Distributed Systems
Principles and Paradigms

Chapter 02

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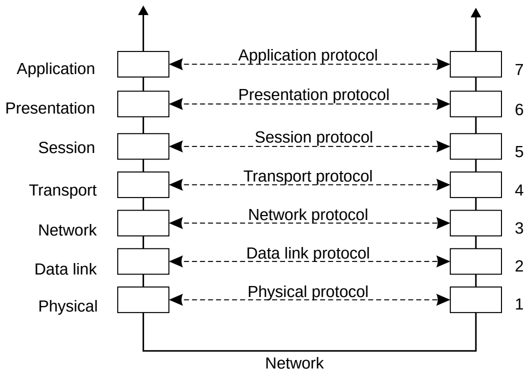
Layered Protocols

- Low-level layers
- Transport layer
- Application layer
- Middleware layer

Basic Networking Model



Drawbacks:

- Focus on message-passing only
- Often unneeded or unwanted functionality
- **Question:** Violates transparency?

Low-level layers

Physical layer: contains the specification and implementation of bits, and their transmission between sender and receiver

Data link layer: prescribes the transmission of a series of bits into a frame to allow for error and flow control

Network layer: describes how packets in a network of computers are to be *routed*.

Observation: for many distributed systems, the lowest-level interface is that of the network layer.

Transport Layer

Important: The transport layer provides the actual communication facilities for most distributed systems.

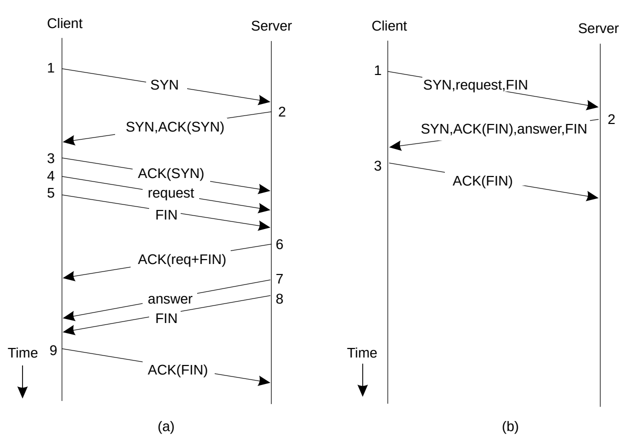
Standard Internet protocols:

- TCP: connection-oriented, reliable, stream-oriented communication
- UDP: unreliable (best-effort) datagram communication

Note: IP multicasting is generally considered a standard available service.

Client–Server TCP

TCP for transactions (T/TCP): A transport protocol aimed to support client–server interaction



Application Layer

Observation: Many application protocols are directly implemented on top of transport protocols, doing a lot of application-independent work.

	News	**FTP**	**WWW**
Transfer	NNTP	FTP	HTTP
Encoding	7-bit + MIME	7-bit text + 8-bit binary (user has to guess)	8-bit + content type
Naming	Newsgroup	Host + path	URL
Distribution	Push	Pull	Pull
Replication	Flooding	Caching + DNS tricks	Caching + DNS tricks
Security	None (PGP)	Username + Password	Username + Password

Middleware Layer

Observation: Middleware is invented to provide **common** services and protocols that can be used by many *different* applications:

- A rich set of communication protocols, but which allow different applications to communicate
- Marshaling and unmarshaling of data, necessary for integrated systems
- Naming protocols, so that different applications can easily share resources
- Security protocols, to allow different applications to communicate in a secure way
- Scaling mechanisms, such as support for replication and caching

Note: what remains are truly *application-specific* protocols

Question: Such as...?

Remote Procedure Call (RPC)

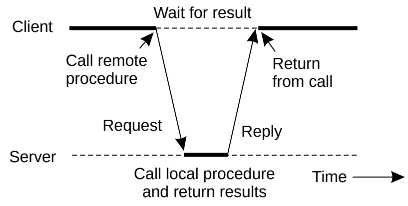
- Basic RPC operation
- Parameter passing
- Variations

Basic RPC Operation

Observations:

- Application developers are familiar with simple procedure model
- Well-engineered procedures operate in isolation (black box)
- There is no fundamental reason not to execute procedures on separate machine

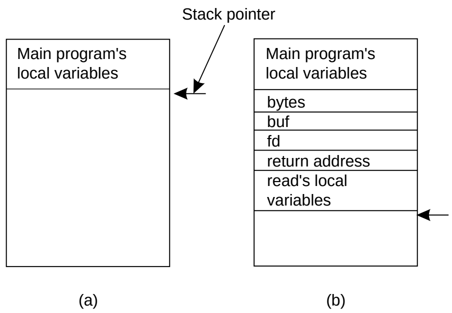
Conclusion: communication between caller & callee can be hidden by using procedure-call mechanism.



RPC Implementation (1/2)

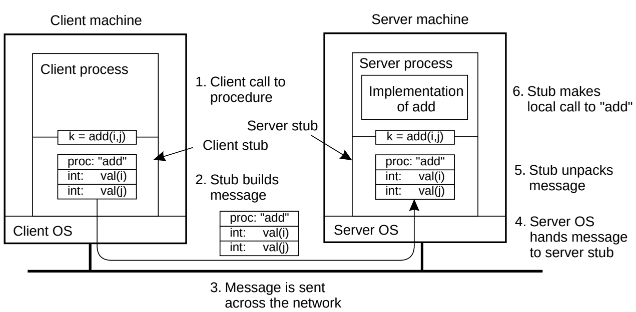
Local procedure call: (read(int fd, char* buf, int nbytes))

1: Push parameter values of the procedure on a stack
2: Call procedure
3: Use stack for local variables
4: Pop results (in parameters)



Principle: "communication" with local procedure is handled by copying data to/from the stack (with a few exceptions)

RPC Implementation (2/2)



RPC: Parameter Passing (1/2)

Parameter marshaling: There's more than just wrapping parameters into a message:

- Client and server *machines* may have different data representations (think of byte ordering)
- Wrapping a parameter means transforming a value into a sequence of bytes
- Client and server have to agree on the same encoding:
  - How are basic data values represented (integers, floats, characters)
  - How are complex data values represented (arrays, unions)
- Client and server need to properly interpret messages, transforming them into machine-dependent representations.

RPC: Parameter Passing (2/2)

RPC parameter passing:

- RPC assumes **copy in/copy out** semantics: while procedure is executed, nothing can be assumed about parameter values (only Ada supports this model).
- RPC assumes *all* data that is to be operated on is passed by parameters. Excludes passing **references** to (global) data.

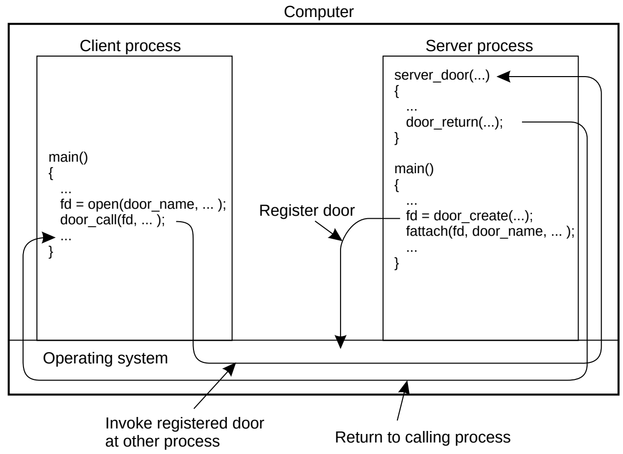
Conclusion: full access transparency cannot be realized.

Observation: If we introduce a **remote reference** mechanism, access transparency can be enhanced:

- Remote reference offers unified access to remote data
- Remote references can be passed as parameter in RPCs

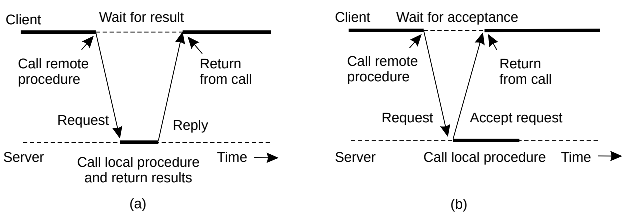
Local RPCs: Doors

Essence: Try to use the RPC mechanism as the only mechanism for **interprocess communication** (IPC). Doors are RPCs implemented for processes on the same machine.

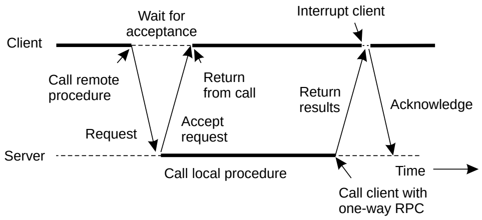


Asynchronous RPCs

Essence: Try to get rid of the strict request-reply behavior, but let the client continue without waiting for an answer from the server.

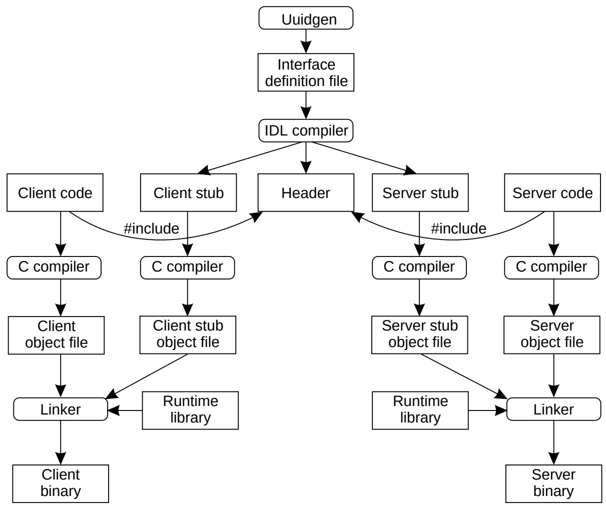


Variation: **deferred synchronous RPC**:



RPC in Practice

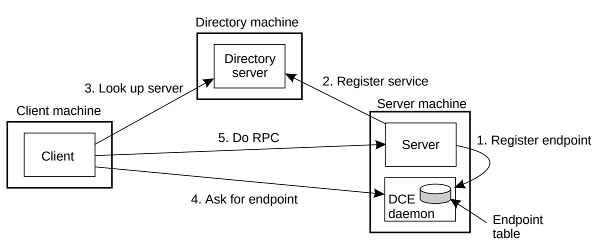
Essence: Let the developer concentrate on only the client- and server-specific code; let the RPC system (generators and libraries) do the rest.



Client-to-Server Binding (DCE)

Issues: (1) Client must locate server machine, and (2) locate the server.

Example: DCE uses a separate daemon for each server machine.

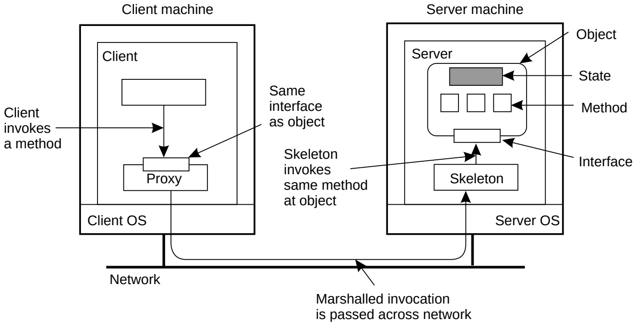


Remote Object Invocation

- Distributed objects
- Remote method invocation
- Parameter passing

Remote Distributed Objects (1/2)

- Data and operations **encapsulated** in an object
- Operations are implemented as **methods**, and are accessible through **interfaces**
- Object offers only its **interface** to clients
- **Object server** is responsible for a collection of objects
- **Client stub (proxy)** implements interface
- **Server skeleton** handles (un)marshaling and object invocation



Remote Distributed Objects (2/2)

Compile-time objects: Language-level objects, from which proxy and skeletons are automatically generated.

Runtime objects: Can be implemented in any language, but require use of an **object adapter** that makes the implementation *appear* as an object.

Transient objects: live only by virtue of a server: if the server exits, so will the object.

Persistent objects: live independently from a server: if a server exits, the object's state and code remain (passively) on disk.

Client-to-Object Binding (1/2)

Object reference: Having an object reference allows a client to **bind** to an object:

- Reference denotes server, object, and communication protocol
- Client loads associated stub code
- Stub is instantiated and initialized for specific object

Two ways of binding:

- **Implicit:** Invoke methods directly on the referenced object
- **Explicit:** Client must first explicitly bind to object before invoking it

Client-to-Object Binding (2/2)

Distr_object* obj_ref; obj_ref = ...; obj_ref→do_something();	**Implicit**
Distr_object obj_ref; Local_object* obj_ptr; obj_ref = ...; obj_ptr = bind(obj_ref); obj_ptr→do_something();	**Explicit**

Some remarks:

- Reference may contain a URL pointing to an implementation file
- (Server,object) pair is enough to locate target object
- We need only a standard protocol for loading and instantiating code

Observation: Remote-object references allows us to pass references as parameters. This was difficult with ordinary RPCs.

Remote Method Invocation

Basics: (Assume client stub and server skeleton are in place)

- Client invokes method at stub
- Stub marshals request and sends it to server
- Server ensures referenced object is active:
  - Create separate process to hold object
  - Load the object into server process
  - ...
- Request is unmarshaled by object's skeleton, and referenced method is invoked
- If request contained an object reference, invocation is applied recursively (i.e., server acts as client)
- Result is marshaled and passed back to client
- Client stub unmarshals reply and passes result to client application

RMI: Parameter Passing (1/2)

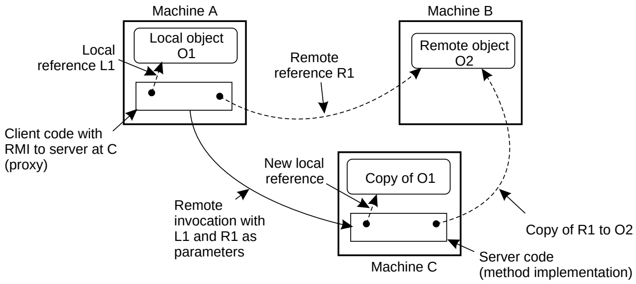
Object reference: Much easier than in the case of RPC:

- Server can simply bind to referenced object, and invoke methods
- Unbind when referenced object is no longer needed

Object-by-value: A client may also pass a complete object as parameter value:

- An object has to be marshaled:
  - Marshall its state
  - Marshall its methods, or give a reference to where an implementation can be found
- Server unmarshals object. Note that we have now created a *copy* of the original object.
- Object-by-value passing tends to introduce nasty problems

RMI: Parameter Passing (2/2)



Question: What's an alternative implementation for a remote-object reference?

Message-Oriented Communication

- Synchronous versus asynchronous communications
- Message-Queuing System
- Message Brokers
- Example: IBM MQSeries

Synchronous Communication

Some observations: Client/Server computing is generally based on a model of **synchronous communication**:

- Client and server have to be active at the time of communication
- Client issues request and blocks until it receives reply
- Server essentially waits only for incoming requests, and subsequently processes them

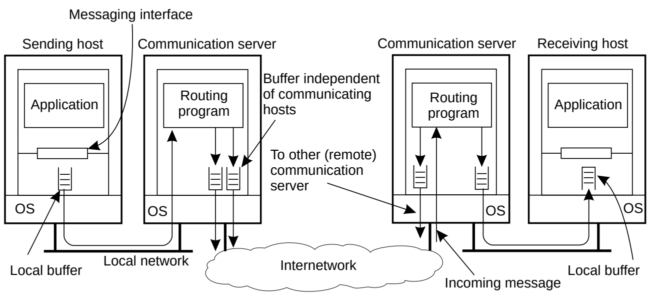
Drawbacks synchronous communication:

- Client cannot do any other work while waiting for reply
- Failures have to be dealt with immediately (the client is waiting)
- In many cases the model is simply not appropriate (mail, news)

Asynchronous Communication: Messaging

Message-oriented middleware: Aims at high-level **asynchronous** communication:

- Processes send each other messages, which are queued
- Sender need not wait for immediate reply, but can do other things
- Middleware often ensures fault tolerance

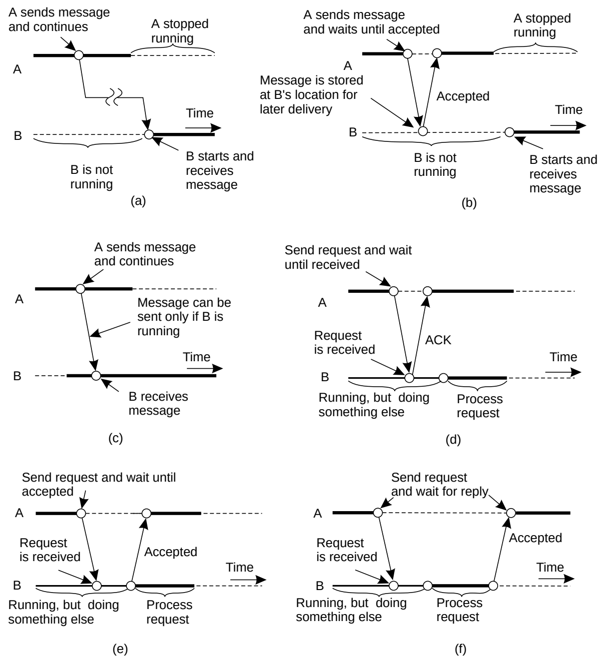


Persistent vs. Transient Communication

Persistent communication: A message is stored at a communication server as long as it takes to deliver it at the receiver.

Transient communication: A message is discarded by a communication server as soon as it cannot be delivered at the next server, or at the receiver.

Messaging Combinations



Message-Oriented Middleware

Essence: Asynchronous persistent communication through support of middleware-level **queues**. Queues correspond to buffers at communication servers.

Canonical example: IBM MQSeries

IBM MQSeries (1/3)

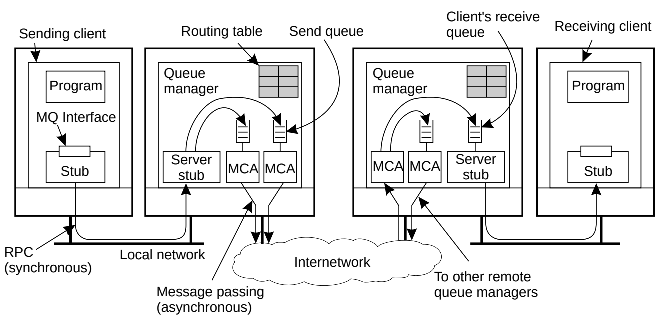
Basic concepts:

- **Application-specific messages** are put into, and removed from **queues**
- Queues always reside under the regime of a **queue manager**
- Processes can put messages only in local queues, or through an RPC mechanism

Message transfer:

- Messages are transferred between queues
- Message transfer between queues at different processes, requires a **channel**
- At each endpoint of channel is a **message channel agent**
- Message channel agents are responsible for:
  - Setting up channels using lower-level network communication facilities (e.g., TCP/IP)
  - (Un)wrapping messages from/in transport-level packets
  - Sending/receiving packets

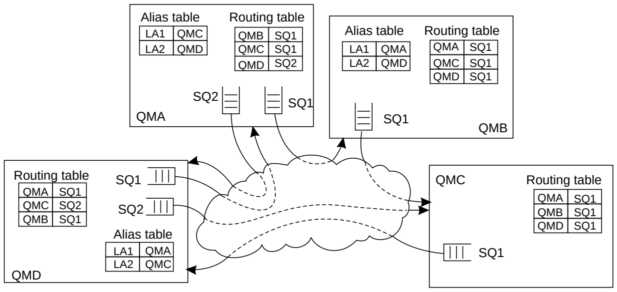
IBM MQSeries (2/3)



- Channels are inherently unidirectional
- MQSeries provides mechanisms to automatically start MCAs when messages arrive, or to have a receiver set up a channel
- Any network of queue managers can be created; routes are set up manually (system administration)

IBM MQSeries (3/3)

Routing: By using **logical names**, in combination with name resolution to local queues, it is possible to put a message in a **remote queue**



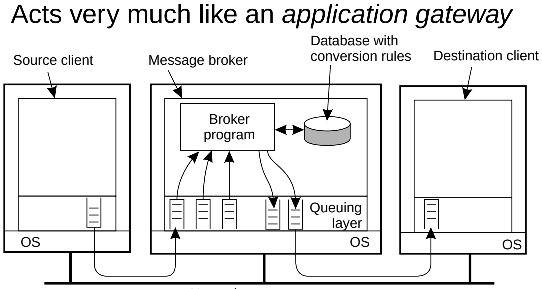
Question: What's a major problem here?

Message Broker

Observation: Message queuing systems assume a *common messaging protocol*: all applications agree on message format (i.e., structure and data representation)

Message broker: Centralized component that takes care of application heterogeneity in a message-queuing system:

- Transforms incoming messages to target format, possibly using intermediate representation
- May provide *subject-based* routing capabilities
- Acts very much like an *application gateway*



Stream-Oriented Communication

- Support for continuous media
- Streams in distributed systems
- Stream management

Continuous Media

Observation: All communication facilities discussed so far are essentially based on a *discrete*, that is *time-independent* exchange of information

Continuous media: Characterized by the fact that values are time dependent:

- Audio
- Video
- Animations
- Sensor data (temperature, pressure, etc.)

Transmission modes: Different timing guarantees with respect to data transfer:

- **Asynchronous:** no restrictions with respect to *when* data is to be delivered
- **Synchronous:** define a maximum end-to-end delay for individual data packets
- **Isochronous:** define a maximum and minimum end-to-end delay (**jitter** is bounded)

Stream (1/2)

Definition: A (continuous) data stream is a connection-oriented communication facility that supports isochronous data transmission

Some common stream characteristics:

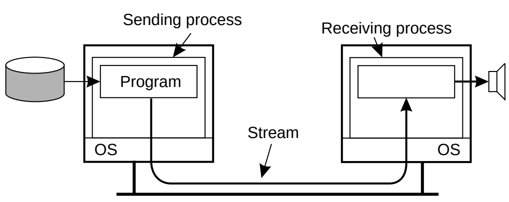
- Streams are unidirectional
- There is generally a single **source**, and one or more **sinks**
- Often, either the sink and/or source is a wrapper around hardware (e.g., camera, CD device, TV monitor, dedicated storage)

Stream types:

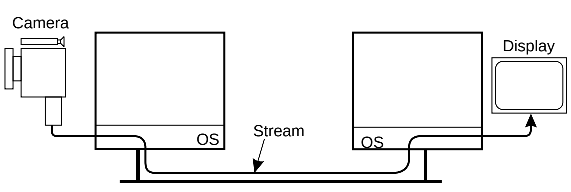
- Simple: consists of a single flow of data, e.g., audio or video
- Complex: multiple data flows, e.g., stereo audio or combination audio/video

Stream (2/2)

Issue: Streams can be set up between two processes at different machines, or directly between two different devices. Combinations are possible as well.



(a)

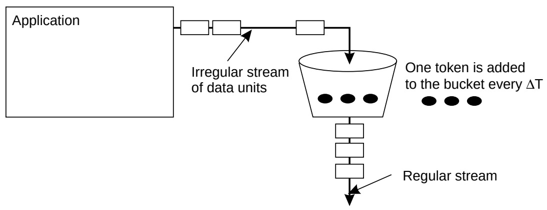


(b)

Streams and QoS

Essence: Streams are all about timely delivery of data. How do you specify this **Quality of Service** (**QoS**)? Make distinction between **specification** and **implementation** of QoS.

Flow specification: Use a token-bucket model and express QoS in that model

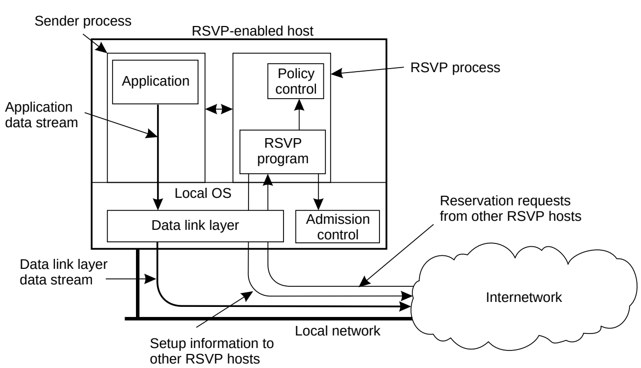


Input characteristics	Required Service
Maximum data unit size (bytes)	Loss sensitivity (bytes)
Token bucket rate (bytes/sec)	Loss interval (μsec)
Token bucket size (bytes)	Burst loss sensitivity (data units)
Max. transmission rate (bytes/sec)	Min. delay noticed (μsec)
	Max. delay variation (μsec)
	Quality of guarantee

Implementing QoS

Problem: QoS specifications translate to resource reservations in underlying communication system. There is no standard way of (1) QoS specs, (2) describing resources, (3) mapping specs to reservations.

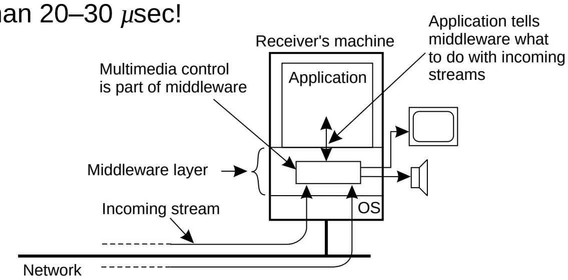
Approach: Use Resource reSerVation Protocol (RSVP) as first attempt. RSVP is a *transport-level* protocol.



Stream Synchronization

Problem: Given a complex stream, how do you keep the different substreams in synch?

Example: Think of playing out two channels, that together form stereo sound. Difference should be less than 20–30 μsec!



Alternative: multiplex all substreams into a single stream, and demultiplex at the receiver. Synchronization is handled at multiplexing/demultiplexing point (MPEG).