Distributed Systems

Communication

Chapter 4

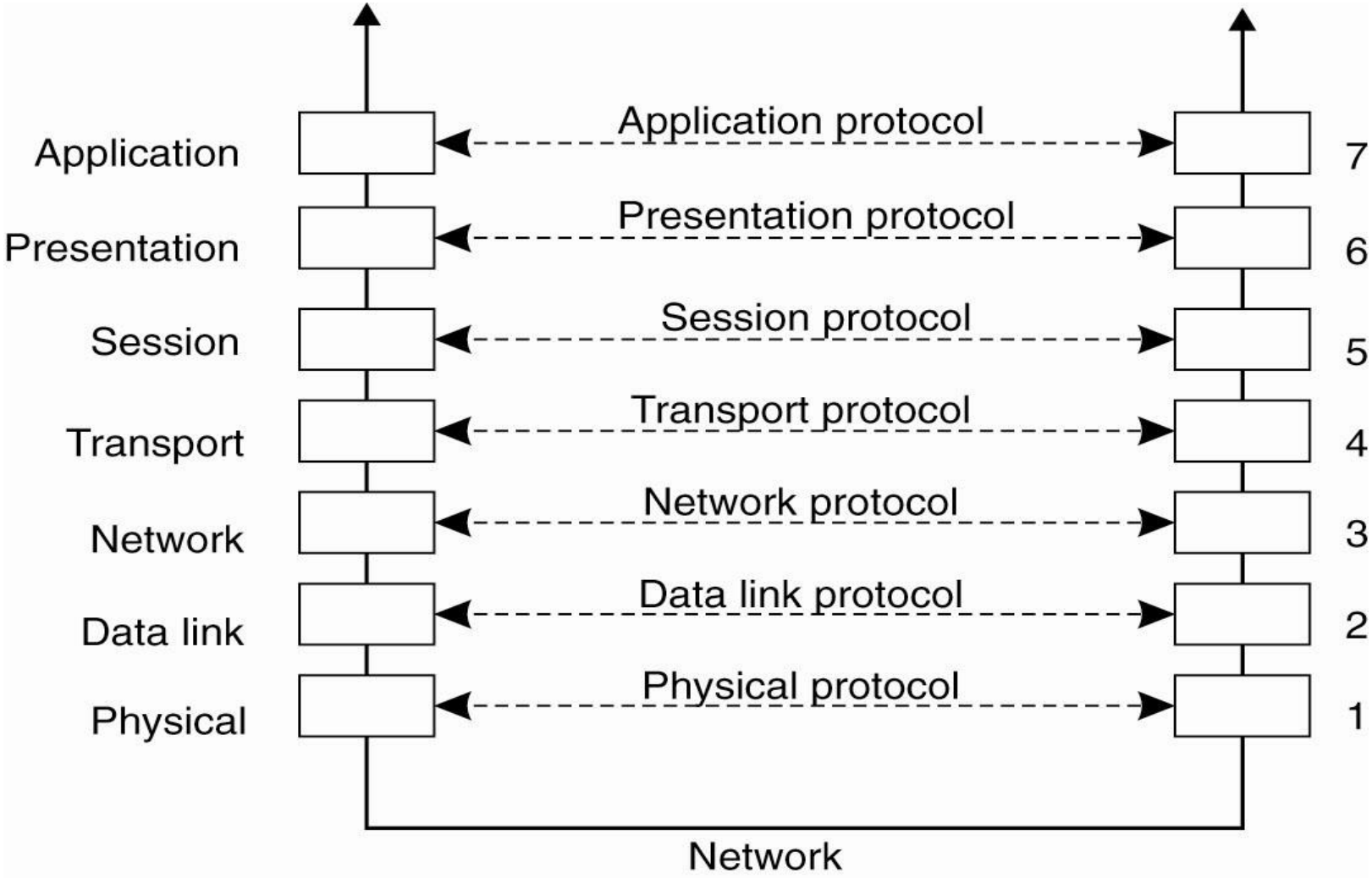
Course/Slides Credits

Note: all course presentations are based on those developed by Andrew S. Tanenbaum and Maarten van Steen. They accompany their "Distributed Systems: Principles and Paradigms" textbook (1st & 2nd editions). http://www.prenhall.com/divisions/esm/app/author_tanenbaum/custom/dist_sys_1e/index.html

And additions made by Paul Barry in course CW046-4: Distributed Systems

http://glasnost.itcarlow.ie/~barryp/net4.html

Layers, interfaces, and protocols in the OSI model



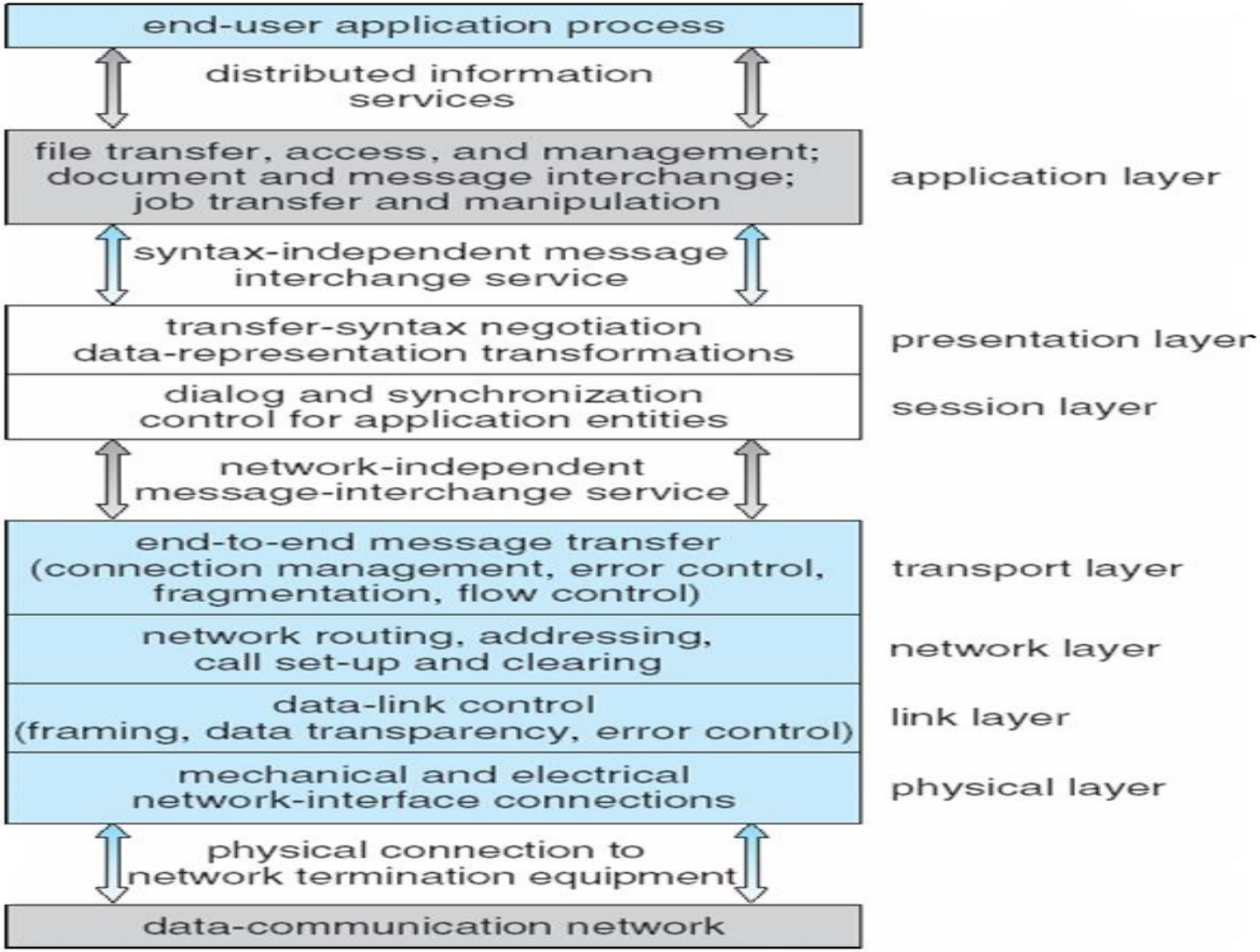
ISO Layers (1)

1. **Physical layer** – handles the mechanical/electrical details of the physical transmission of a bit stream.
2. **Data-link layer** – handles the *frames*, or fixed-length parts of packets, including any error detection and recovery that occurred in the physical layer.
3. **Network layer** – provides connections and routes packets in the communication network, including handling the address of outgoing packets, decoding the address of incoming packets, and maintaining routing information for proper response to changing load levels.

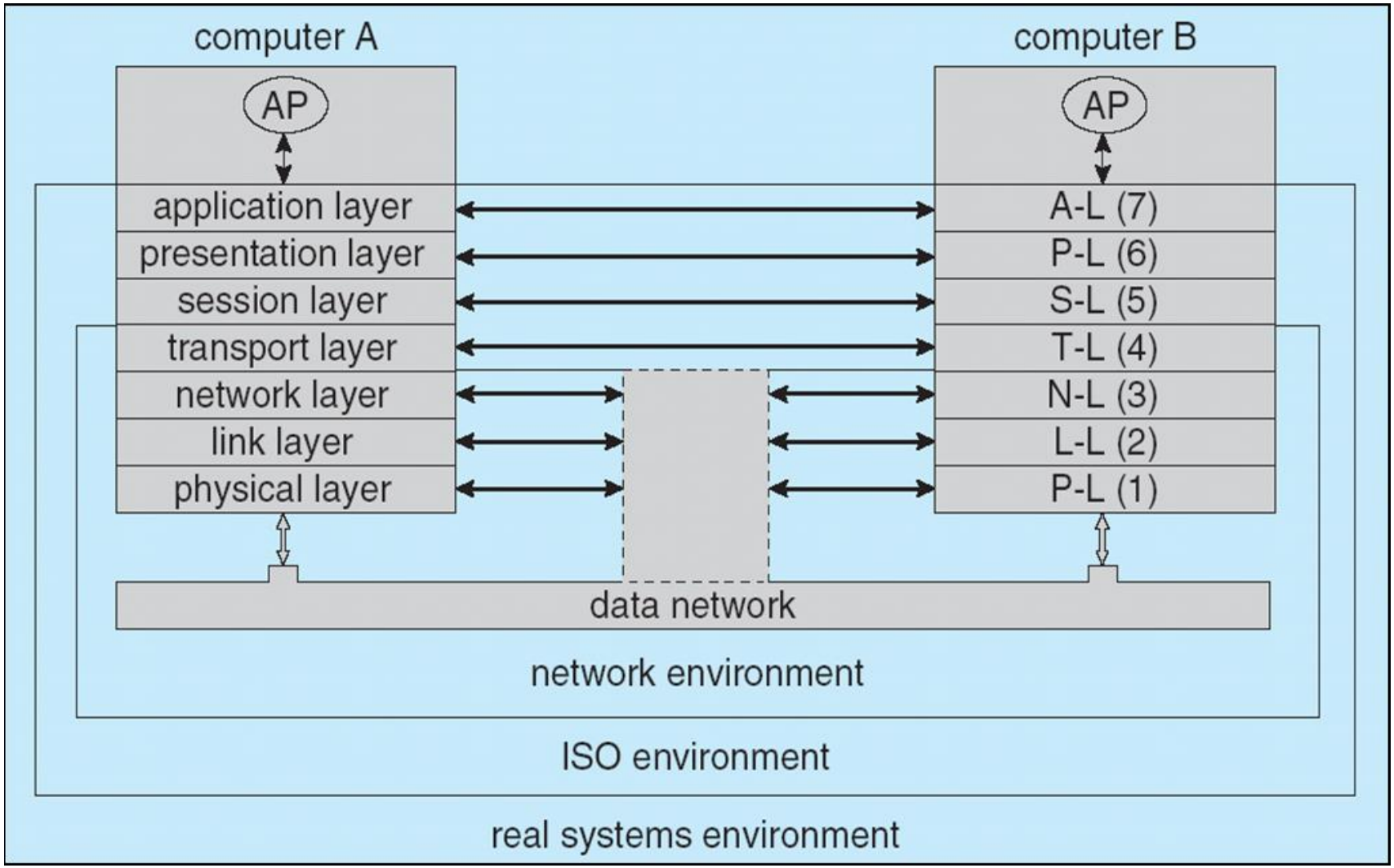
ISO Layers (2)

4. **Transport layer** – responsible for low-level network access and for message transfer between clients, including partitioning messages into packets, maintaining packet order, controlling flow, and generating physical addresses.
5. **Session layer** – implements sessions, or process-to-process communications protocols.
6. **Presentation layer** – resolves the differences in formats among the various sites in the network, including character conversions, and half duplex/full duplex (echoing).
7. **Application layer** – interacts directly with the users' deals with file transfer, remote-login protocols and electronic mail, as well as schemas for distributed databases.

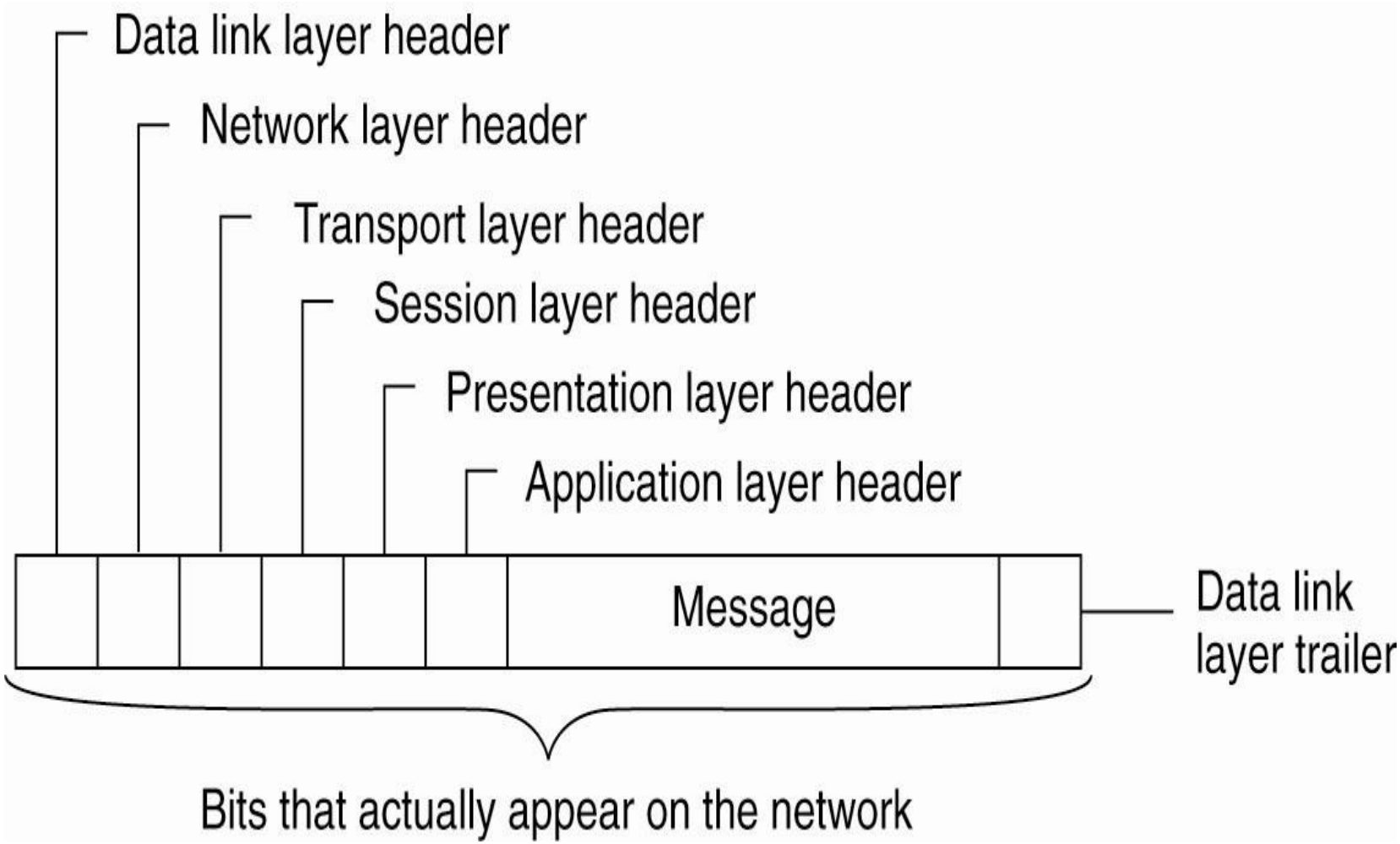
The ISO Protocol Layer



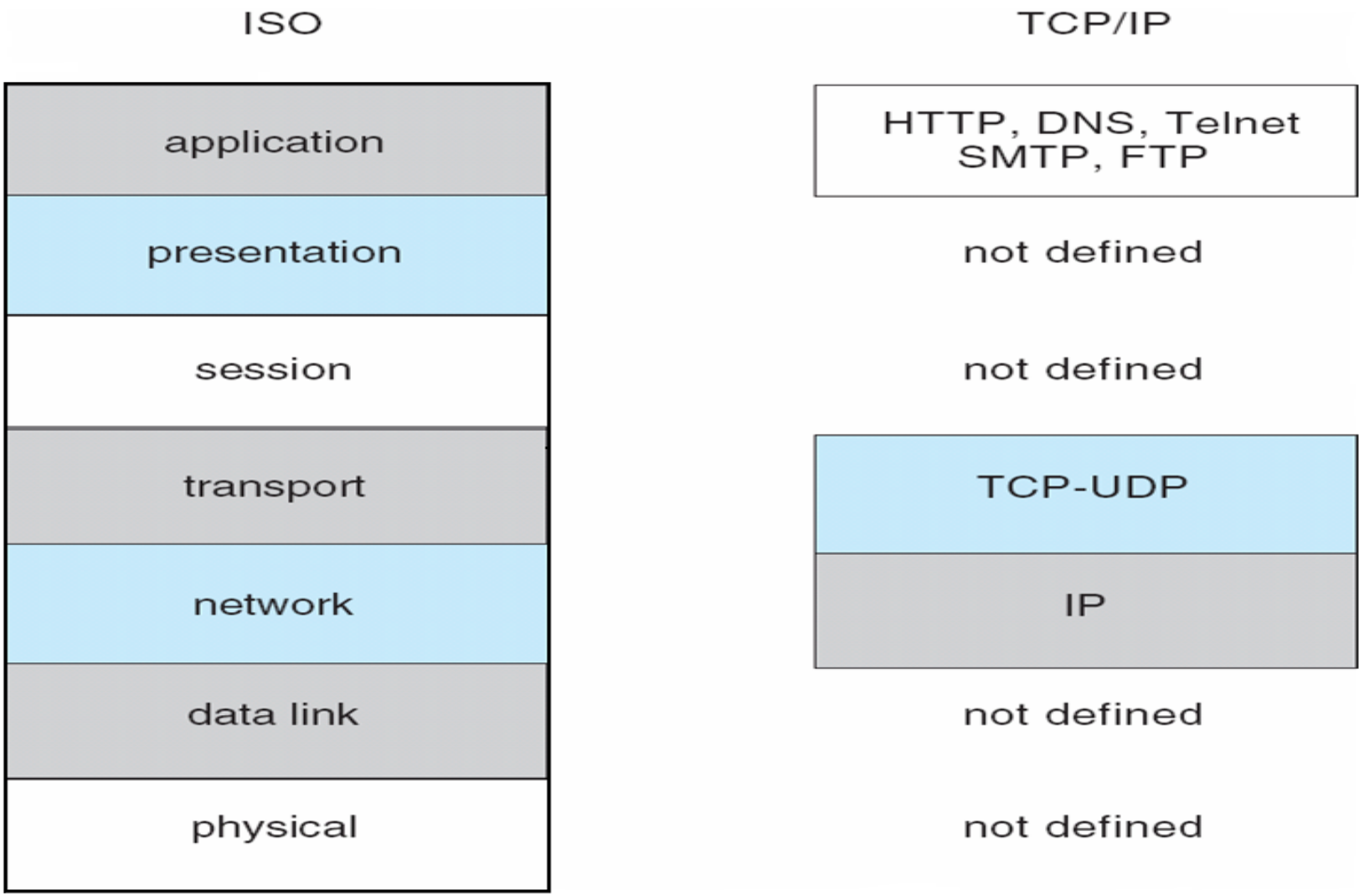
Communication via ISO Network Model



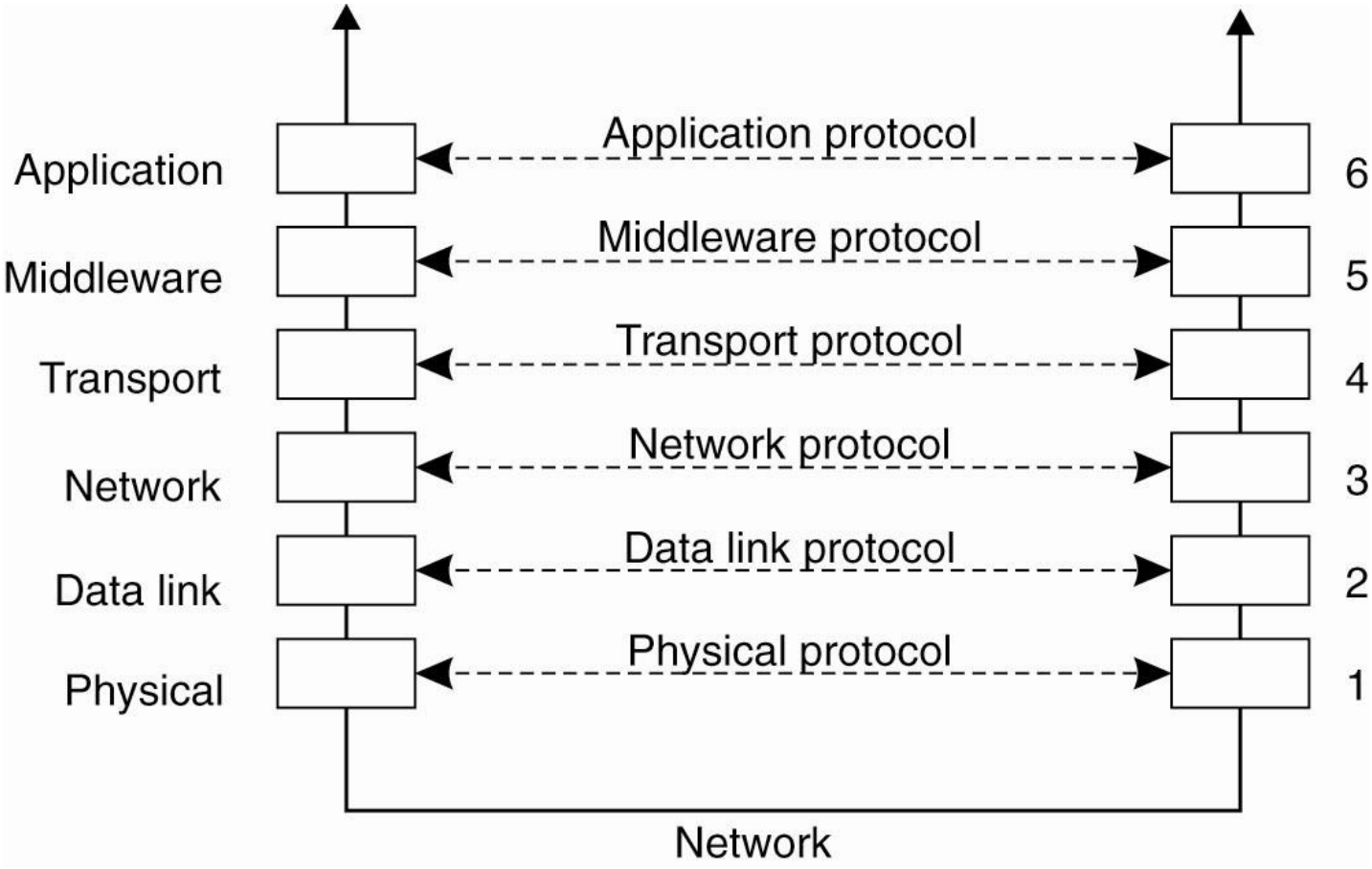
A typical message as it appears on the network



The TCP/IP Protocol Layers

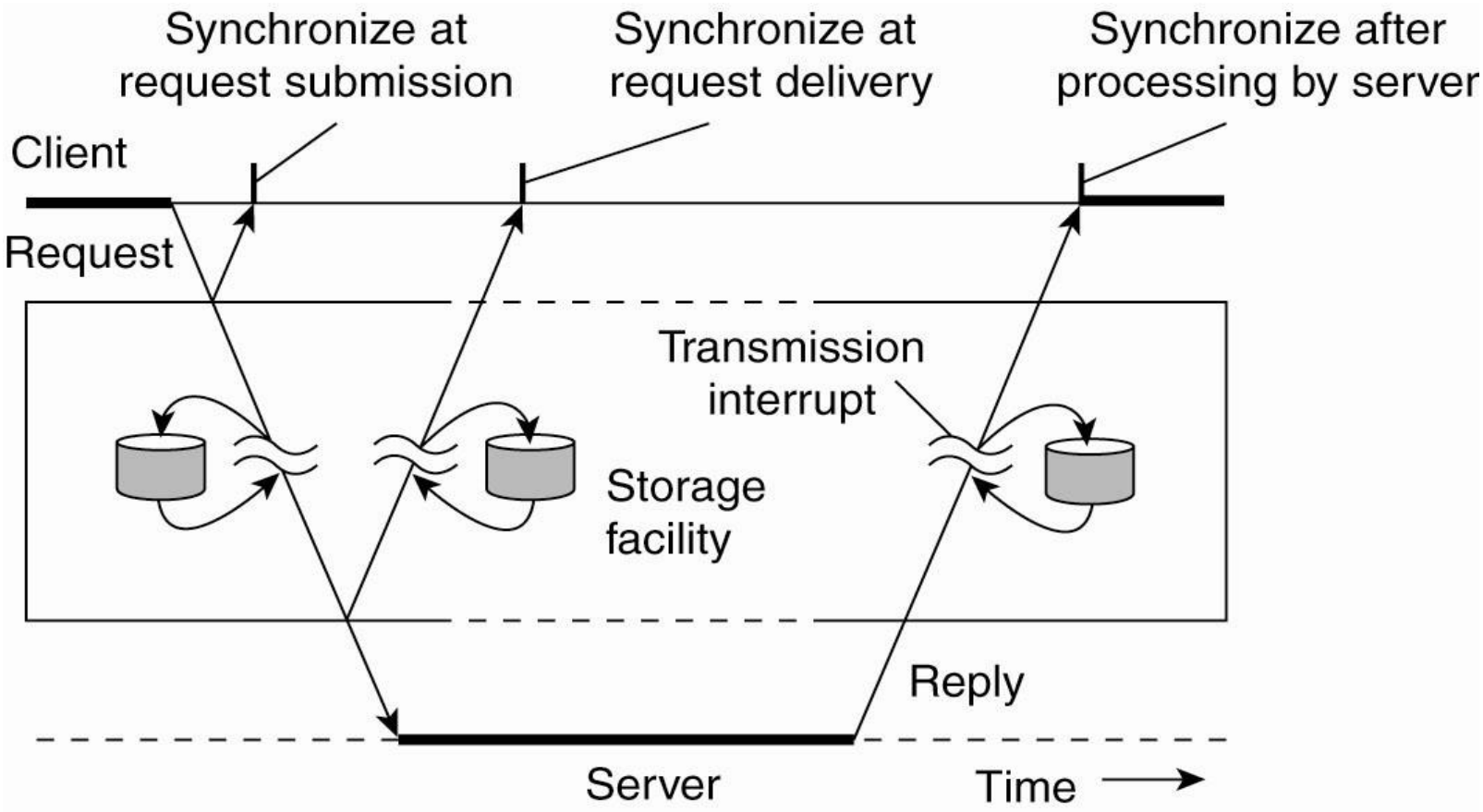


Middleware Protocols



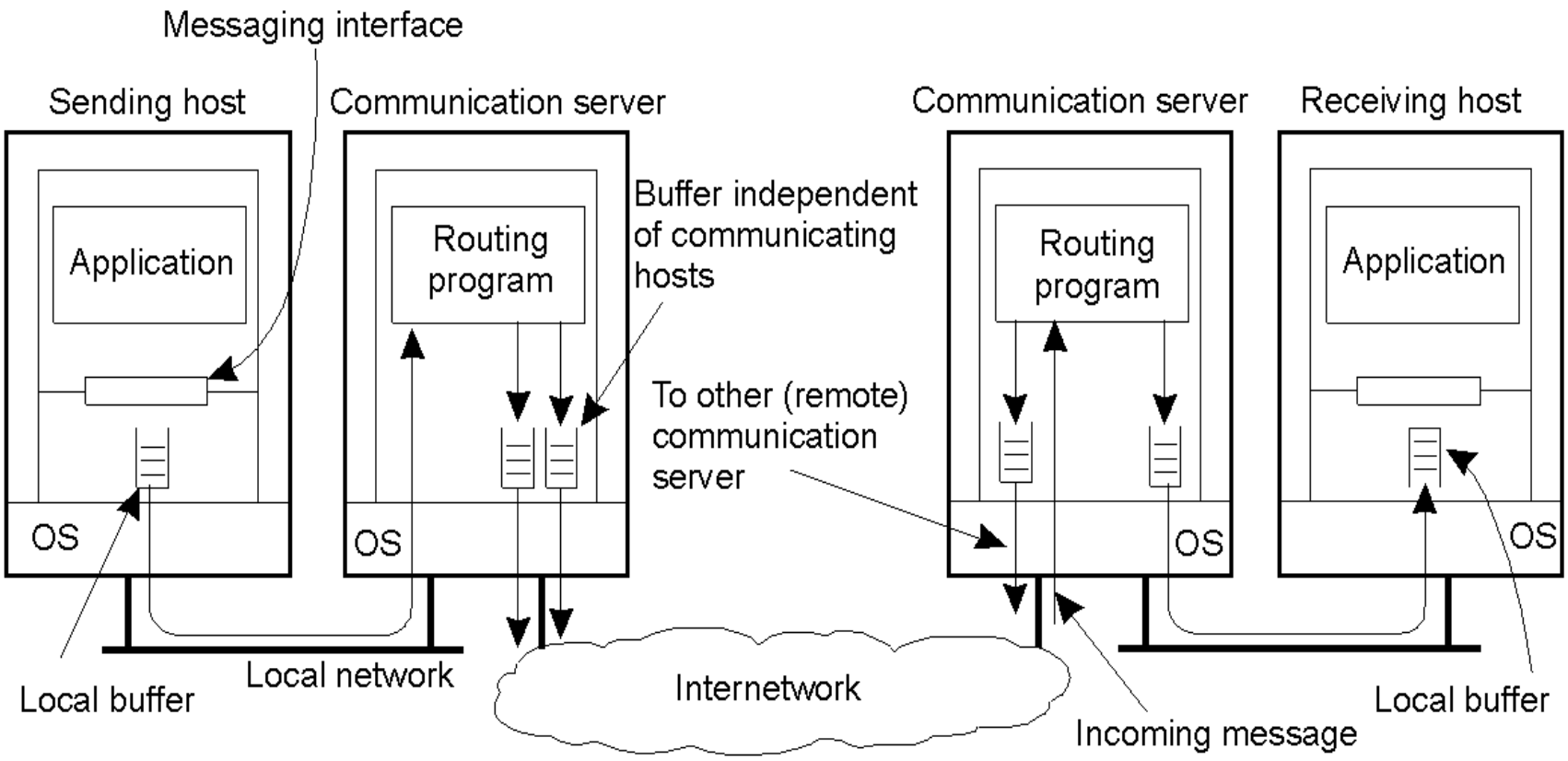
An adapted reference model for networked communication

Types of Communication



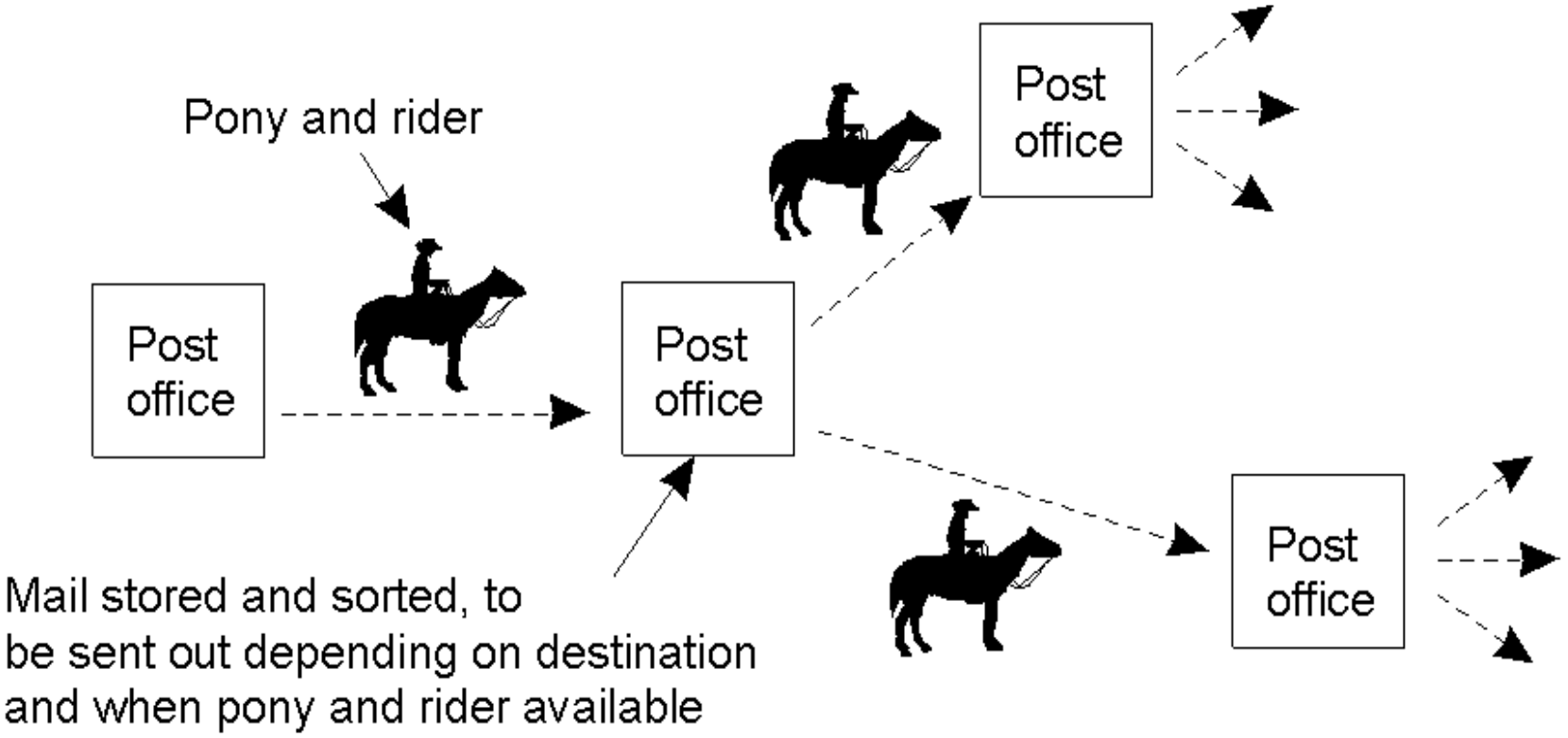
Viewing middleware as an intermediate (distributed) service in application-level communication

Persistence and Synchronicity in Communication (1)



General organization of a communication system in which hosts are connected through a network.

Persistence and Synchronicity in Communication (2)



Persistent communication of letters back in the days of the Pony Express.

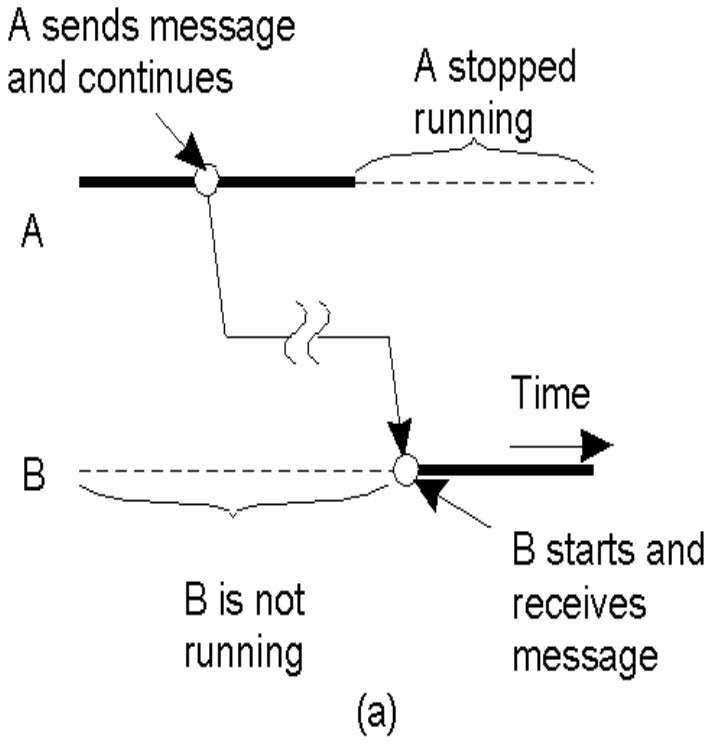
DS Communications Terminology (1)

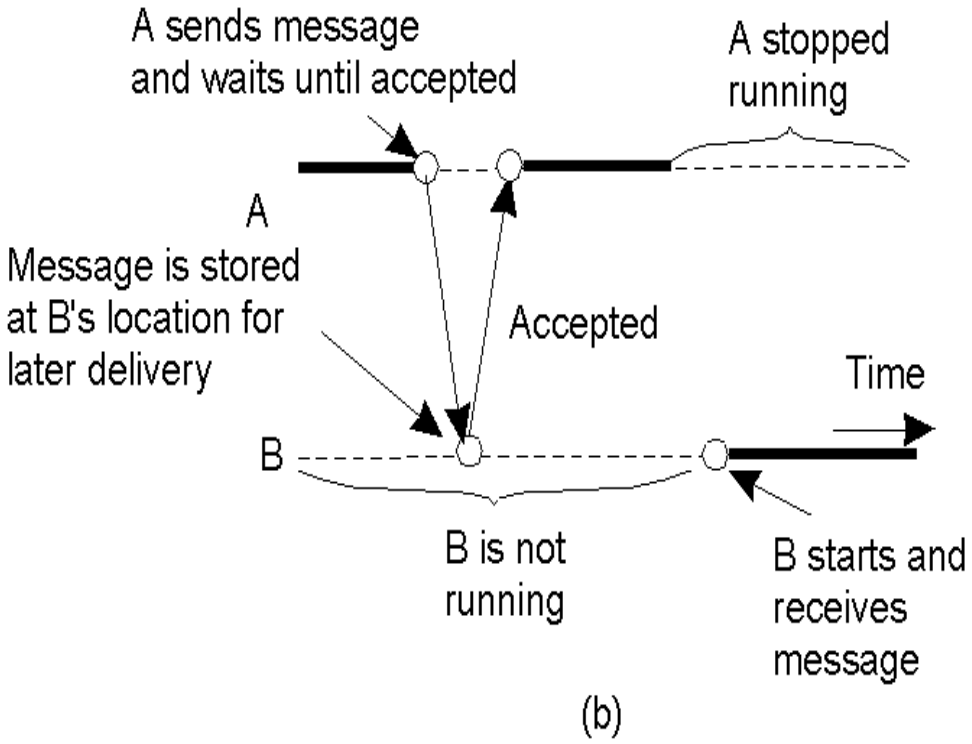
- *Persistent Communications:*
  - Once sent, the "sender" can stop executing. The "receiver" need not be operational at this time – the communications system **buffers** the message as required (until it can be delivered).
- *Transient Communications:*
  - The message is only stored as long as the "sender" and "receiver" are executing. If problems occur, the message is simply **discarded** …

DS Communications Terminology (2)

- *Asynchronous Communications:*
  - A sender **continues** with other work immediately upon sending a message to the receiver.
- *Synchronous Communications:*
  - A sender **blocks**, **waiting** for a reply from the receiver before doing any other work. (This tends to be the default model for RPC/RMI technologies).

Classifying Distributed Communications (1)

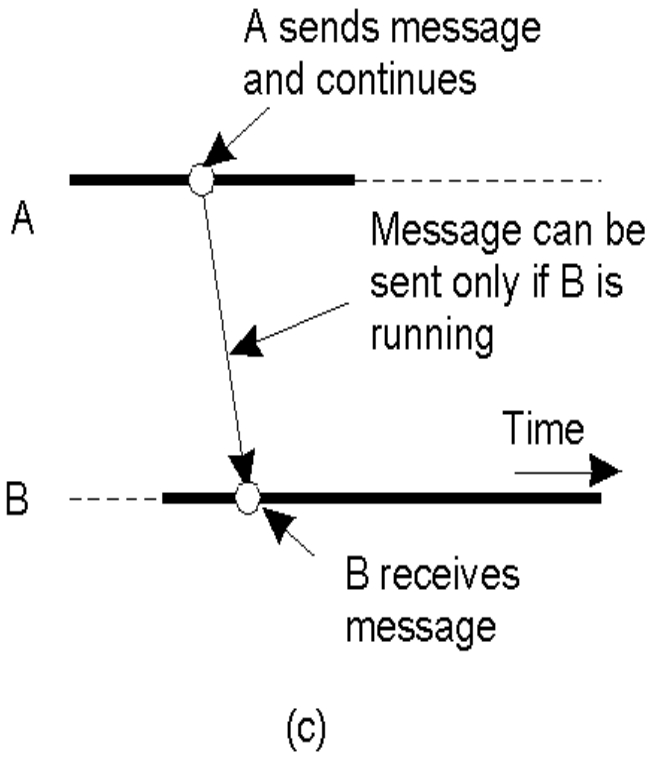


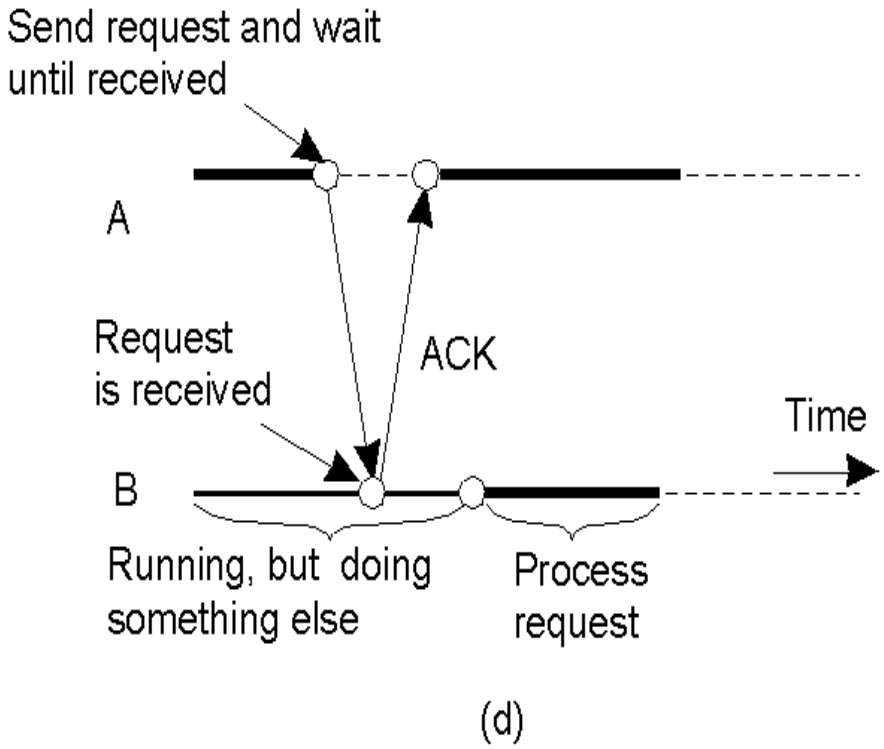


a) Persistent asynchronous communication.

b) Persistent synchronous communication.

Classifying Distributed Communications (2)

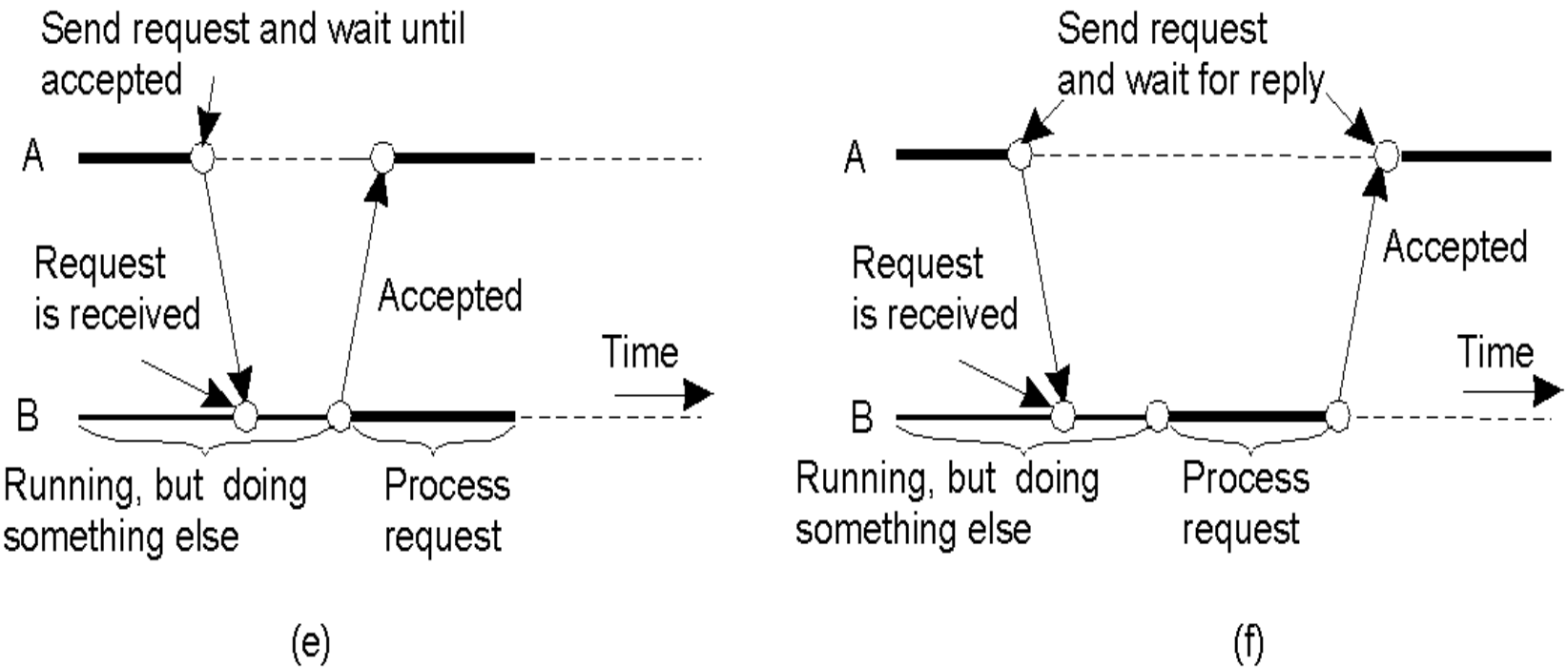




c) Transient asynchronous communication.

d) Receipt-based transient synchronous communication.

Classifying Distributed Communications (3)



e) Delivery-based transient synchronous communication at message delivery.

f) Response-based transient synchronous communication.

Interprocess Communication

- The “heart” of every distributed system.
- Question: how do processes on different machines exchange information?
- Answer: with difficulty … ☹
- Established computer network facilities are **too primitive**, resulting in DSs that are too difficult to develop – a new model is required.
- Four IPC models are popular:
  - RPC; RMI; MOM and Streams

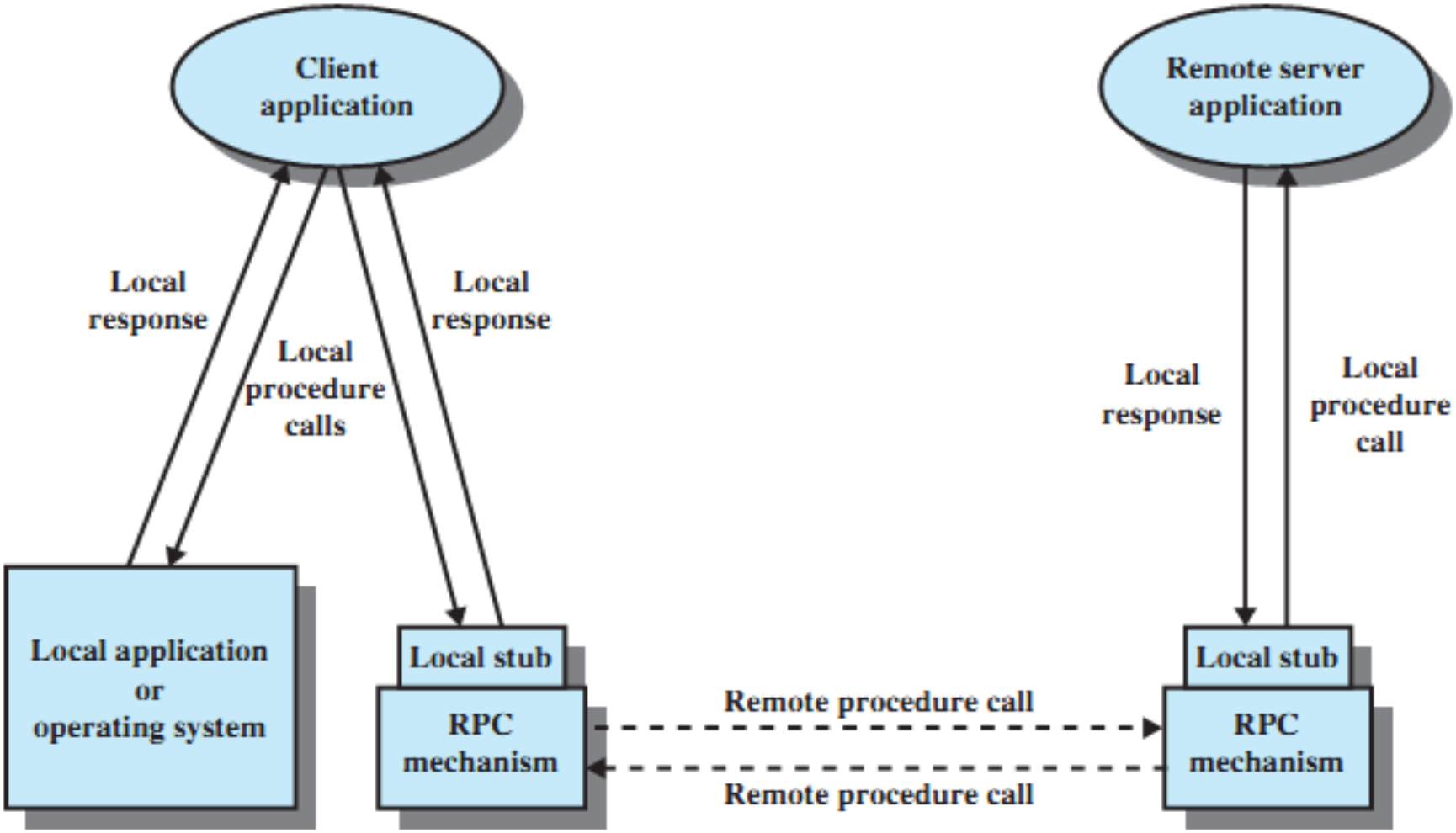
RPC: Remote Procedure Call

- Based on Birrell and Nelson (1984).
- “To allow programs to call procedures located on other machines.”
- Effectively removing the need for the DS programmer to worry about all the details of network programming (i.e., *no more sockets*).
- Conceptually simple, but …

Complications: More on RPC

- Two machine architectures may not (or need not) be identical.
- Each machine can have a different address space.
- How are parameters (of different, possibly very complex, types) passed to/from a remote procedure?
- What happens if one, the other, or both of the machines crash while the procedure is being called?

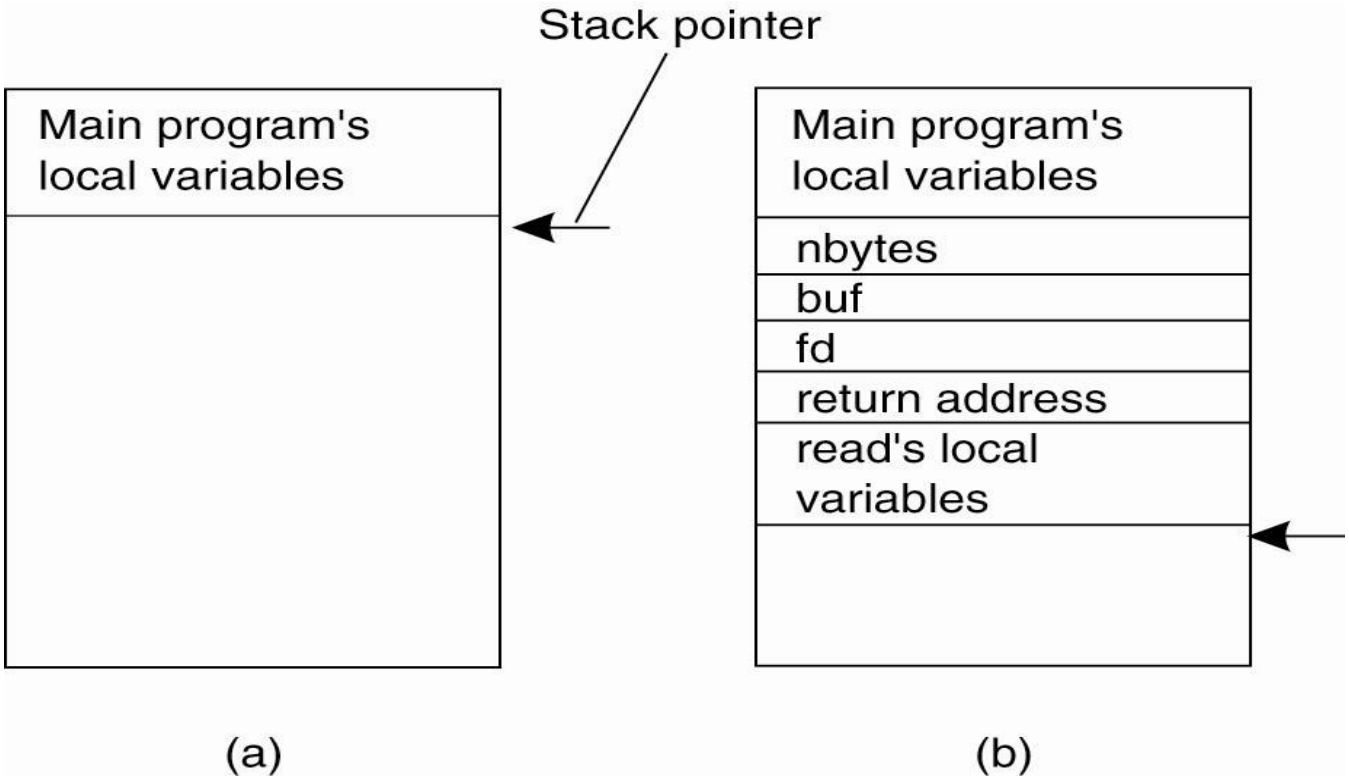
LPC/RPC Mechanisms



How RPC Works: Part 1

- As far as the programmer is concerned, a “remote” procedure call looks and works identically to a “local” procedure call.
- In this way, **transparency** is achieved.
- Before looking a RPC in action, let’s consider a conventional “local” procedure call (LPC).

Conventional Procedure Call

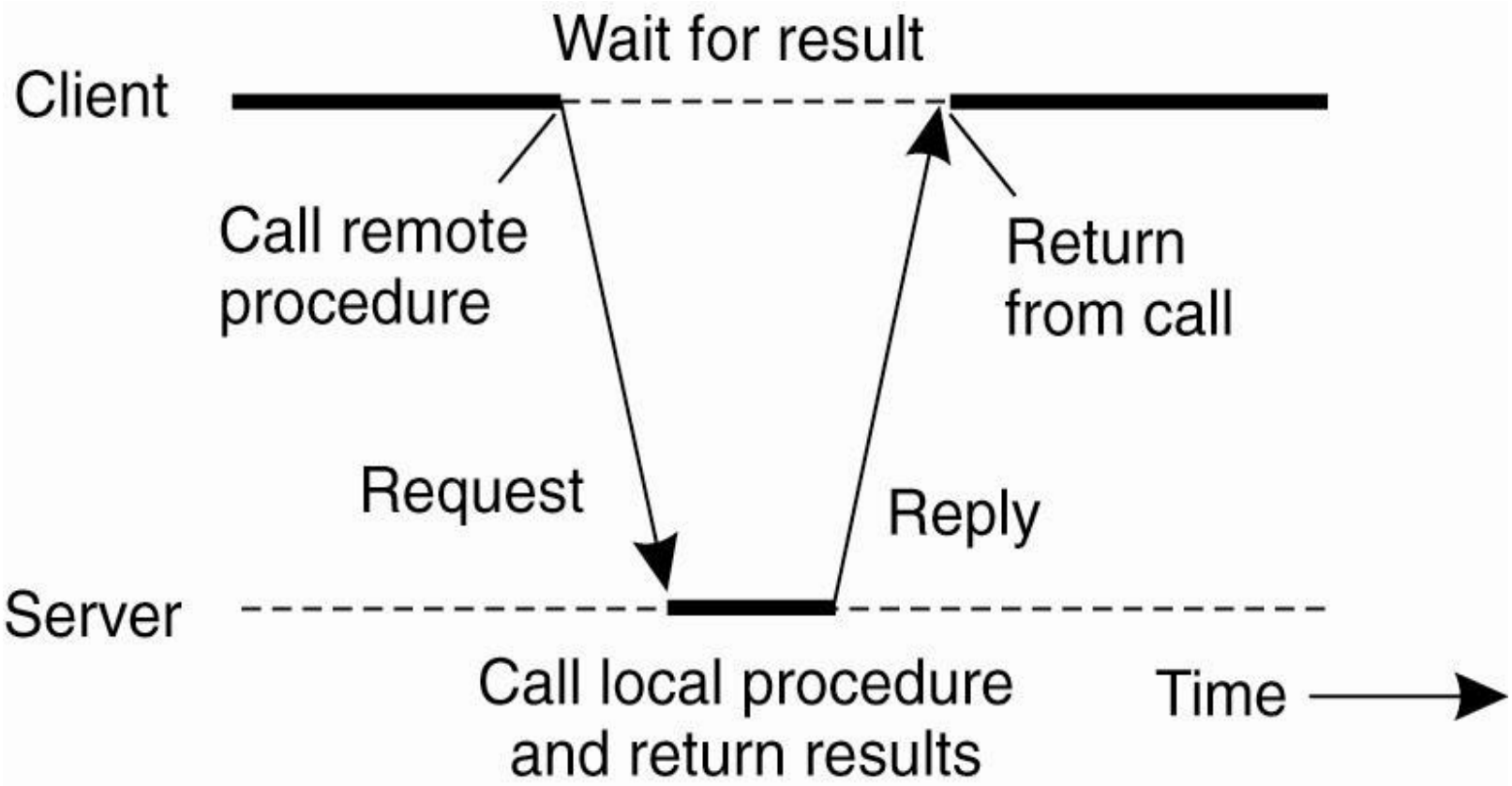


(a) Parameter passing in a local procedure call: the stack before the call to read. (b) The stack while the called procedure is active.

How RPC Works: Part 2

- The procedure is “split” into two parts:
  1. The CLIENT “stub” – implements the interface on the local machine through which the remote functionality can be invoked.
  2. The SERVER “stub” – implements the actual functionality, i.e., does the real work!
- Parameters are “marshaled” by the client prior to transmission to the server.

Client and Server Stubs

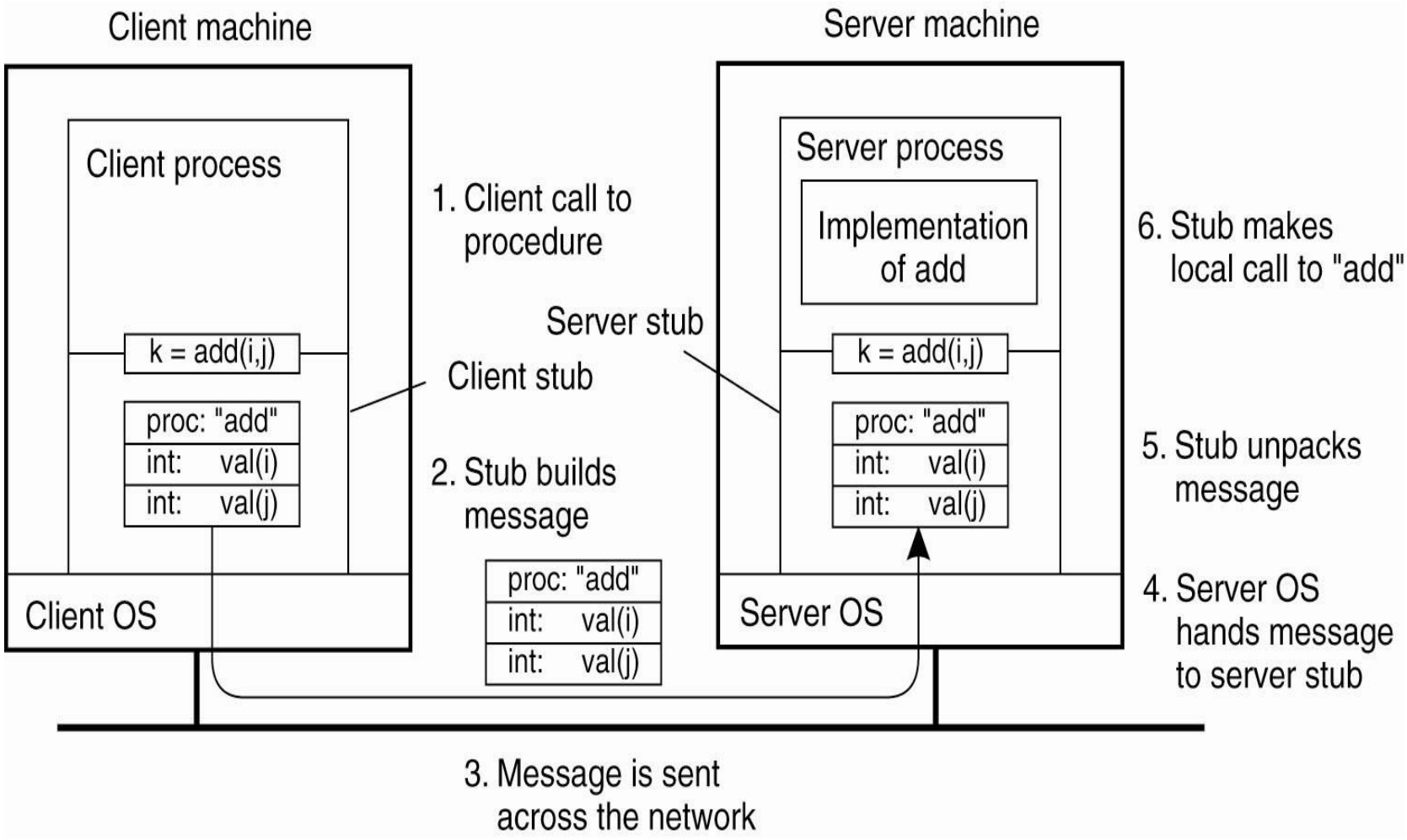


Principle of RPC between a client and server program

The 10 Steps of a 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

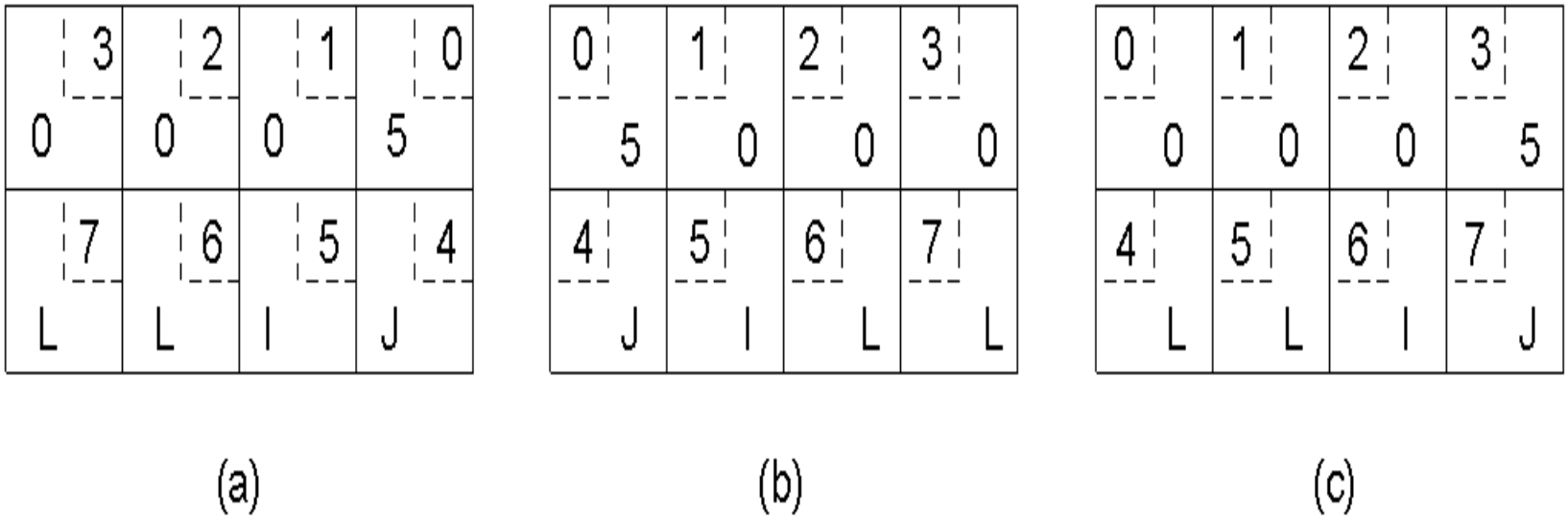
The steps involved in a doing a remote computation through RPC



RPC Problems

- RPC works really well if all the machines are homogeneous.
- Complications arise when two machines use different character sets, e.g., EBCDIC or ASCII.
- Byte-ordering is also a problem:
  - Intel machines are “big-endian”.
  - Sun Sparc’s are “little-endian”.
- Extra mechanisms are required to be built into the RPC mechanism to provide for these types of situations – this adds **complexity**.

Passing Value Parameters



a) Original message on the Pentium.

b) The message after receipt on the SPARC.

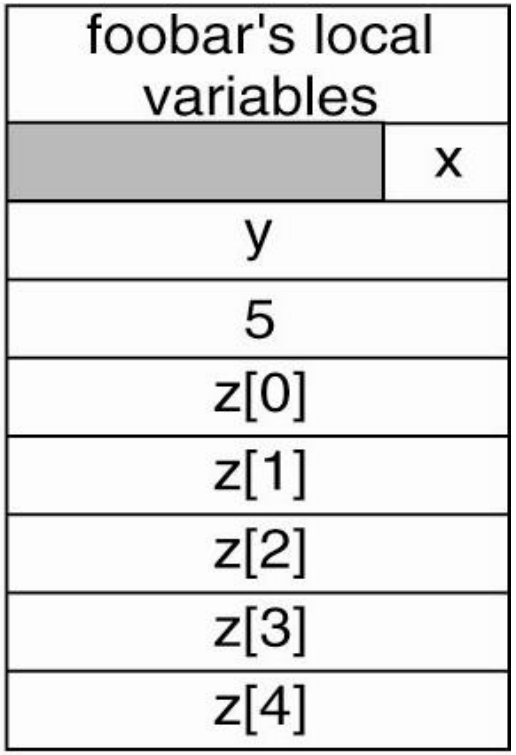
c) The message after being inverted.

The little numbers in boxes indicate the address of each byte.

Parameter Specification and Stub Generation

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

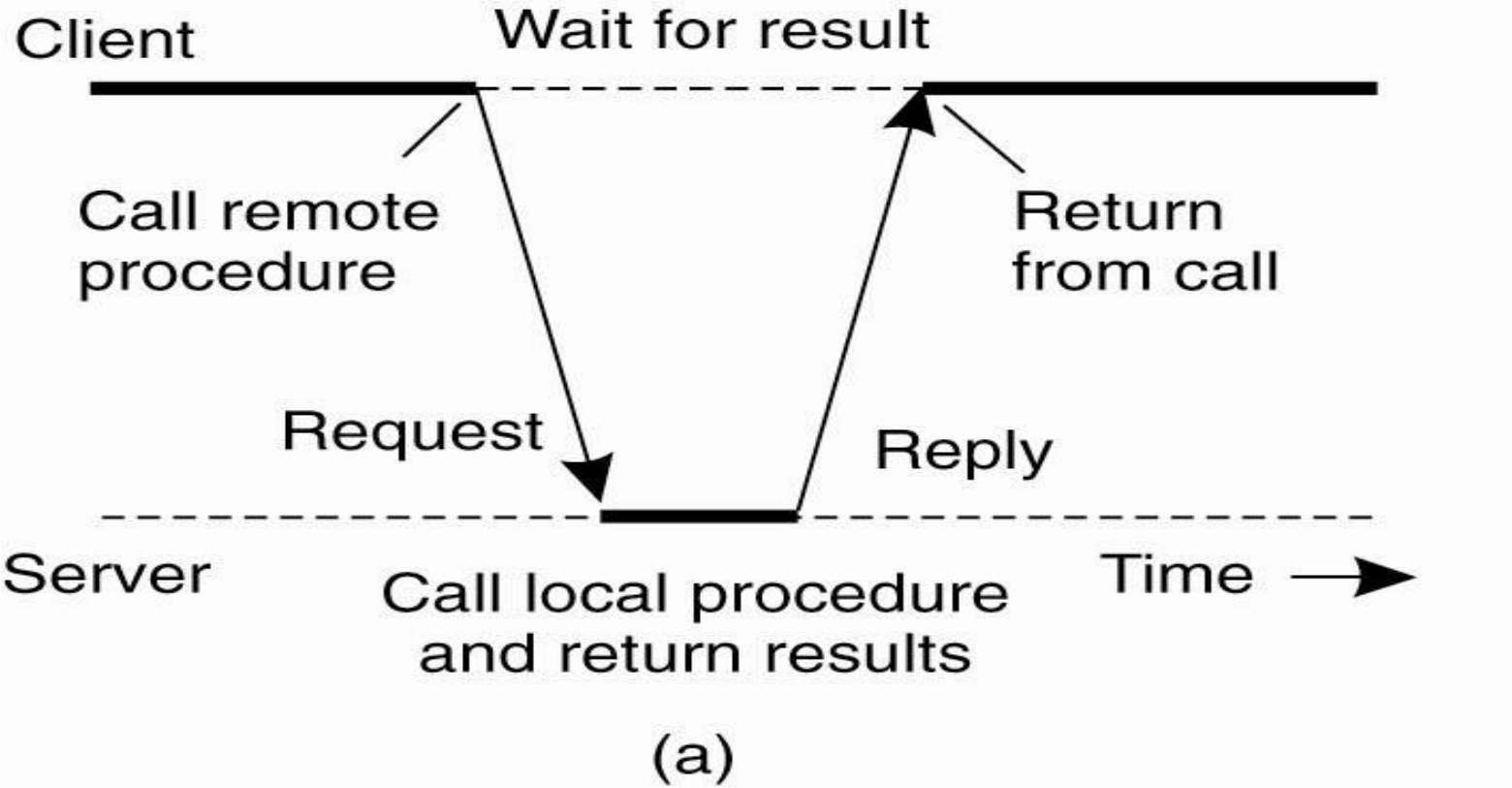
(a)



(b)

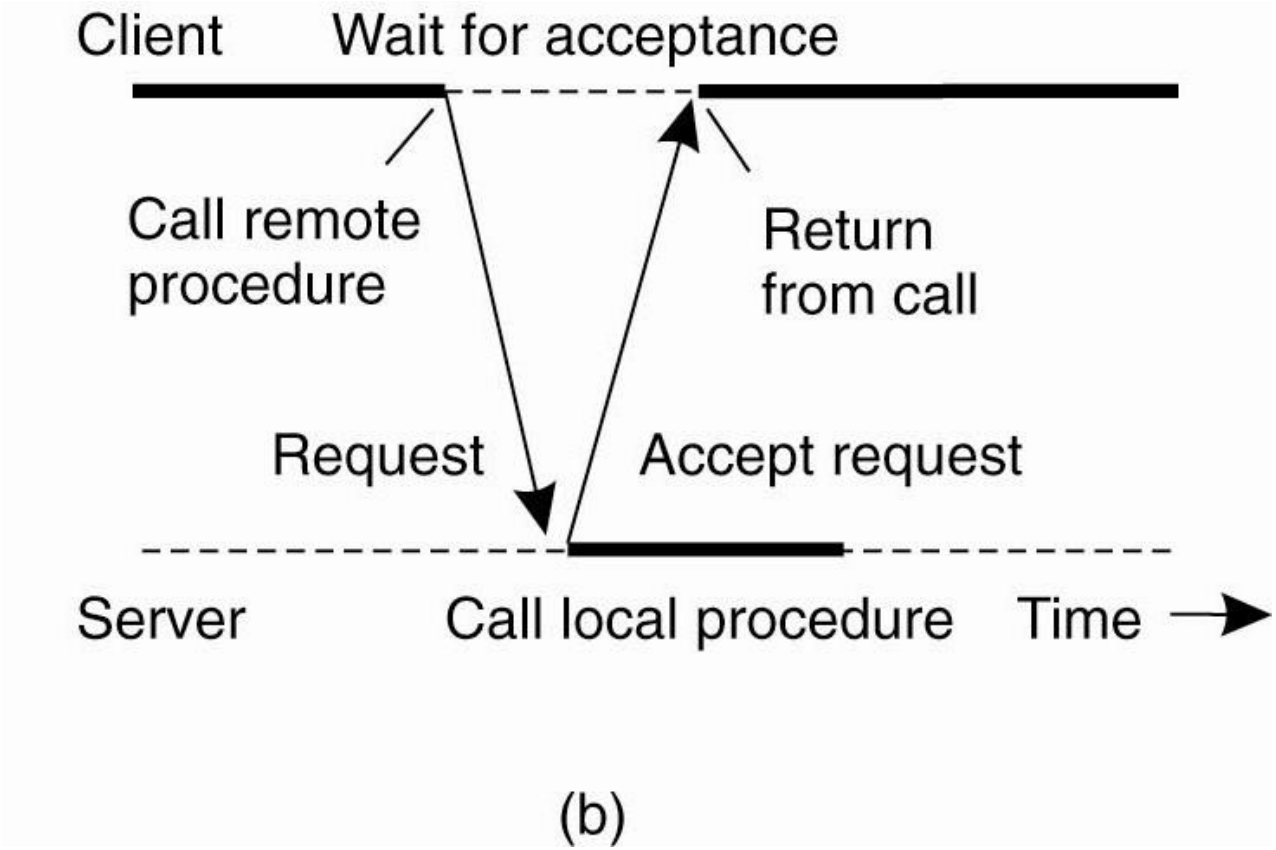
(a) A procedure. (b) The corresponding message.

Asynchronous RPC (1)



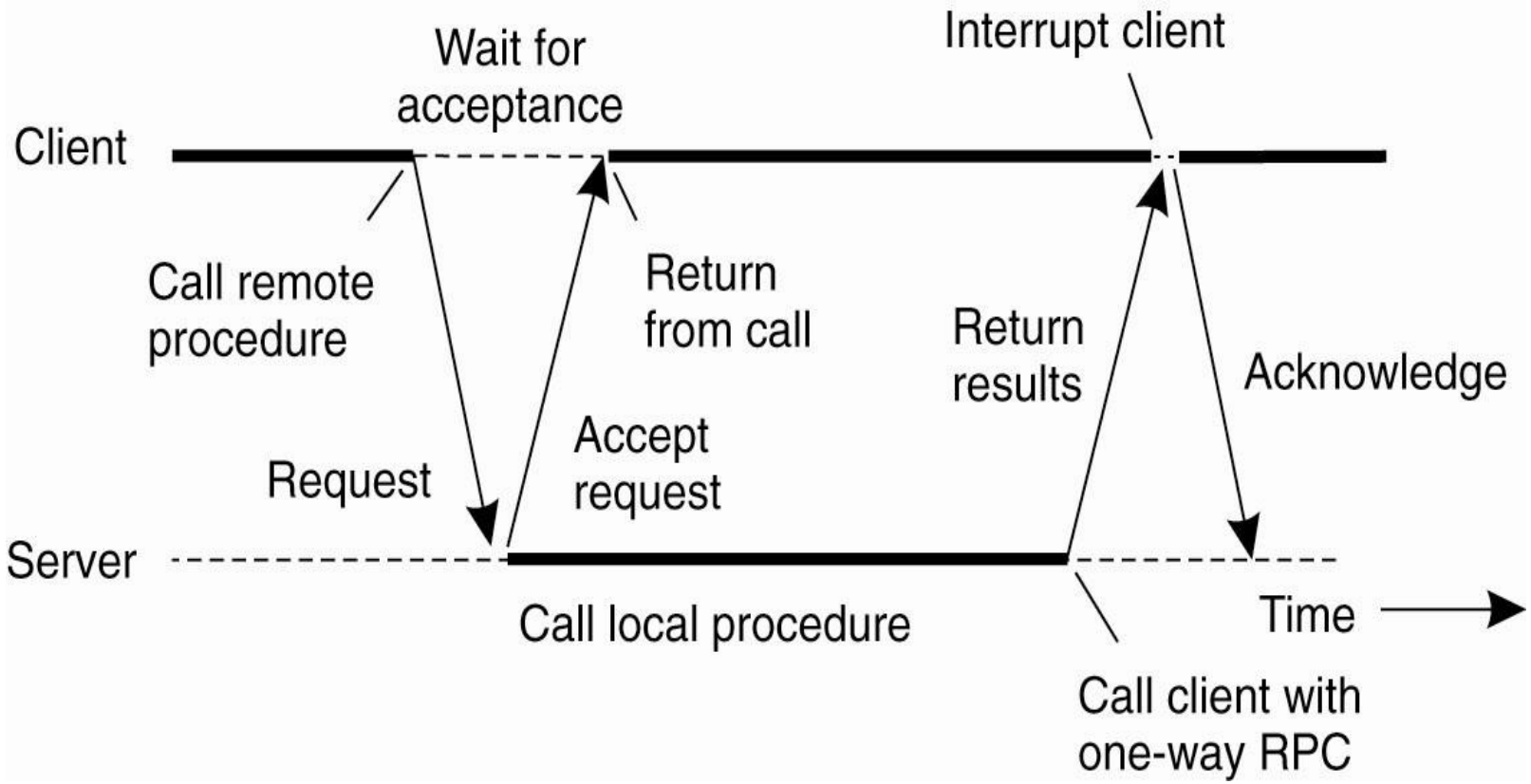
(a) The interaction between client and server in a traditional synchronous RPC

Asynchronous RPC (2)



(b) The interaction using asynchronous RPC

Asynchronous RPC (3)



Deferred Synchronous RPC: A client and server interacting through two asynchronous RPCs

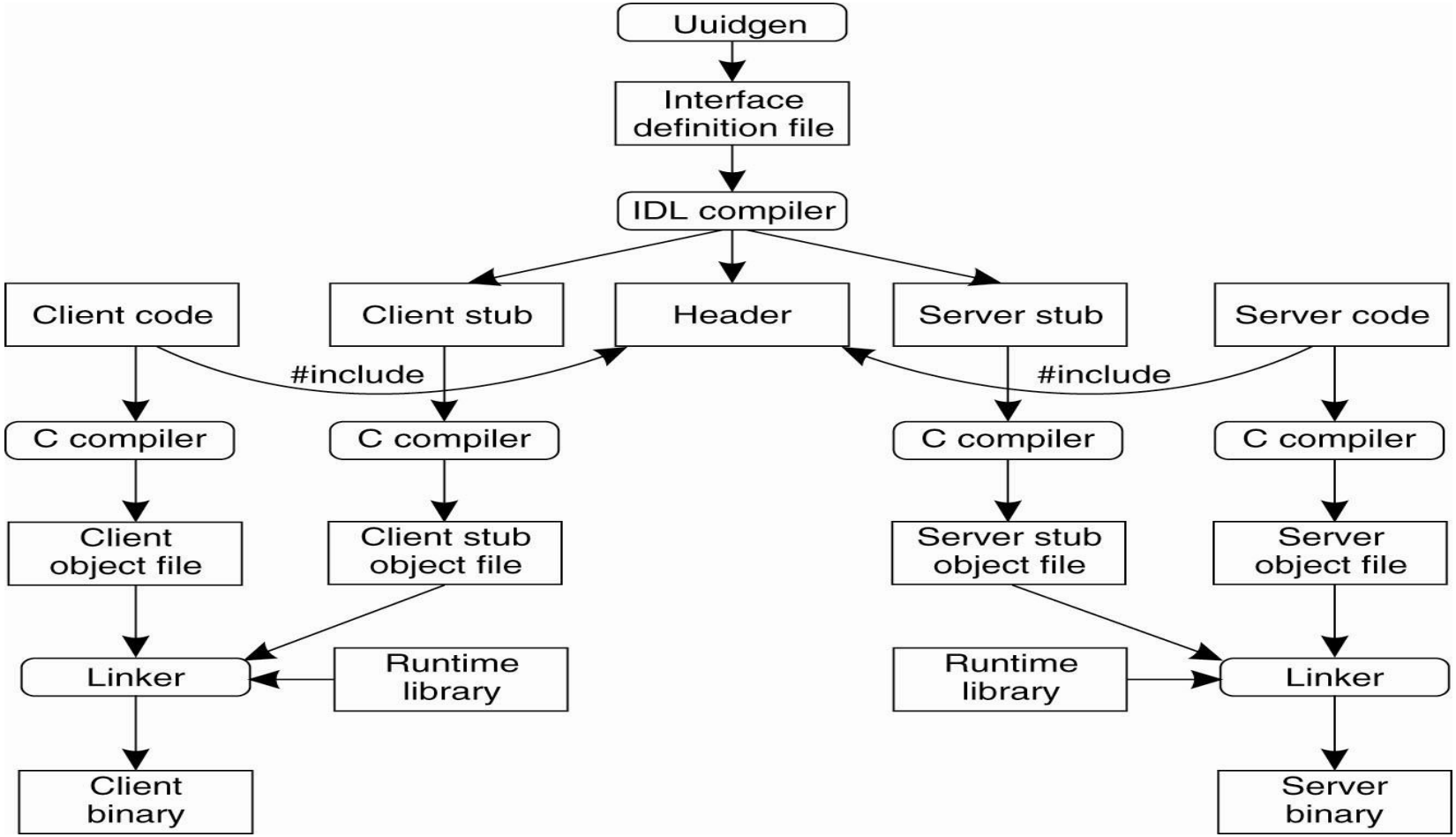
Interface Definition Language (IDL)

- RPCs typically require development of custom protocol interfaces to be effective.
- Protocol interfaces are described by means of an Interface Definition Language (IDL).
- IDLs are “language-neutral” – they do not presuppose the use of any one programming language.
- That said, most IDLs look a lot like C …

DCE: An Example RPC

- The Open Group's standard RPC mechanism.
- In addition to RPC, DCE provides:
  - Distributed File Service.
  - Directory Service (name lookups).
  - Security Service.
  - Distributed Time Service.

Writing a Client and a Server (1)



The steps in writing a client and a server in DCE RPC

Writing a Client and a Server (2)

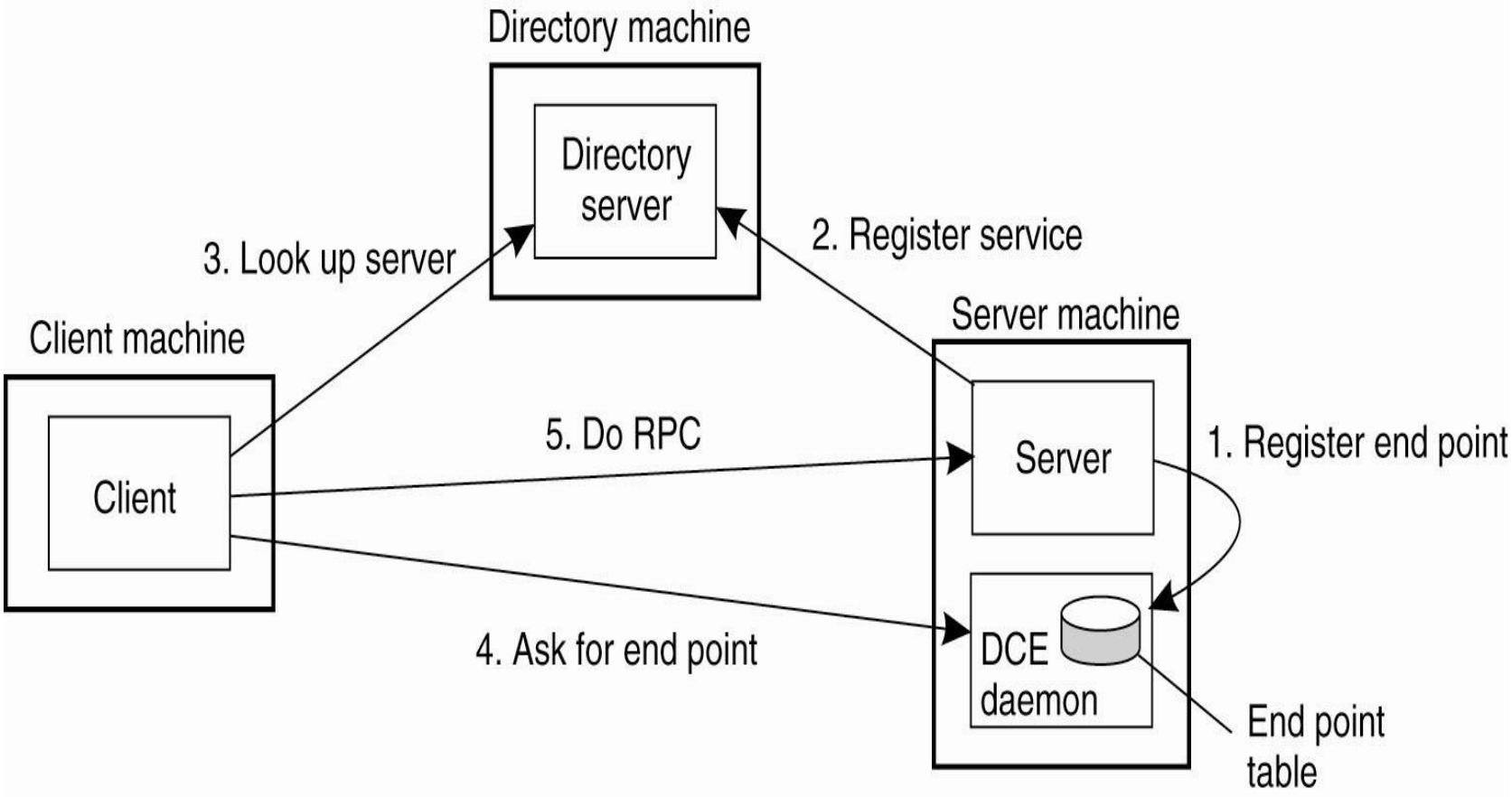
- Three files are output by the IDL compiler:

1. A header file (e.g., interface.h, in C terms).
2. The client stub.
3. The server stub.

Binding a Client to a Server (1)

- Registration of a server makes it possible for a client to locate the server and bind to it.
- Server location is done in two steps:
  1. Locate the server's machine.
  2. Locate the server on that machine.

Binding a Client to a Server (2)



Client-to-server binding in DCE

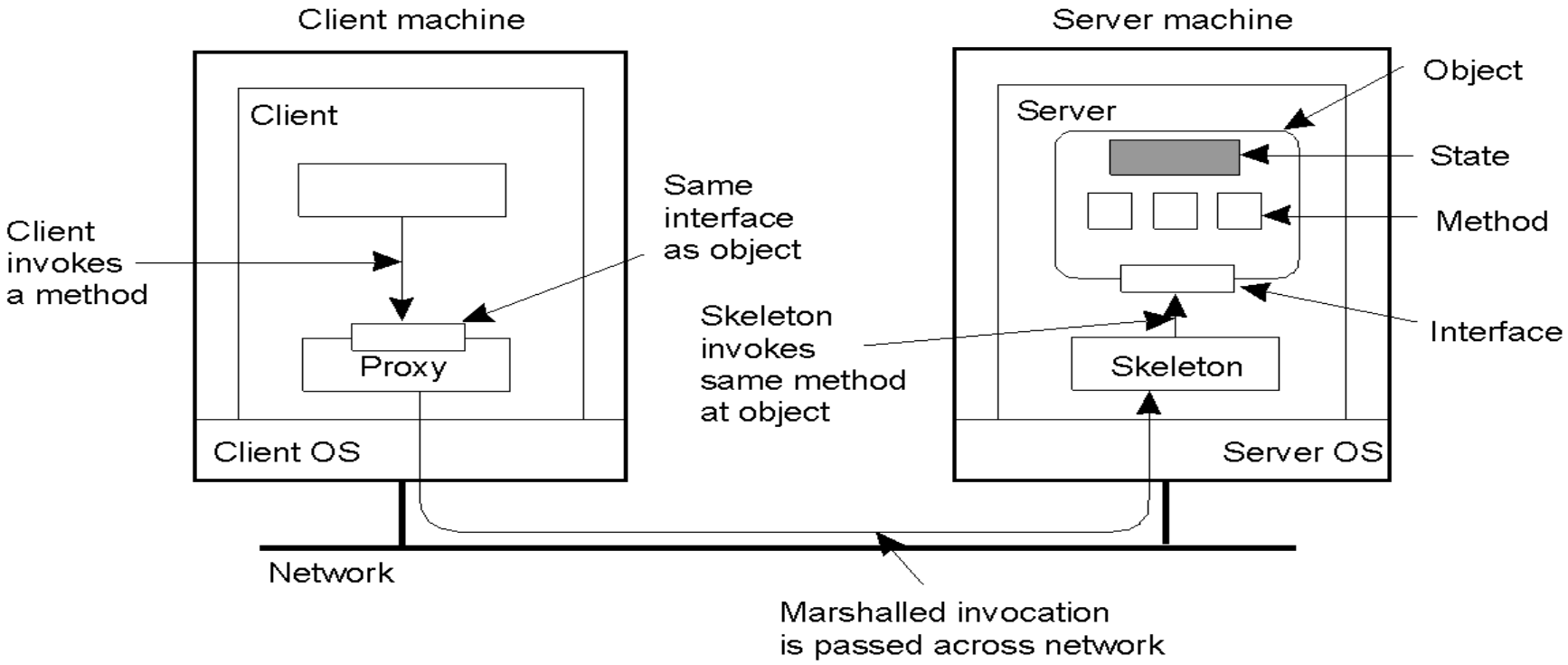
RPC Summary

- The distributed systems de-facto standard for communication and application distribution (at the procedure level):
  - It is mature.
  - It is well understood.
  - It works!

RMI: Remote Method Invocation

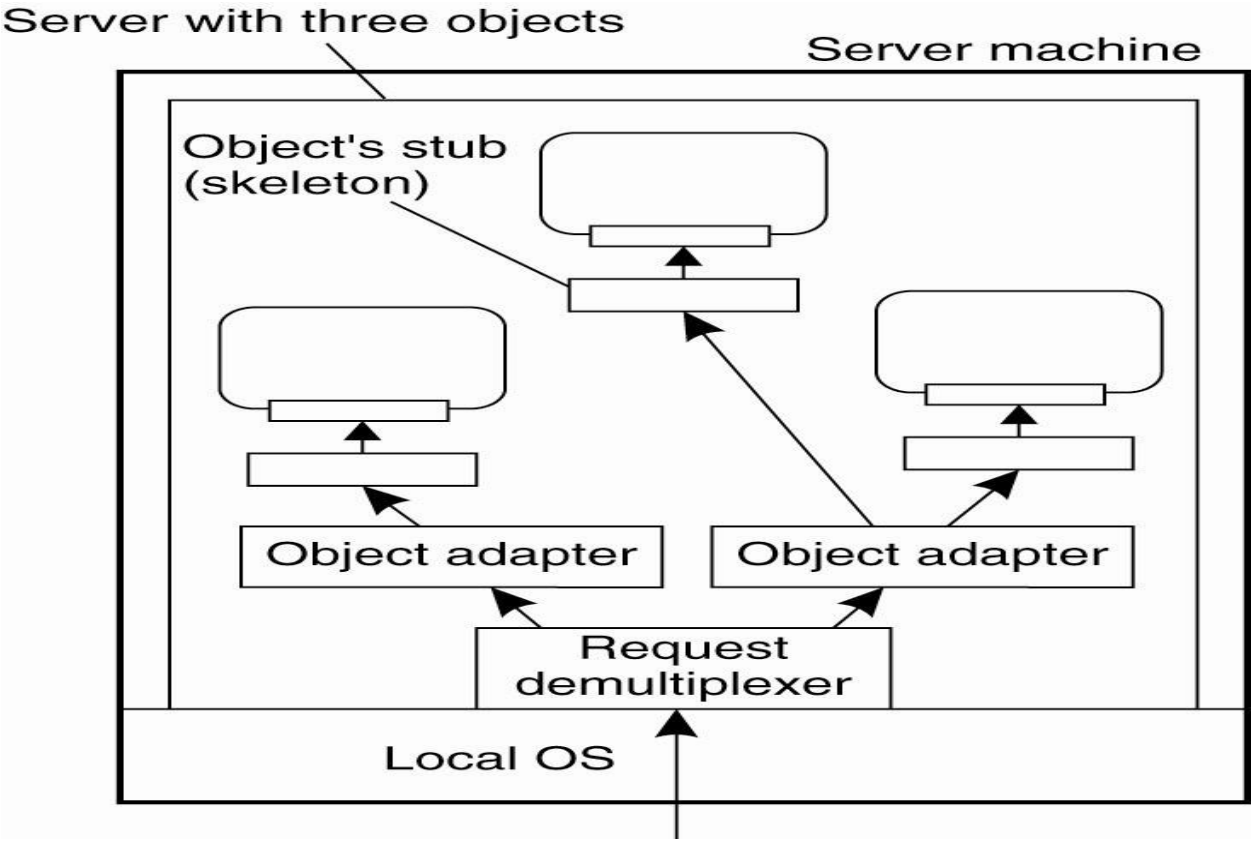
- “Remote objects” can be thought of as an expansion of the RPC mechanism (to support OO systems).
- An important aspect of objects is the definition of a well-defined interface to “hidden” functionality.
- Method calls support state changes within the object through the defined interface.
- An object may offer multiple interfaces.
- An interface may be implemented by multiple objects.
- Within a DS, the object interface resides on one machine, and the object implementation resides on another.

The Distributed Object



- Organization of a remote object with client-side “proxy”.
- The “proxy” can be thought of as the “client stub”.
- The “skeleton” can be thought of as the “server stub”.

Object Server/Adapter



Organization of an object server supporting different activation policies

Compile-time vs. Runtime Objects

- Compile-time distributed objects generally assume the use of a particular programming language (Java or C++).
- This is often seen as a drawback (inflexible).
- Runtime distributed objects provide *object adaptors* to objects, designed to remove the compile-time programming language restriction.
- Using **object adaptors** allows an object implementation to be developed in any way – as long as the resulting implementation "appears" like an object, then things are assumed to be OK.

Persistent vs. Transient Objects

- A “persistent” distributed object continues to exist even after it no longer exists in the address space of the server.
- It is stored (perhaps on secondary storage) and can be re-instantiated at a later date by a newer server process (i.e., by a newer object).
- A “transient” distributed object does not persist.
- As soon as the server exits, the transient object is destroyed.
- Which one is better is the subject of much controversy …

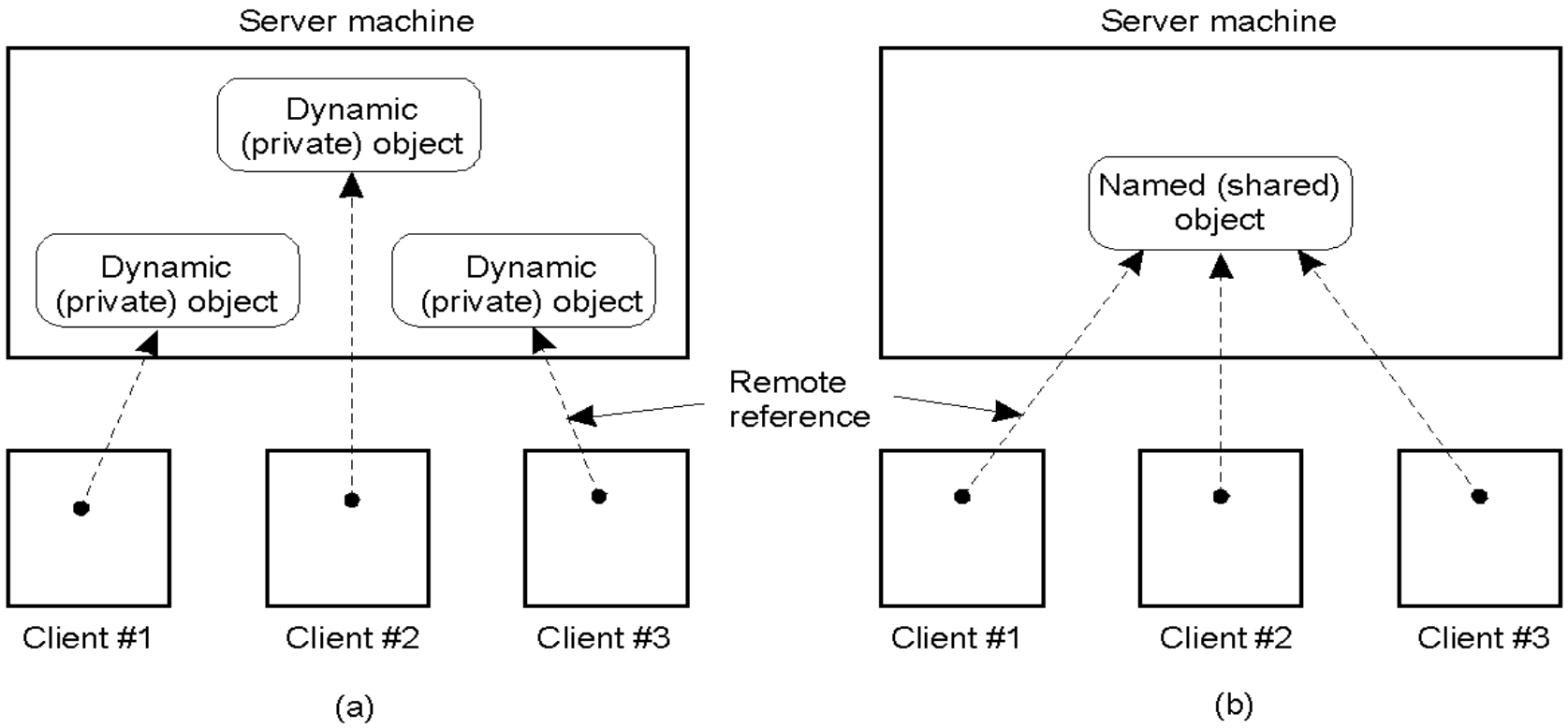
Static vs. Dynamic Invocation

- Predefined interface definitions support *static invocation*:
  - all interfaces are known up-front.
  - a change to the interface requires all applications (i.e., clients) to be recompiled.
- Dynamic invocation "composes" a method at run-time:
  - interface can "come and go" as required.
  - interfaces can be changed without forcing a recompile of client applications.

Example: DCE Remote Objects

- DCE's RPC mechanism has been "enhanced" to directly support remote method invocation.
- DCE Objects = xIDL plus C++.
- That is, the DCE IDL has been extended to support objects that are implemented in C++.
- Two types of DCE objects are supported:
  - *Distributed Dynamic Objects* – a "private" object created by the server for the client.
  - *Distributed Named Objects* – a "shared" object that lives on the server and can be accessed by more than one client.

The DCE Distributed-Object Model



a) DCE dynamic objects – requests for creation sent via RPC.

b) DCE named objects – registered with a DS naming service.

Example: Java RMI

- In Java, distributed objects are integrated into the language proper.
- This affords a very high degree of *distribution transparency* (with exceptions, where it makes sense, perhaps to improve efficiency).
- Java does not support RPC, only distributed objects.
- The distributed object's state is stored on the server, with interfaces made available to remote clients (via distributed object proxies).
- To build the DS application, the programmer simply implements the client proxy as a class, and the server skeleton as another class.

Message-Oriented Middleware: MOM

- As a communications mechanism, RPC/RMI is often inappropriate.
- For example: what happens if we cannot assume that the receiving side is “awake” and waiting to communicate?
- Also: the default “synchronous, blocking” nature of RPC/RMI is often *too restrictive*.
- Something else is needed: **Messaging**.

Message Passing (MP) Systems

- Fundamentally different approach.
- All communications primitives are defined in terms of passing “messages”.
- Initially, MP systems were “transient”, but these did not scale well *geographically*.
- Recent emphasis has been on “persistent” solutions.

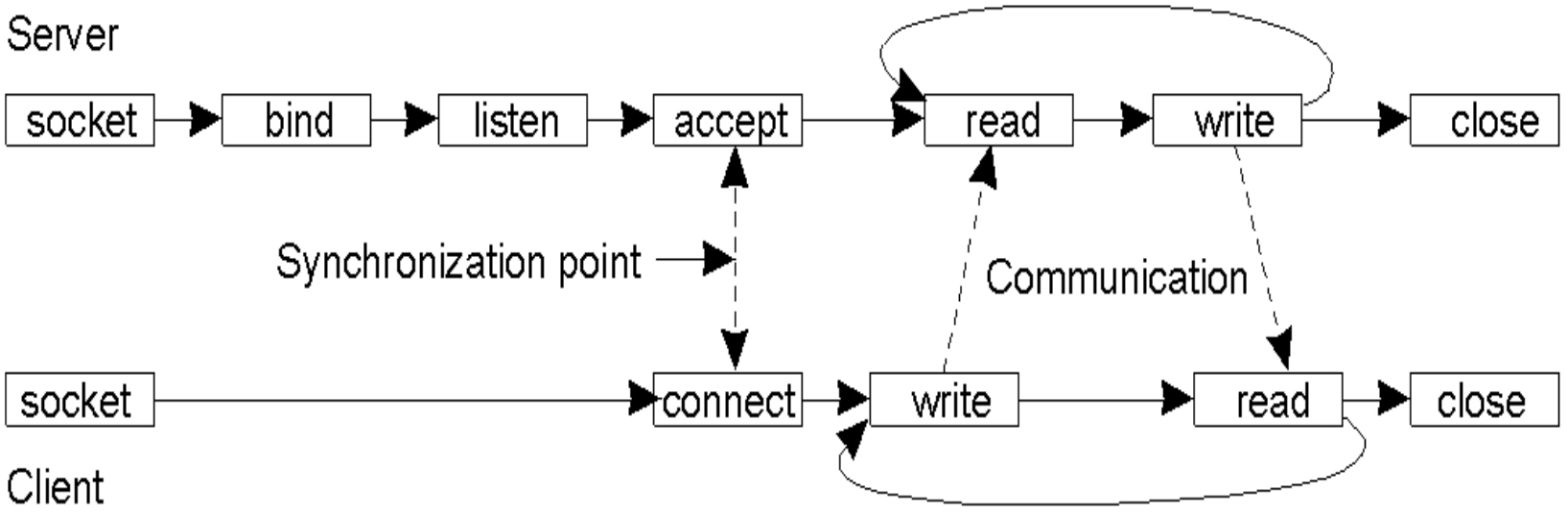
Berkeley Sockets

Primitive	Meaning
Socket	Create a new communication end point
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

The socket primitives for TCP/IP

Message-Oriented Transient Communications

Initial efforts relied on connection-oriented communication patterns using Sockets (API).



However, DS developers rejected Sockets:

- Wrong level of abstraction (only “send” and “receive”).
- Too closely coupled to TCP/IP networks – not diverse enough.

The Message-Passing Interface (1)

- Middleware vendors looked to provide a higher-level of abstraction.
- Every vendor did their own thing (which is typical).
- As can be imagined, this lead to *portability problems*, as no two vendors product interfaces were the same.
- The solution?
  - The “Message-Passing Interface” (MPI).

The Message-Passing Interface (2)

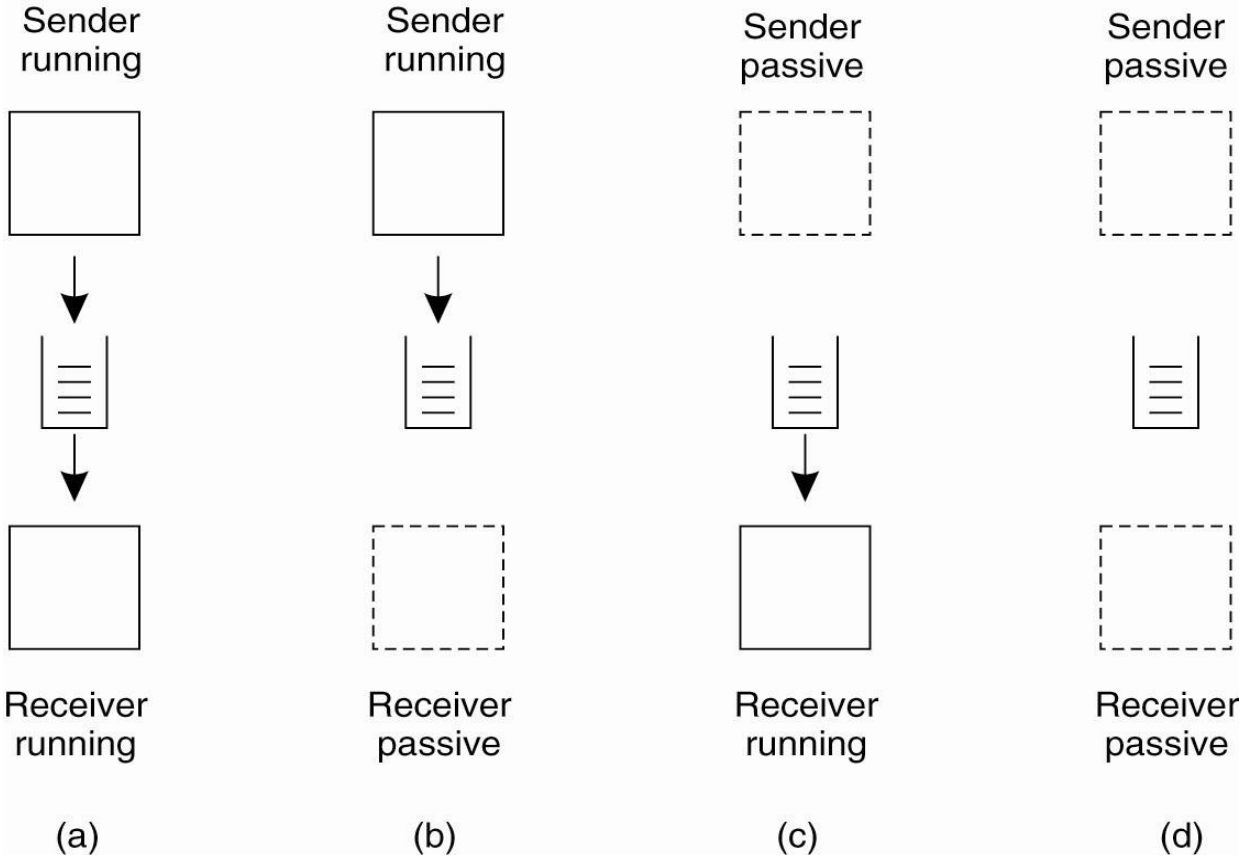
Primitive	Meaning
MPI_bsend	Append outgoing message to a local send buffer
MPI_send	Send a message and wait until copied to local or remote buffer
MPI_ssend	Send a message and wait until receipt starts
MPI_sendrecv	Send a message and wait for reply
MPI_isend	Pass reference to outgoing message, and continue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

Some of the most intuitive message-passing primitives of MPI

Message-Oriented Persistent Communications

- Also known as: “message-queuing systems”.
- They support persistent asynchronous communications.
- Typically, transport can take minutes (hours?) as opposed to seconds/milliseconds.
- **The basic idea**: applications communicate by putting messages into and taking messages out of “message queues”.
- Only guarantee: your message will eventually make it into the receiver’s message queue.
- This leads to “loosely-coupled” communications.

Message-Queuing Model (1)



Four combinations for loosely-coupled communications using queues

Message-Queuing Model (2)

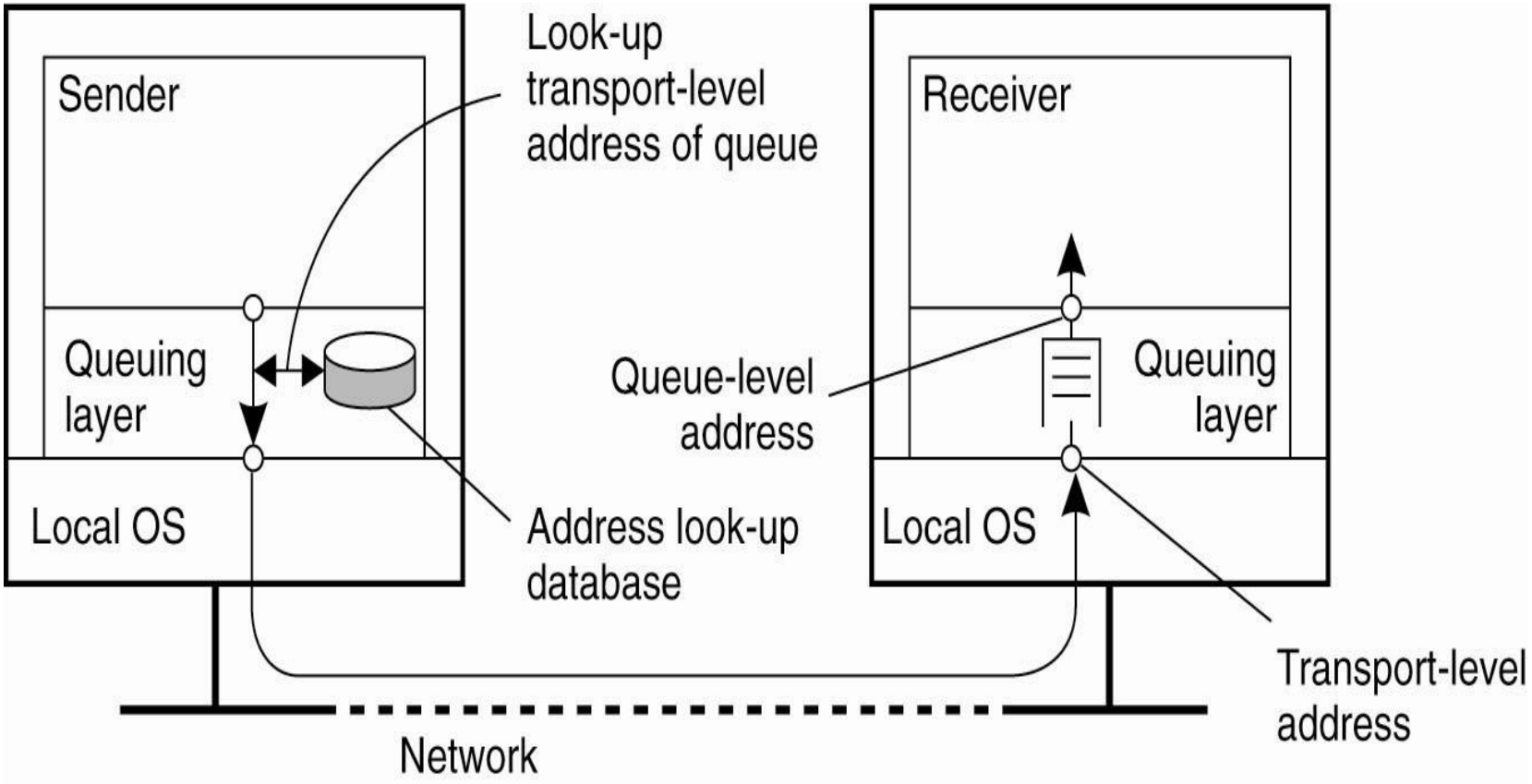
Primitive	Meaning
Put	Append a message to a specified queue
Get	Block until the specified queue is nonempty, and remove the first message
Poll	Check a specified queue for messages, and remove the first. Never block
Notify	Install a handler to be called when a message is put into the specified queue

Basic interface to a queue in a message-queuing system

Message-Queuing System Architecture

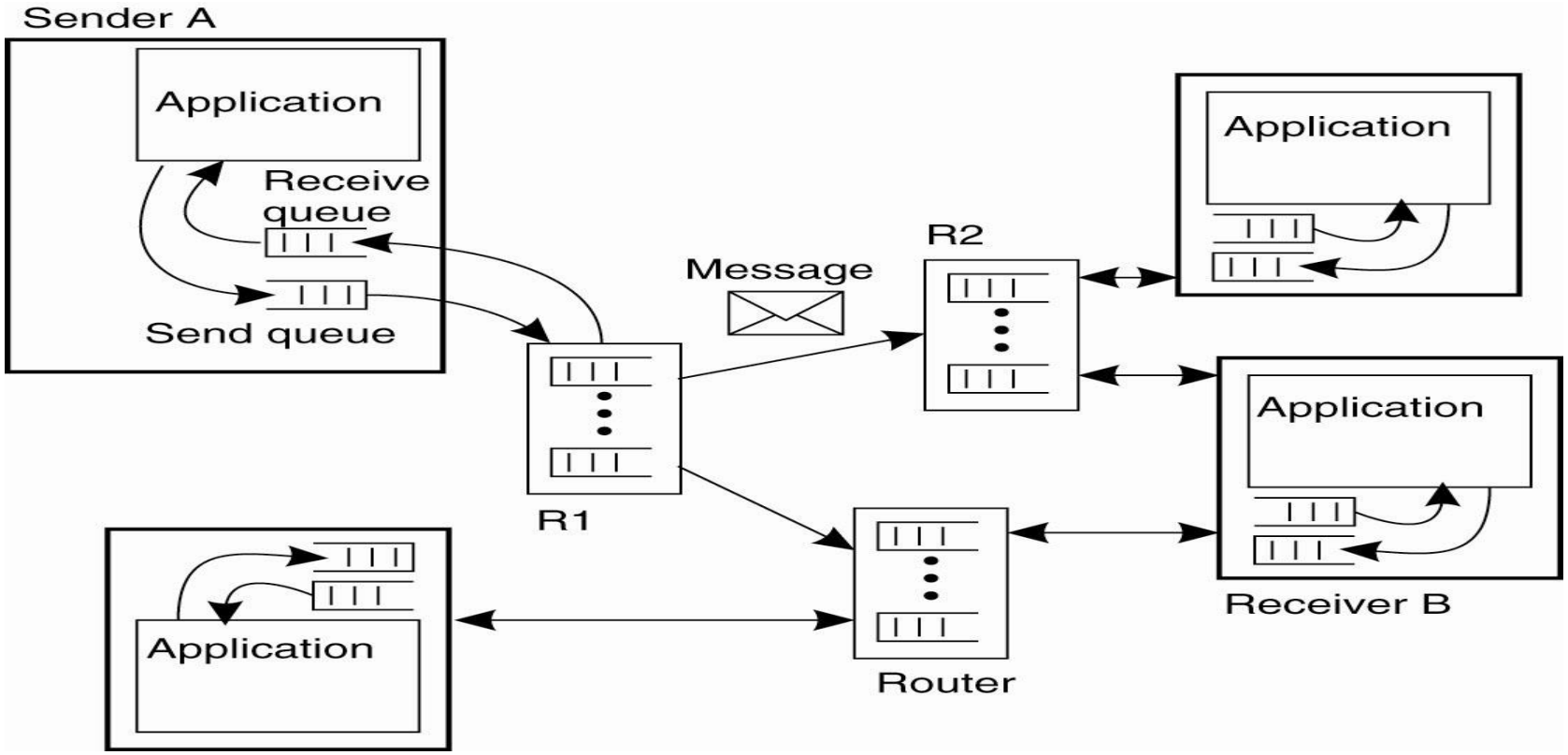
- Messages are “put into” a *source queue*.
- They are then “taken from” a *destination queue*.
- Obviously, a mechanism has to exist to move a message from a source queue to a destination queue.
- This is the role of the *Queue Manager*.
- These are message-queuing “relays” that interact with the distributed applications and with each other. Not unlike routers, these devices support the notion of a DS “overlay network”.

General Architecture of a Message-Queuing System (1)



The relationship between queue-level addressing and network-level addressing

General Architecture of a Message-Queuing System (2)

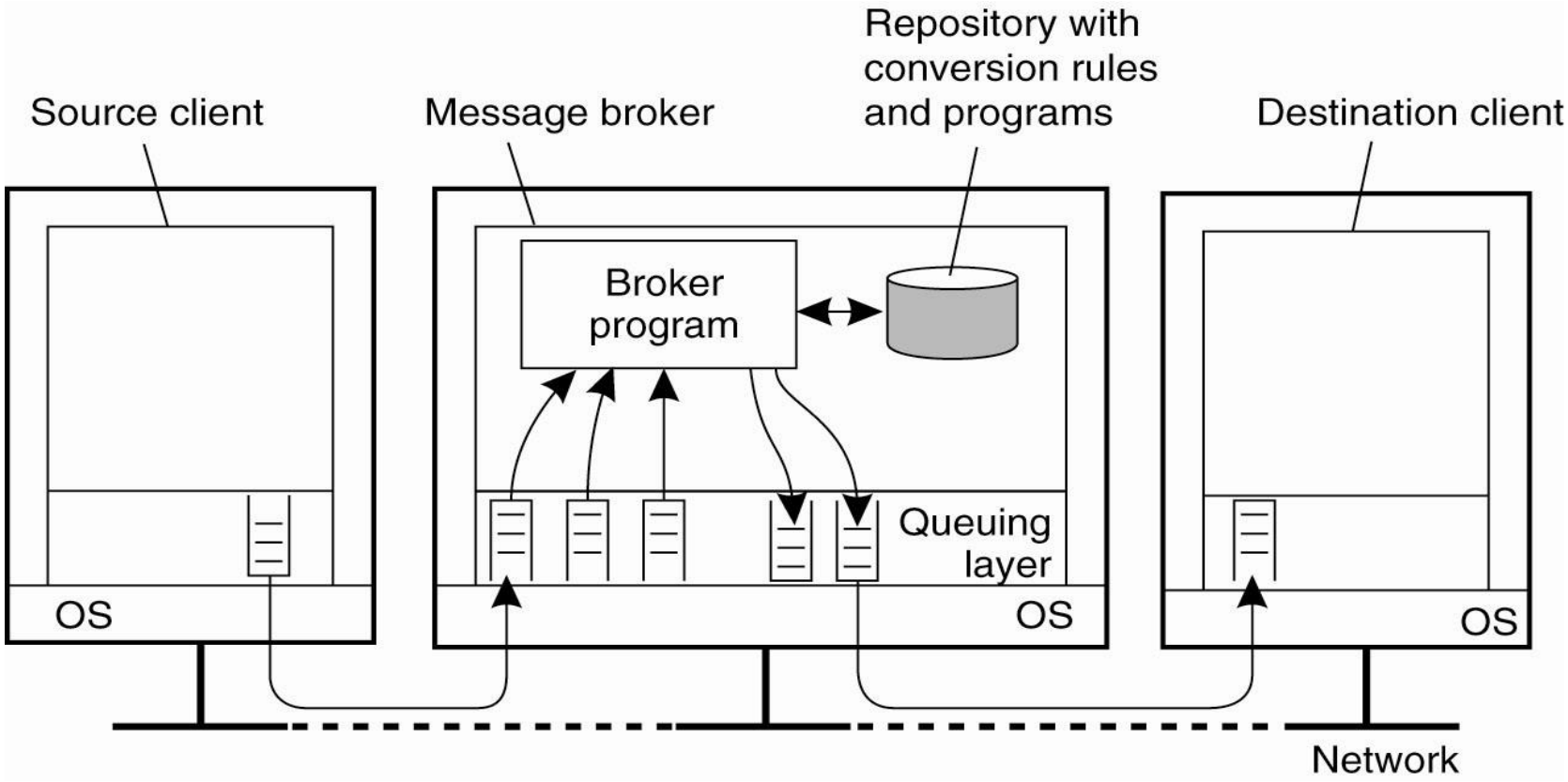


The general organization of a message-queuing system with routers

The Role of Message Brokers

- Often, there's a need to integrate new/existing apps into a "single, coherent Distributed Information System (DIS)".
- In other words, it is not always possible to start with a *blank page* – DSs have to live in the real world.
- **Problem**: different message formats exist in legacy systems (cooperation and adherence to open standards was not how things were done in the past).
- It may not be convenient to "force" legacy systems to adhere to a single, global message format (cost!?).
- It is often necessary to live with diversity (no choice).
- **How?** Meet the "Message Broker".

Message Brokers

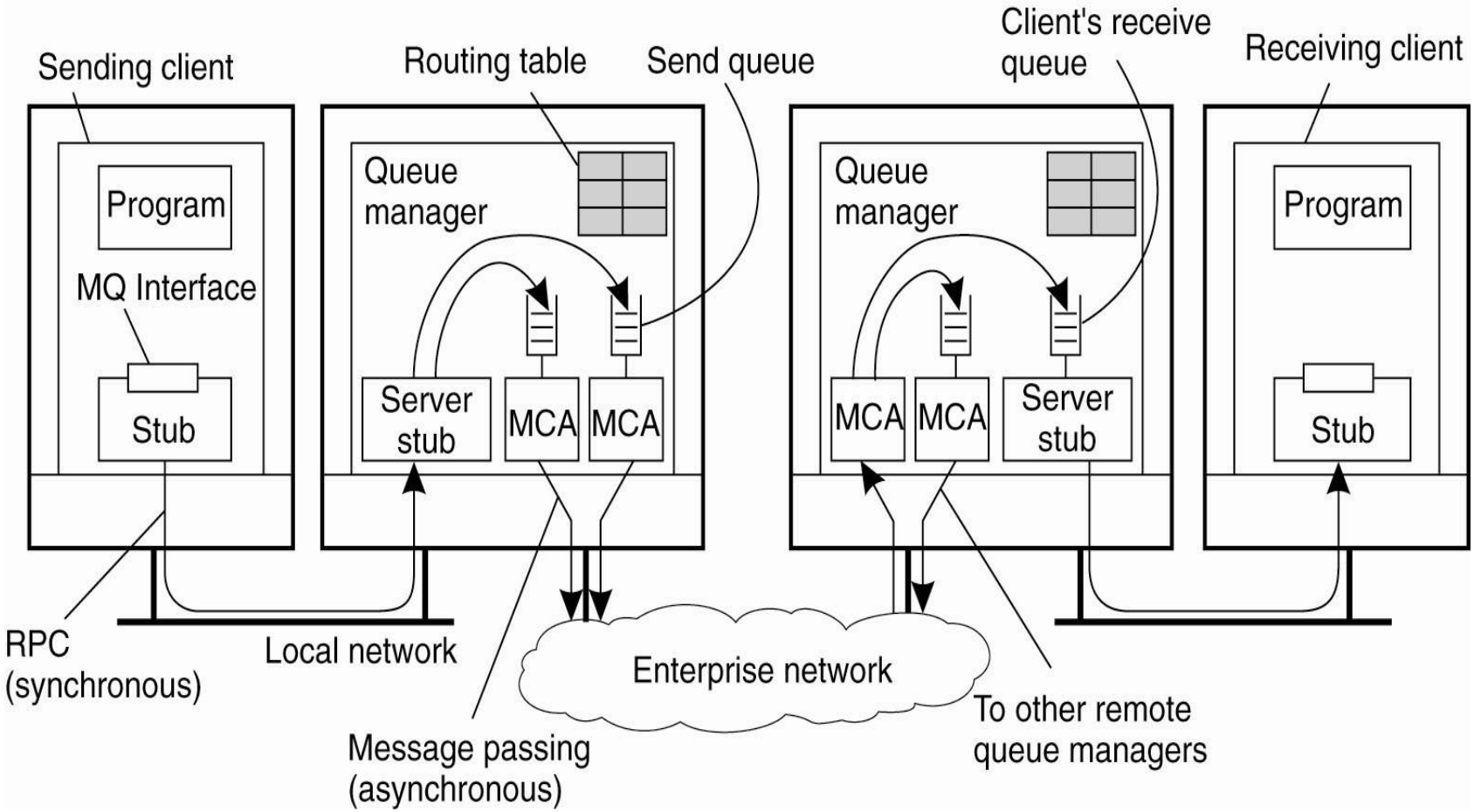


The general organization of a message broker in a message-queuing system

Message-Queuing (MQ) Applications

- General-purpose MQ systems support a wide range of applications, including:
  - Electronic mail
  - Workflow
  - Groupware
  - Batch Processing
- Most important MQ application area:
  - The integration of a widely dispersed collection of **database applications** (which is all but impossible to do with traditional RPC/RMI techniques).

IBM's WebSphere Message-Queuing System



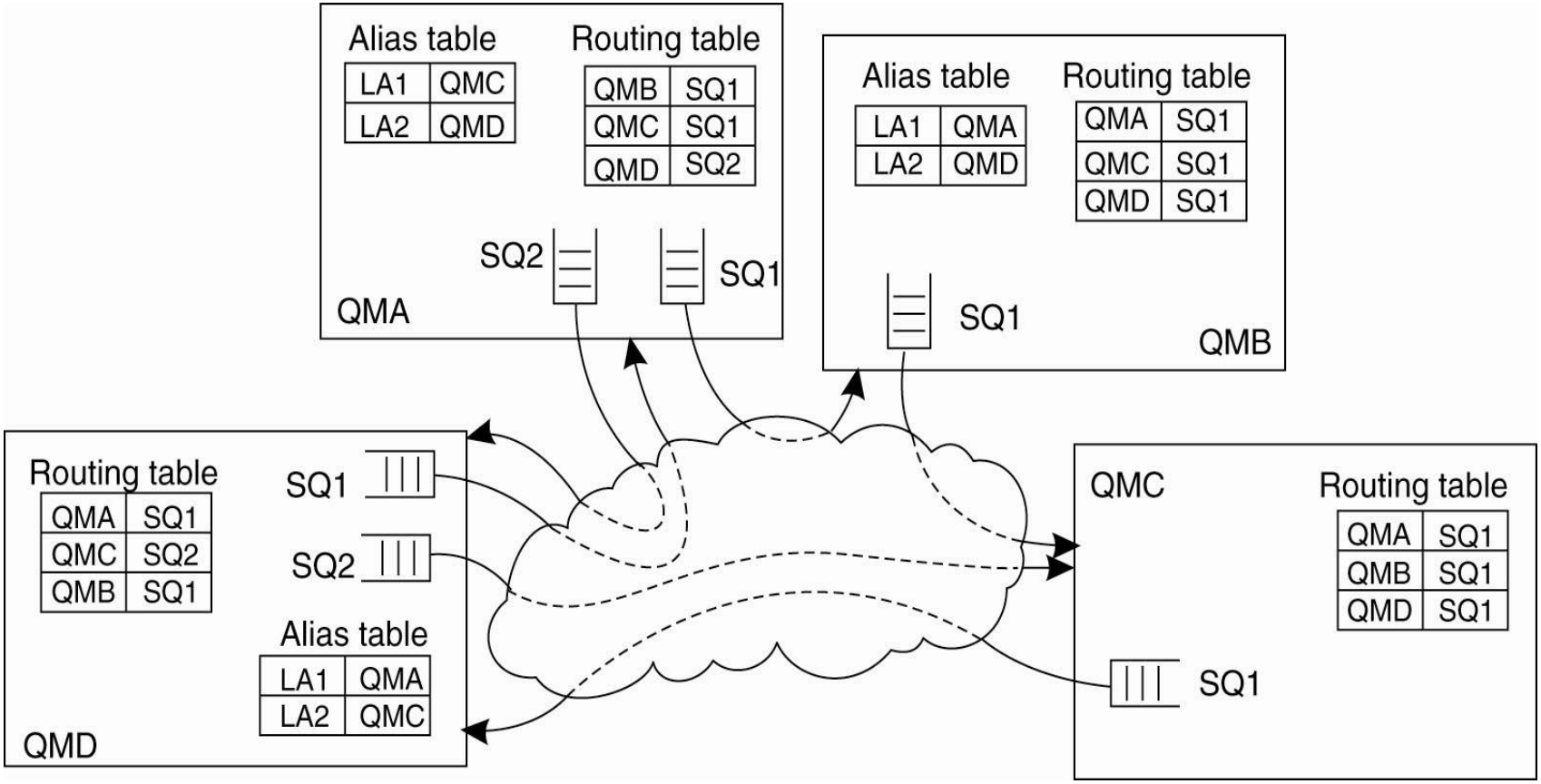
General organization of IBM's message-queuing system

Channels

Attribute	Description
Transport type	Determines the transport protocol to be used
FIFO delivery	Indicates that messages are to be delivered in the order they are sent
Message length	Maximum length of a single message
Setup retry count	Specifies maximum number of retries to start up the remote MCA
Delivery retries	Maximum times MCA will try to put received message into queue

Some attributes associated with message channel agents

Message Transfer (1)



The general organization of an MQ queuing network using routing tables and aliases

Message Transfer (2)

Primitive	Description
MQopen	Open a (possibly remote) queue
MQclose	Close a queue
MQput	Put a message into an opened queue
MQget	Get a message from a (local) queue

Primitives available in the message-queuing interface

Stream-Oriented Communications

- With RPC, RMI and MOM, the effect that time has on correctness is of *little consequence*.
- However, audio and video are *time-dependent data streams* – if the timing is off, the resulting "output" from the system will be incorrect.
- Time-dependent information – known as "continuous media" communications:
  - *Example*: voice: PCM: 1/44100 sec intervals on playback.
  - *Example*: video: 30 frames per second (30-40ms per image).
- ***KEY MESSAGE: Timing is crucial!***

Transmission Modes

- *Asynchronous transmission mode* – the data stream is transmitted in order, but there's no timing constraints placed on the actual delivery (e.g., File Transfer).
- *Synchronous transmission mode* – the maximum end-to-end delay is defined (but data can travel faster).
- *Isochronous transmission mode* – data transferred "on time" – there's a **maximum** and **minimum** end-to-end delay (known as "bounded jitter").
- Known as "streams" – isochronous transmission mode is very useful for multimedia systems.

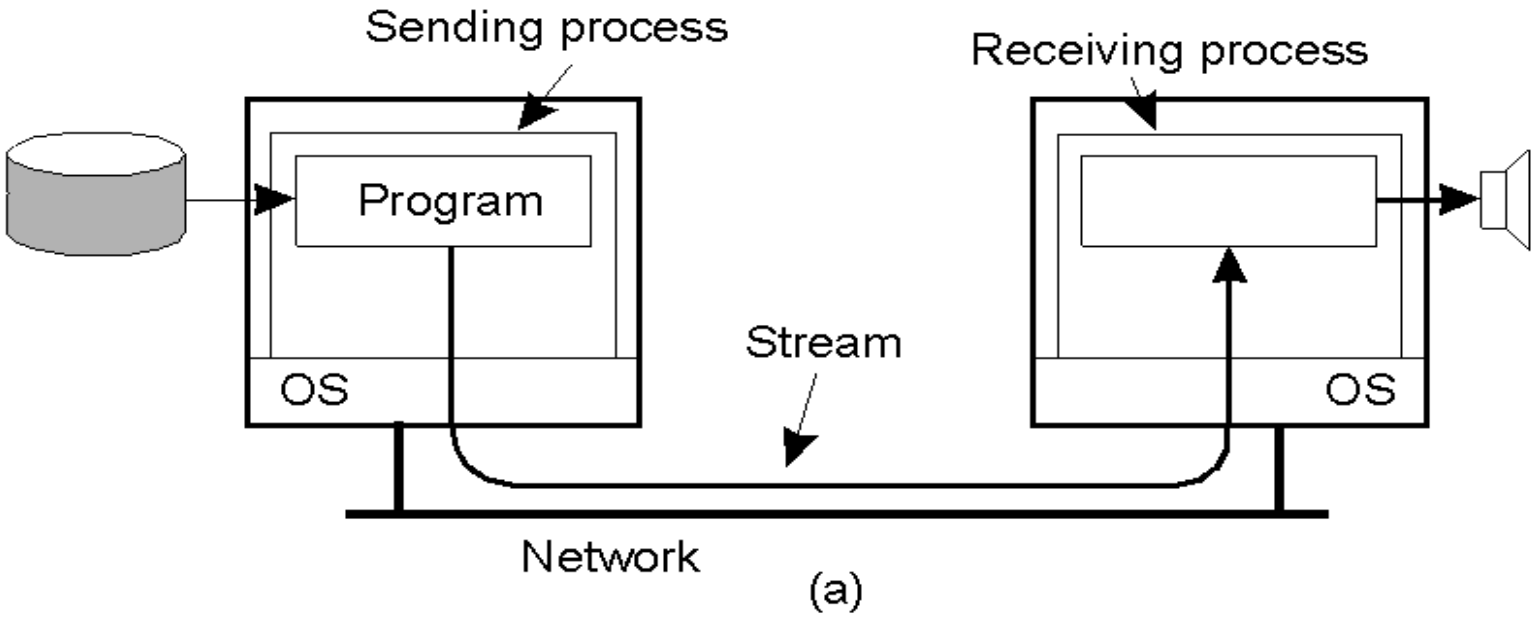
Two Types of Streams

- *Simple Streams* – one single sequence of data, for example: voice.
- *Complex Streams* – several sequences of data (sub-streams) that are "related" by time. Think of a lip-synchronized movie, with sound and pictures, together with sub-titles …
- This leads to data synchronization problems … not at all easy to deal with.

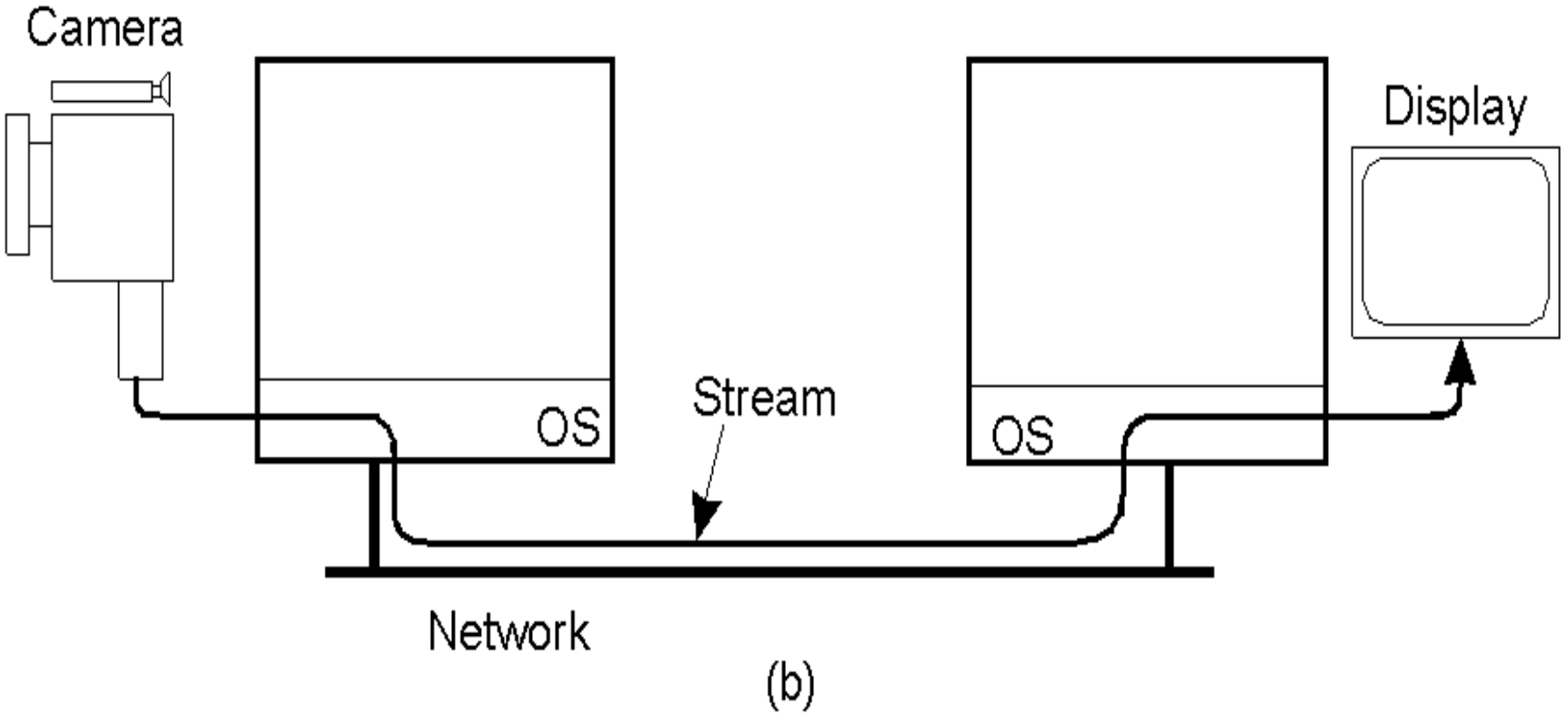
Components of a Stream

Two parts: a “source” and a “sink”.

The source and/or the sink may be a networked process (a) or an actual end-device (b).

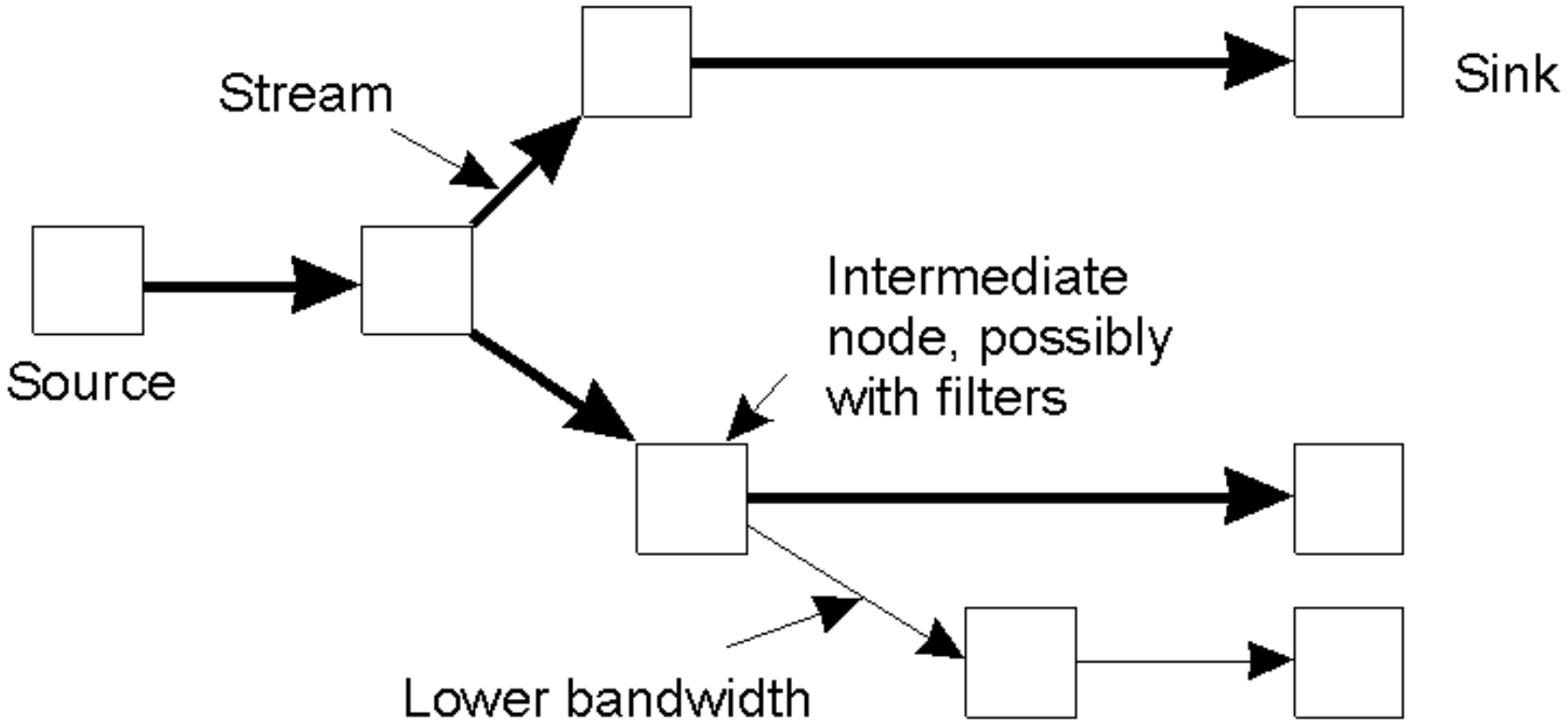


End-device to End-device Streams



Setting up a stream directly between two devices – i.e., no inter-networked processes.

Multi-party Data Streams



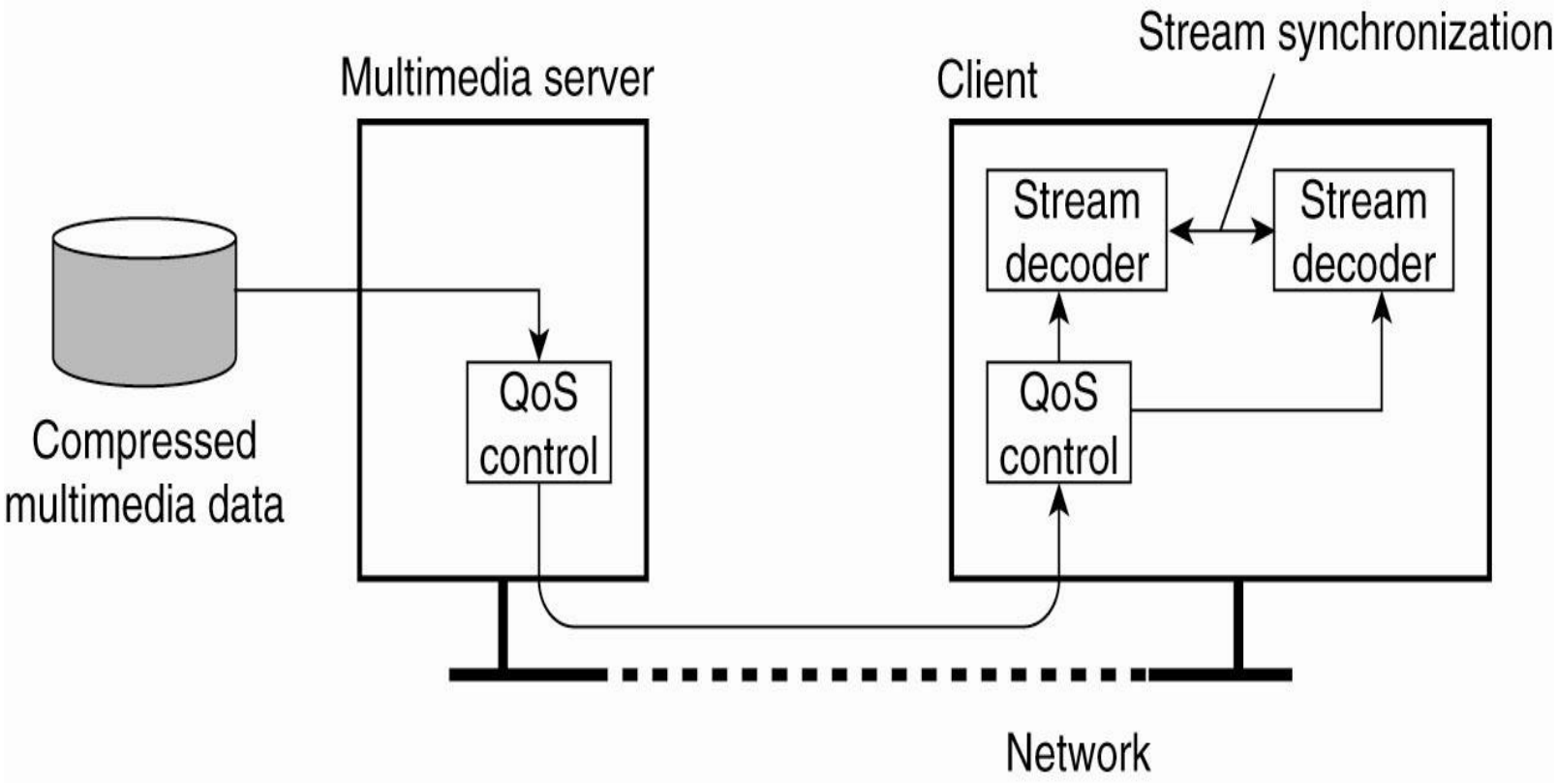
An example of multicasting a stream to several receivers.

This is “multiparty communications” – different delivery transfer rates may be required by different end-devices.

Quality of Service (QoS)

- Definition: “ensuring that the temporal relationships in the stream can be preserved”.
- QoS is all about three things:
  1. Timeliness
  2. Volume
  3. Reliability
- But, how is QoS actually specified?
- Unfortunately, most technologies do their own thing.

Data Stream

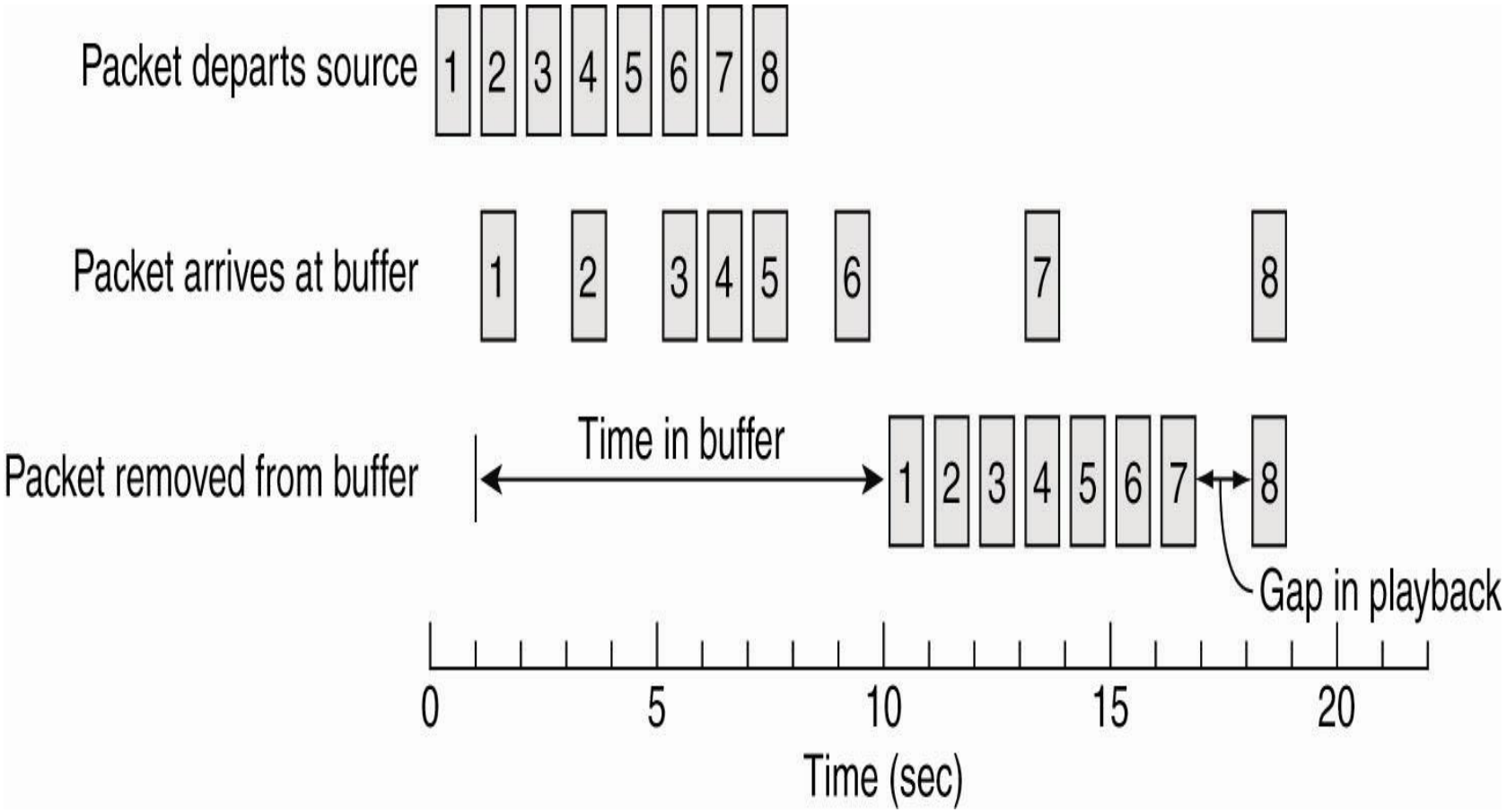


A general architecture for streaming stored multimedia data over a network

Streams and Quality of Service

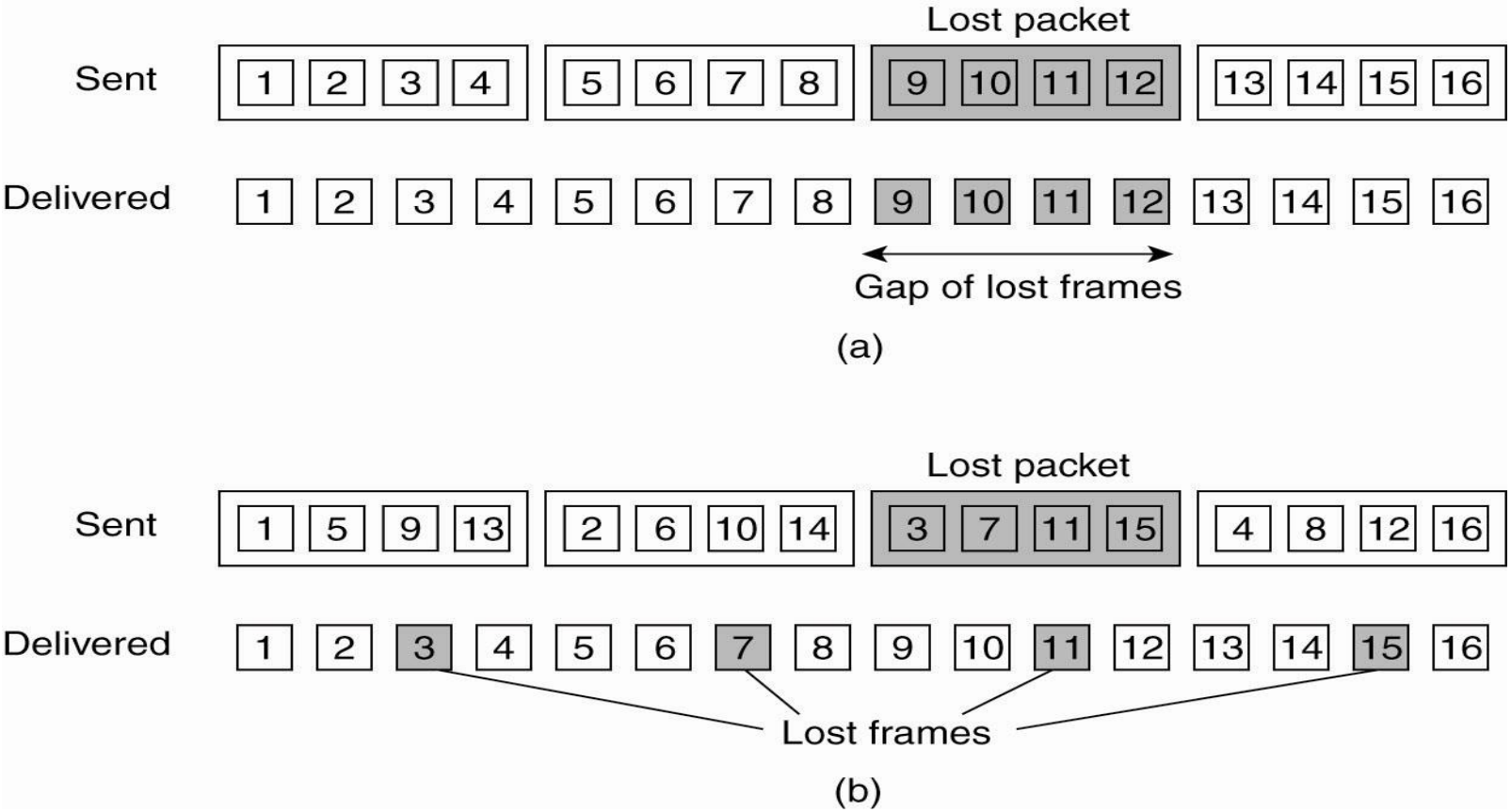
- Properties for Quality of Service (QoS):
- The required bit rate at which data should be transported.
- The maximum delay until a session has been set up.
- The maximum end-to-end delay.
- The maximum delay variance, or jitter.
- The maximum round-trip delay.

Enforcing QoS (1)



Using a buffer to reduce jitter

Enforcing QoS (2)

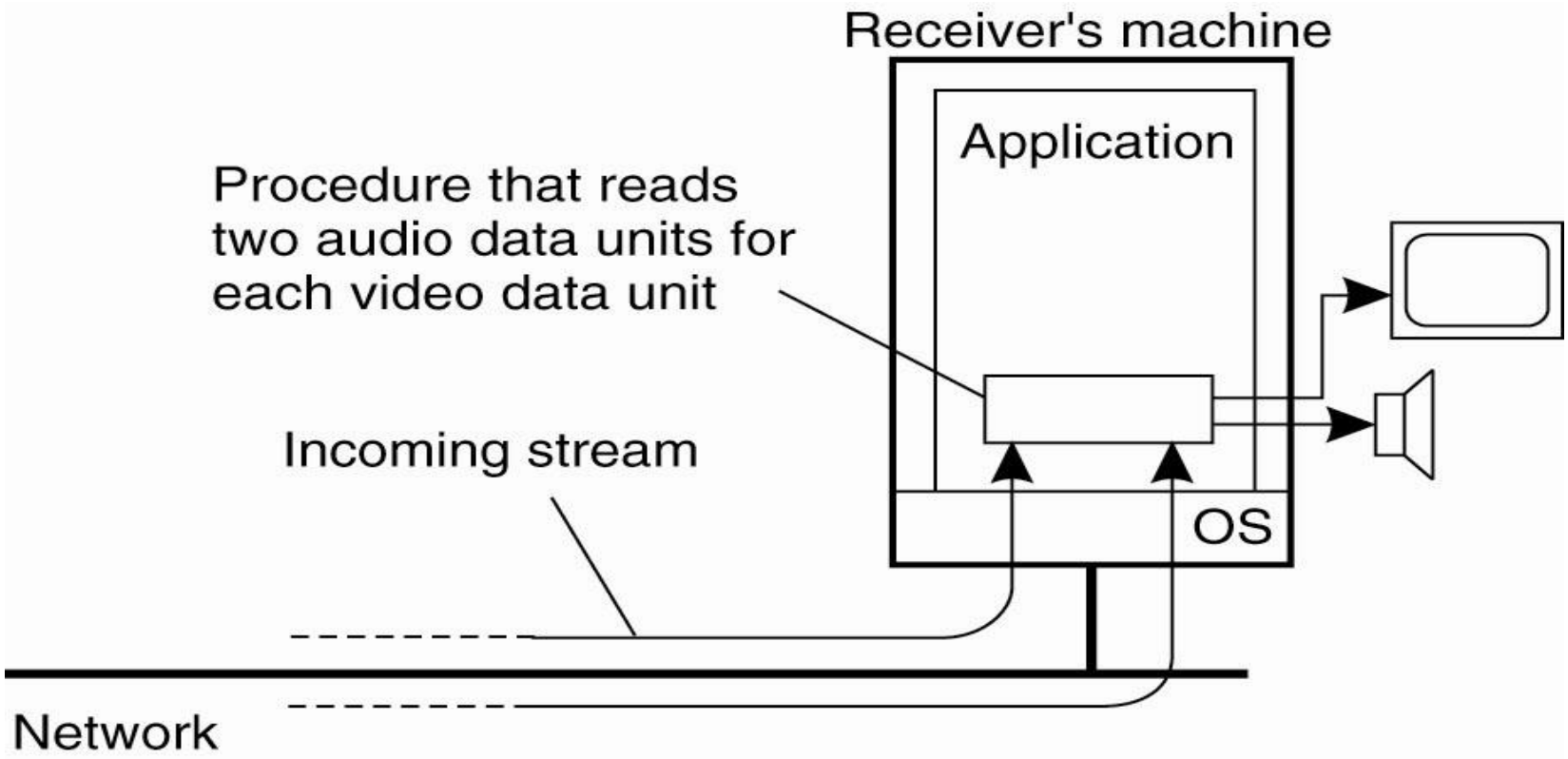


The effect of packet loss in (a) non interleaved transmission and (b) interleaved transmission

Stream Synchronization

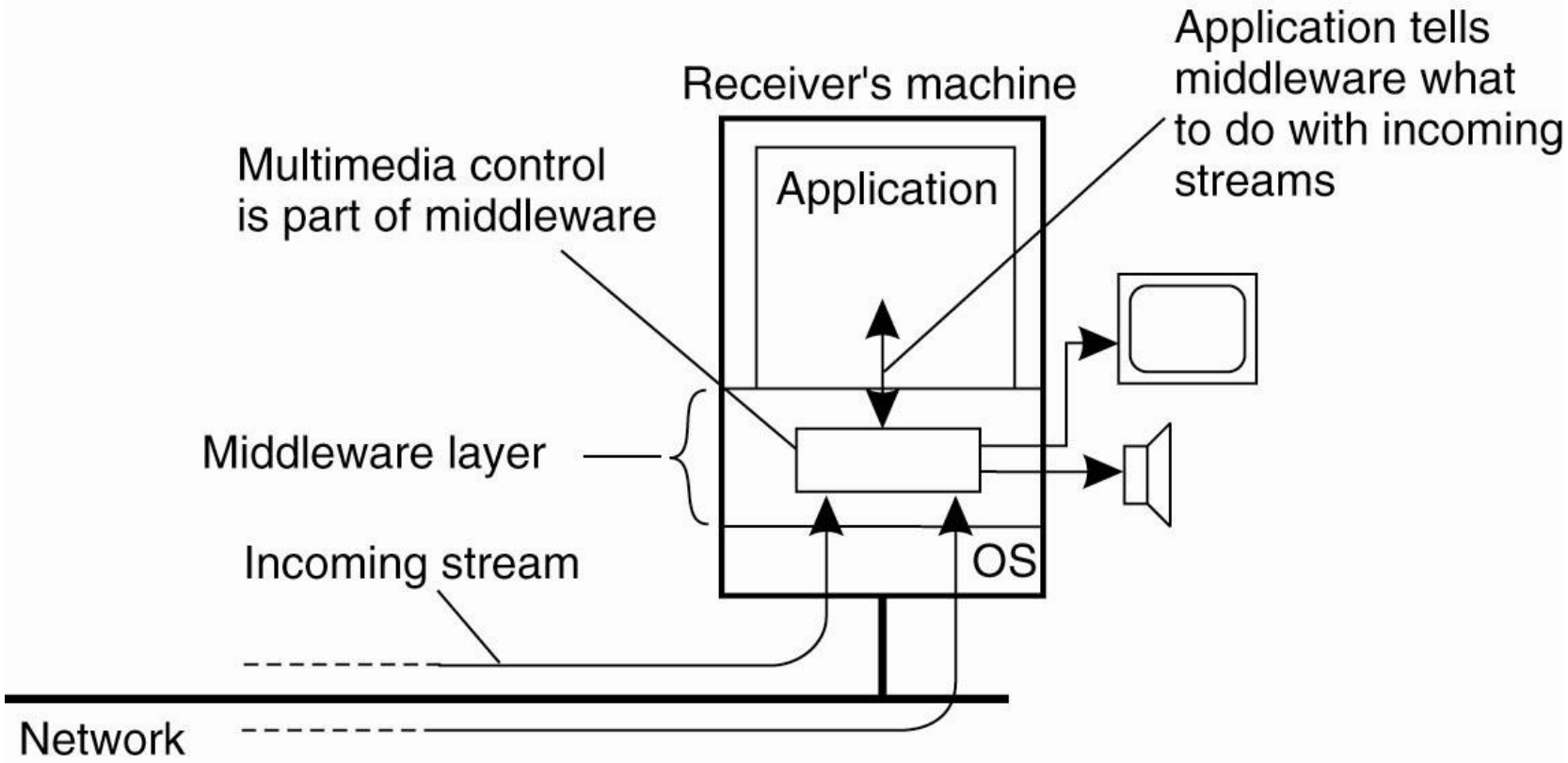
- A key question is:
  - "Where does the synchronization occur?"
    - On the sending side?
    - On the receiving side?
- Think about the advantages/disadvantages of each …

Synchronization Mechanisms (1)



The principle of explicit synchronization on the level data units

Synchronization Mechanisms (2)



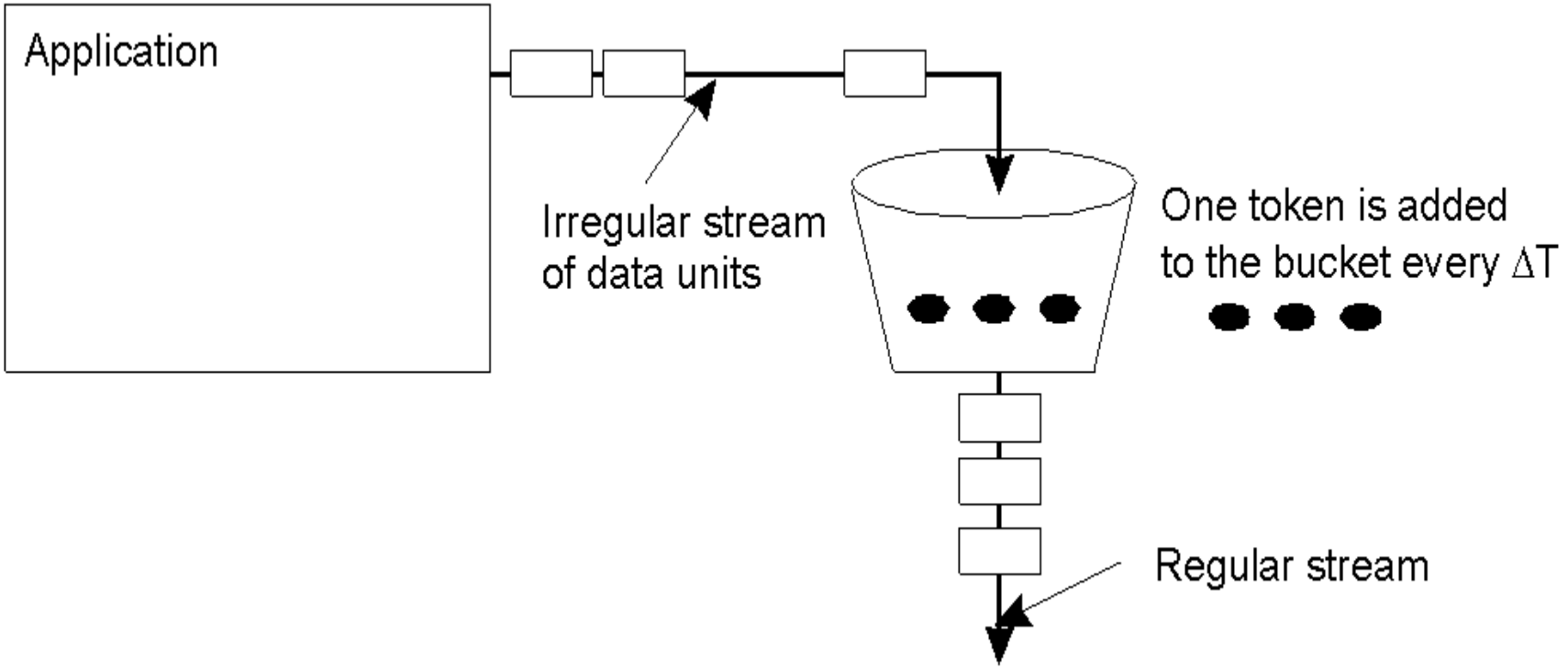
The principle of synchronization as supported by high-level interfaces

Specifying QoS with Flow Specifications

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

A flow specification – one way of specifying QoS – a little complex, but it does work (but not via a user controlled interface).

An Approach to Implementing QoS

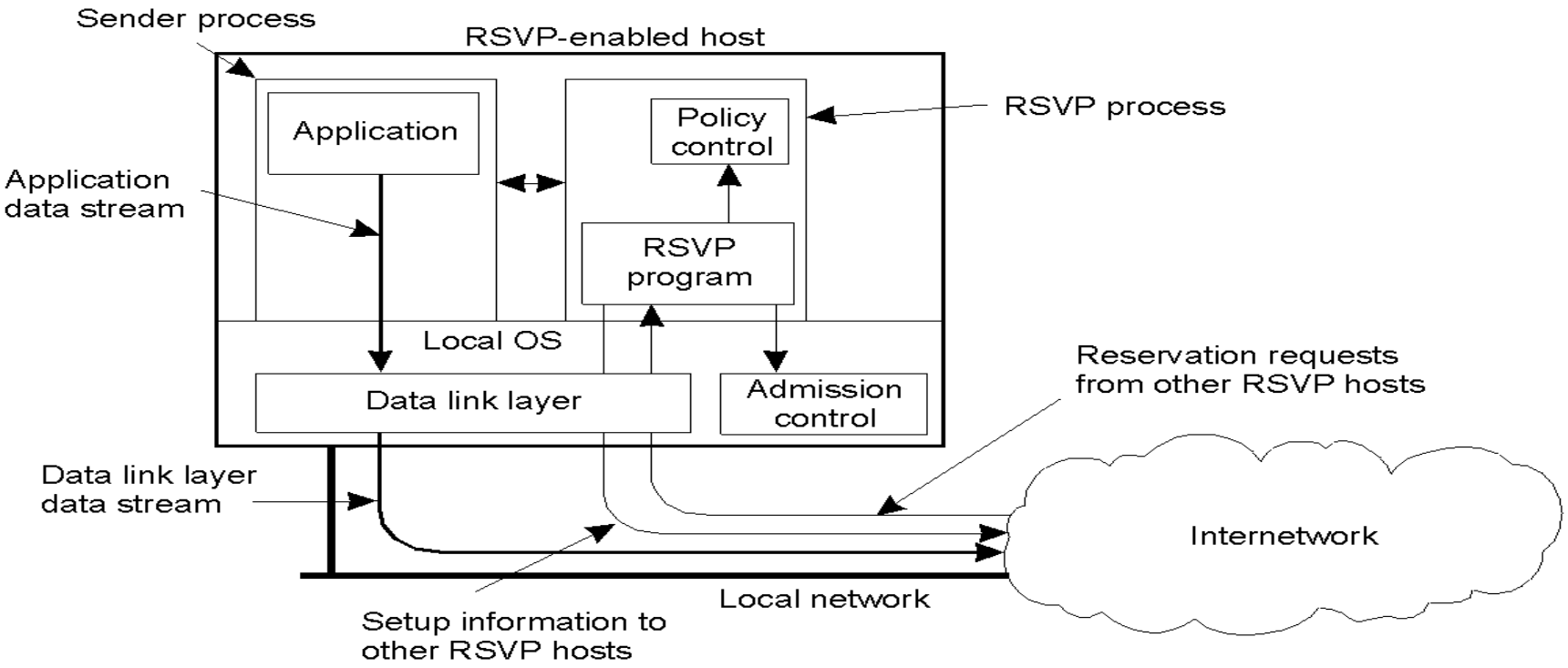


The principle of a token bucket algorithm – a "classic" technique for controlling the flow of data (and implementing QoS characteristics).

Stream Management

- Managing streams is all about managing bandwidth, buffers, processing capacity and scheduling priorities – which are all needed in order to realize QoS guarantees.
- This is not as simple as it sounds, and there's no general agreement as to "how" it should be done.
- For instance: ATM's QoS (which is very "rich") has proven to be unworkable (difficult to implement).
- Another technique is the Internet's RSVP.

Internet RSVP QoS



The basic organization of RSVP for resource reservation in a distributed system – transport-level control protocol for enabling resource reservations in routers.

Interesting characteristic: *receiver initiated*.