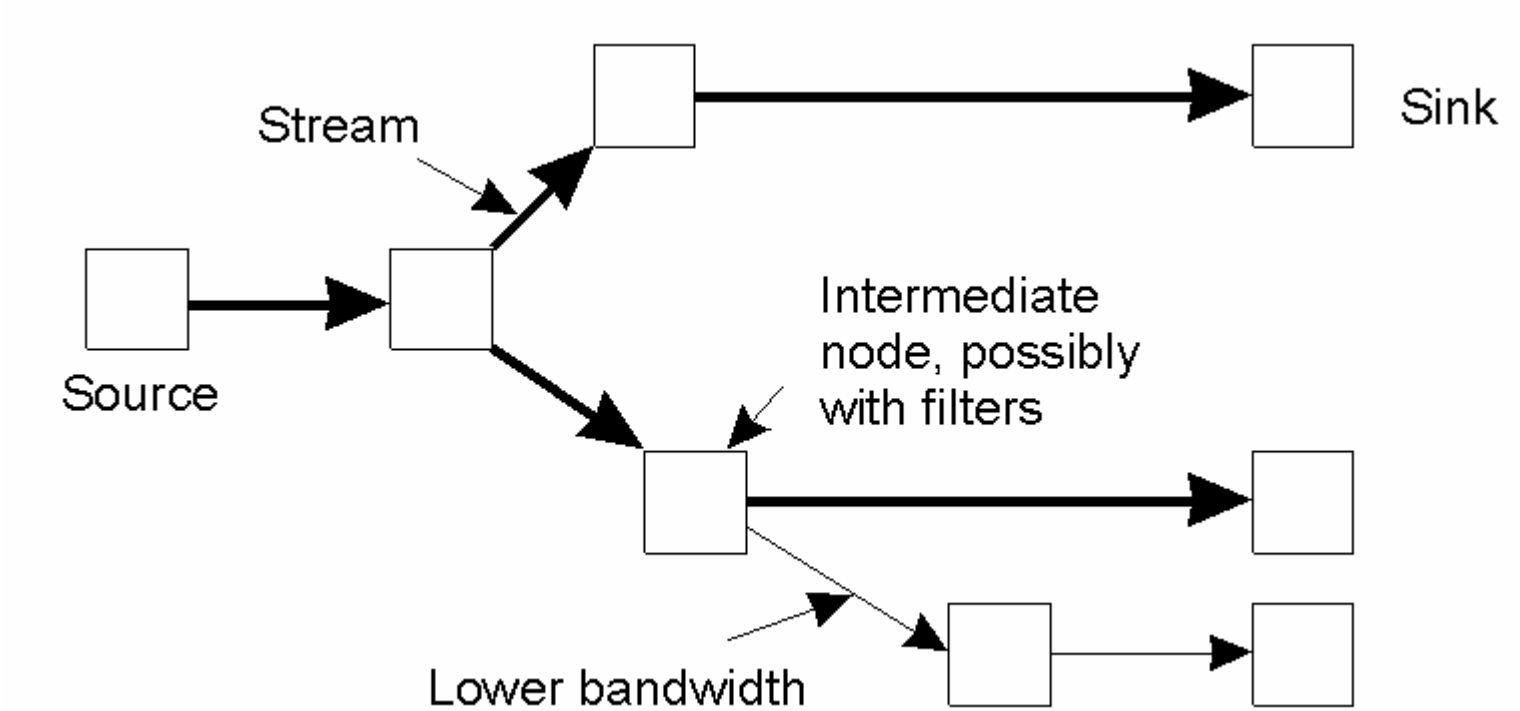
- Some concepts and definitions
- Layered protocols
- Remote Procedure Calls
- Remote Method Invocation
- Message oriented communication
- Stream oriented

Streams

- Stream: no imposed message structure
  - `continuous' media, e.g. multimedia
  - single source, multiple sinks
  - usually: timing requirements
  - e.g. sockets



Multicast & transcoding



Timing requirements

- Bounded delay
  - end-to-end
- Bounded interpacket delays
  - minimum & maximum: jitter – isochronous
- Soft (firm) real-time
  - missing a packet is a pity but no disaster
  - graceful reduction in quality

- General issue: *quality of service*
  - no discrete success/failure but a range of qualities, decided dynamically
  - is often end-to-end concern, points along the route must cooperate
  - RSVP: resource reservation protocol

Synchronization of streams

- discrete + continuous
  - e.g. slides + sound
- 2 continuous but different granularities
  - e.g. sound & video
- at sender
  - encode within stream
- at receiver
  - fairly difficult to control
    - e.g., video to desktop, sound to earphone

Example QoS specification

Characteristics of the Input	Service Required
• maximum data unit size (bytes) • Token bucket rate (bytes/sec) • Toke bucket size (bytes) • Maximum transmission rate (bytes/sec)	• Loss sensitivity (bytes) • Loss interval (μsec) • Burst loss sensitivity (data units) • Minimum delay noticed (μsec) • Maximum delay variation (μsec) • Quality of guarantee