Communications

Distributed Systems

Middleware layer

Observation

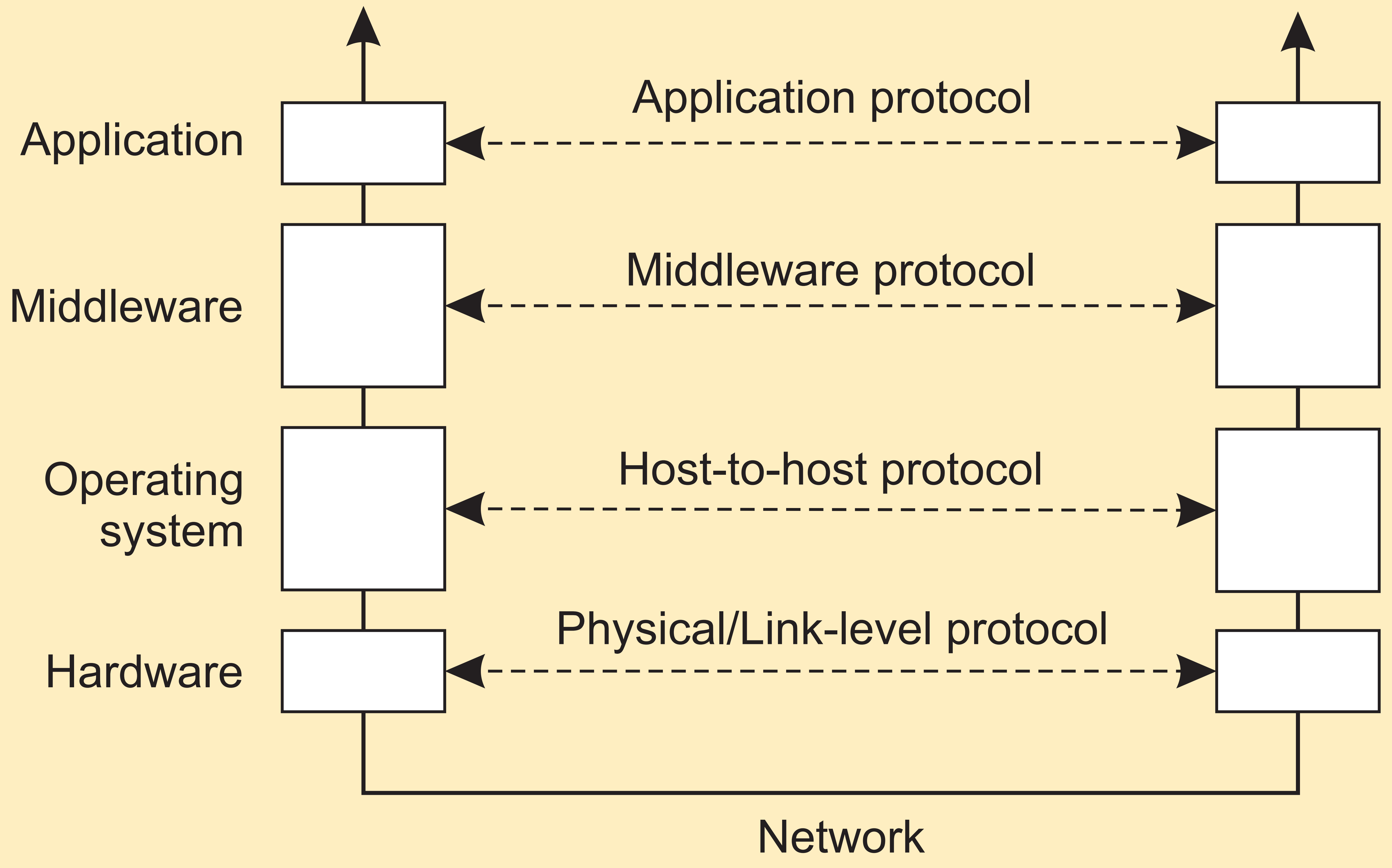
Middleware is invented to provide common services and protocols that can be used by many different applications

- A rich set of communication protocols
- (Un)marshaling of data, necessary for integrated systems
- Naming protocols, to allow easy sharing of resources
- Security protocols for secure communication
- Scaling mechanisms, such as for replication and caching

Note

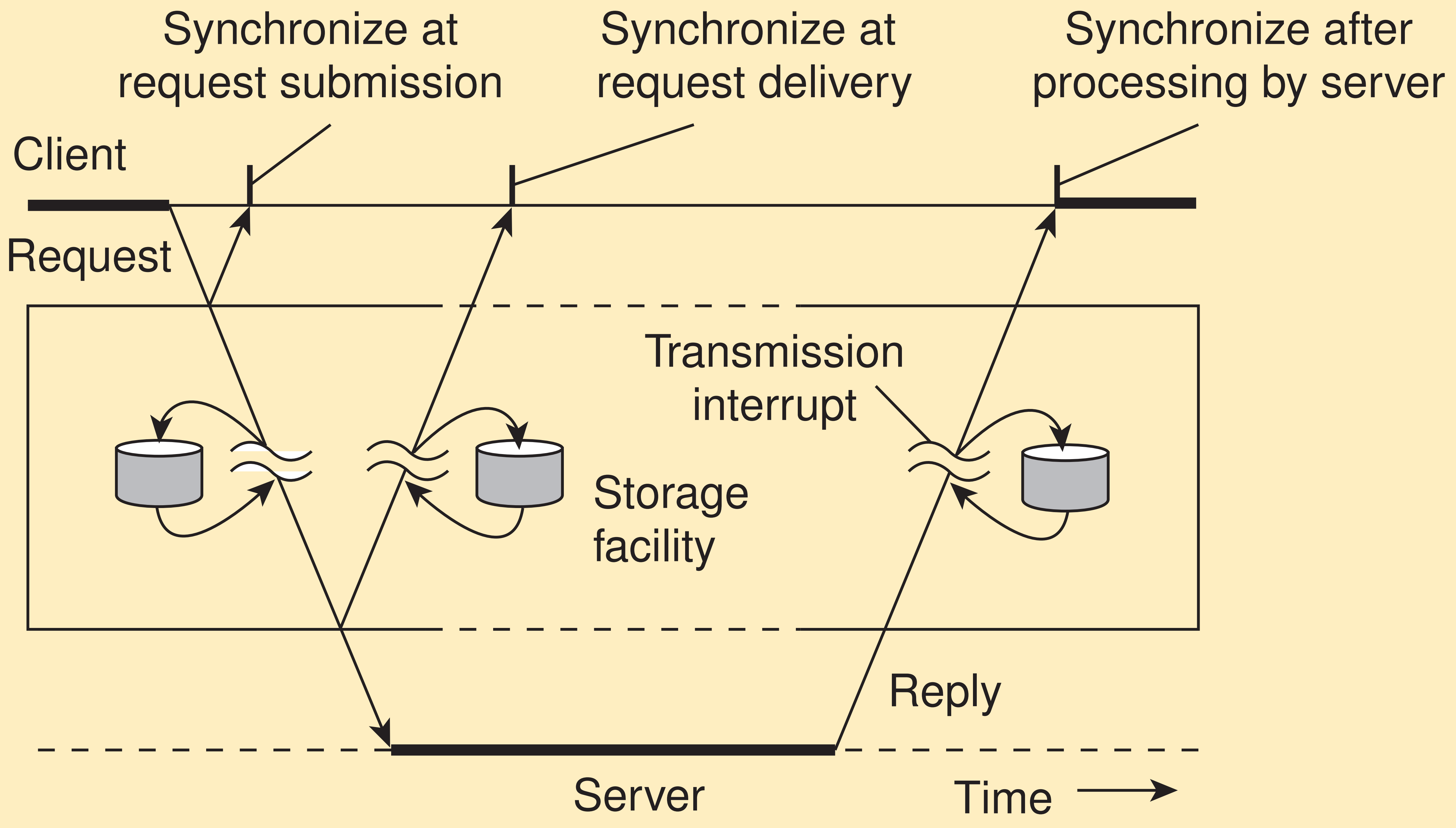
What remains are truly application-specific protocols.

An adapted layering scheme



Types of communication

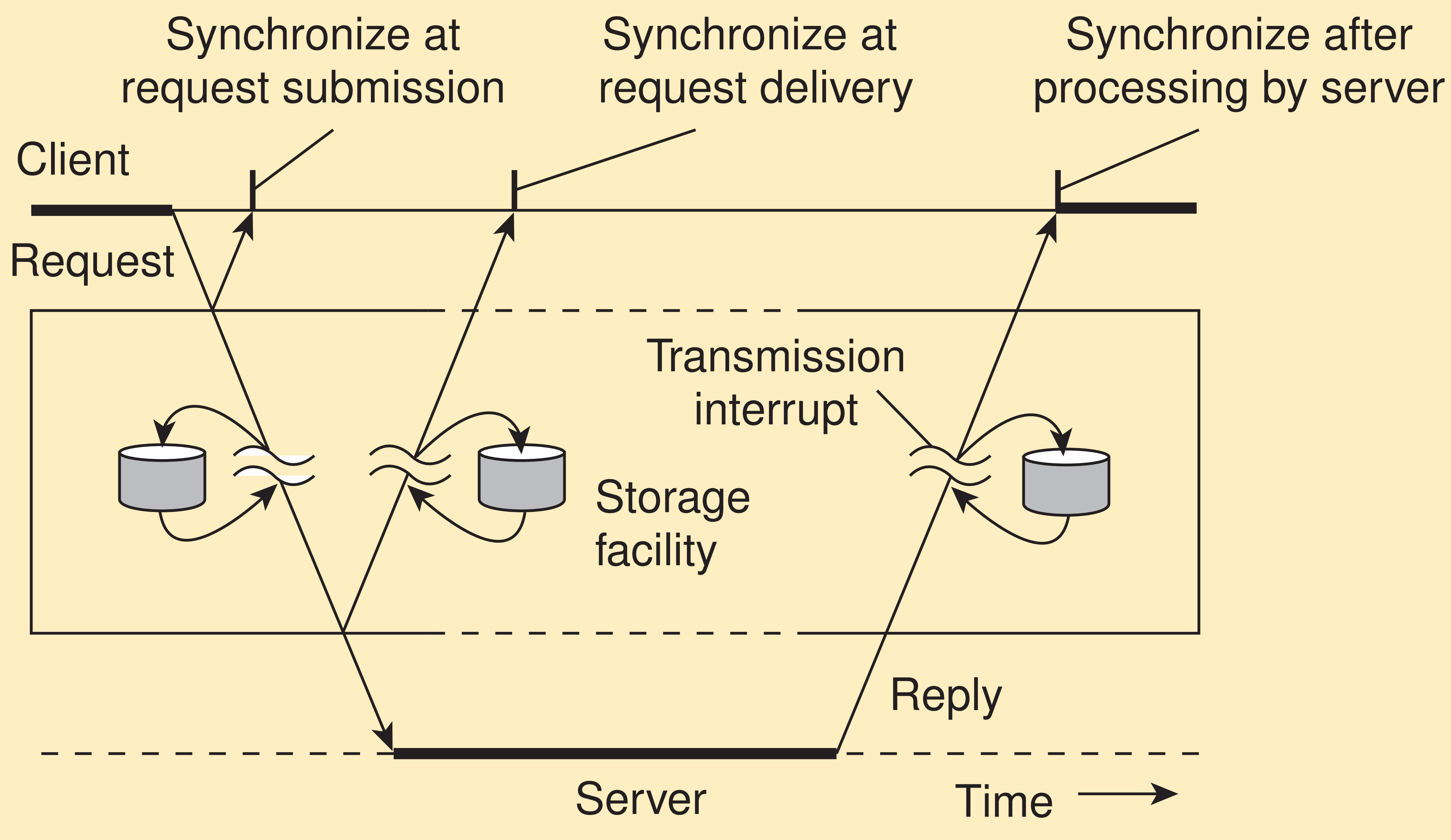
Distinguish...



- Transient versus persistent communication
- Asynchronous versus synchronous communication

Types of communication

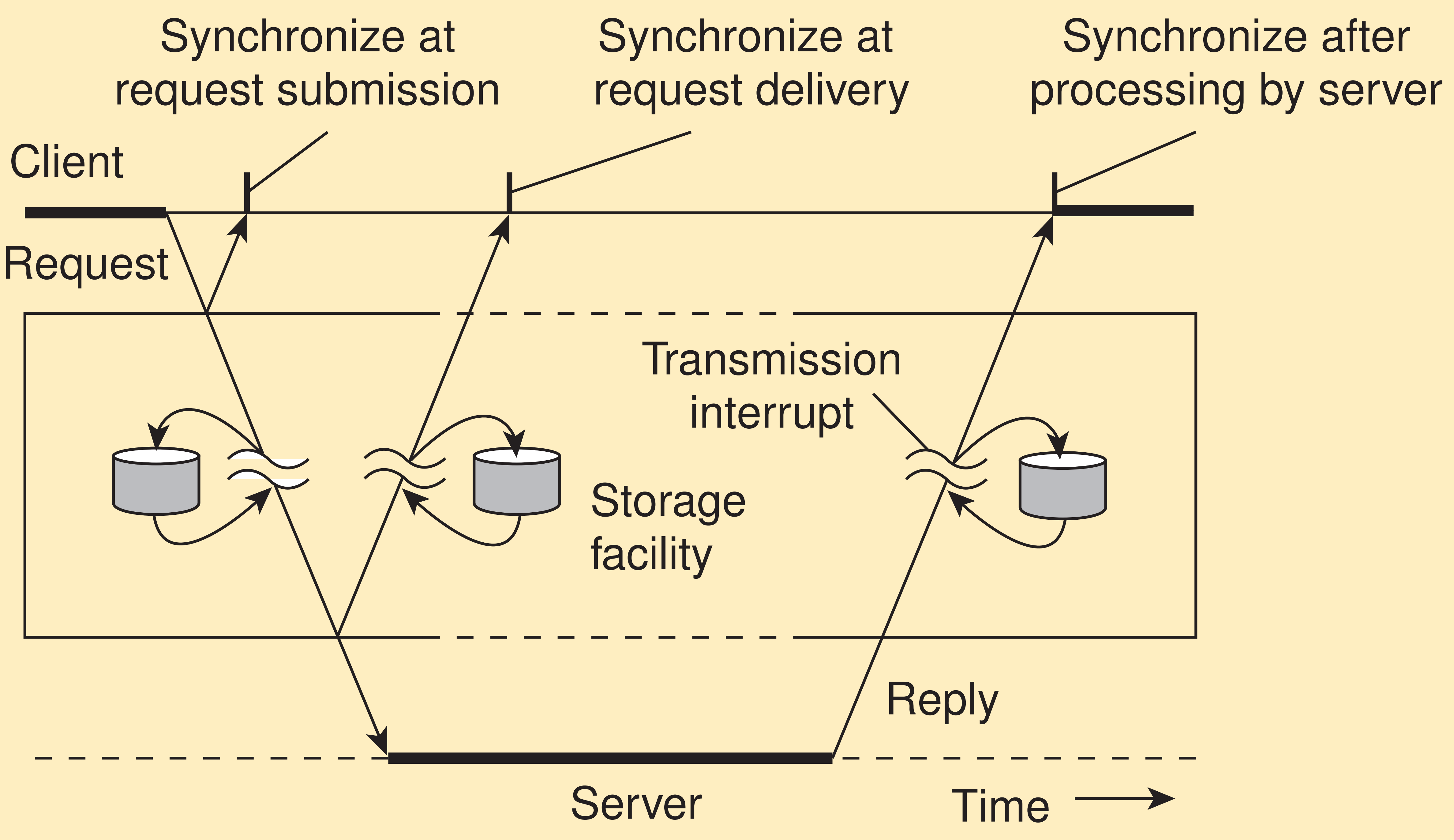
Transient versus persistent



- Transient communication: Comm. server discards message when it cannot be delivered at the next server, or at the receiver.
- Persistent communication: A message is stored at a communication server as long as it takes to deliver it.

Types of communication

Places for synchronization



- At request submission
- At request delivery
- After request processing

Client/Server

Some observations

Client/Server computing is generally based on a model of transient synchronous communication:

- Client and server have to be active at 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 handled immediately: the client is waiting
- The model may simply not be appropriate (mail, news)

Messaging

Message-oriented middleware

Aims at high-level persistent 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

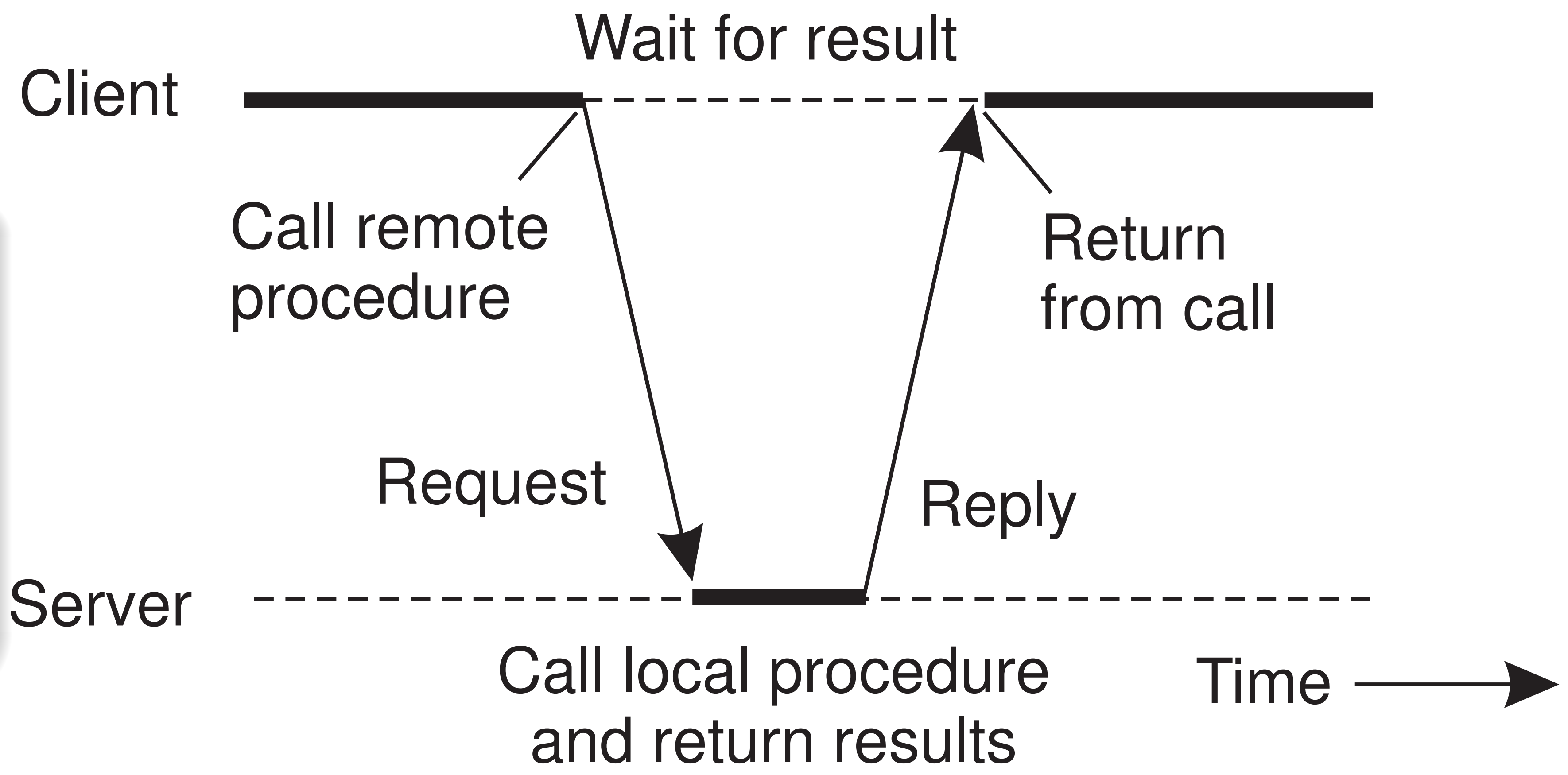
Basic RPC operation

Observations

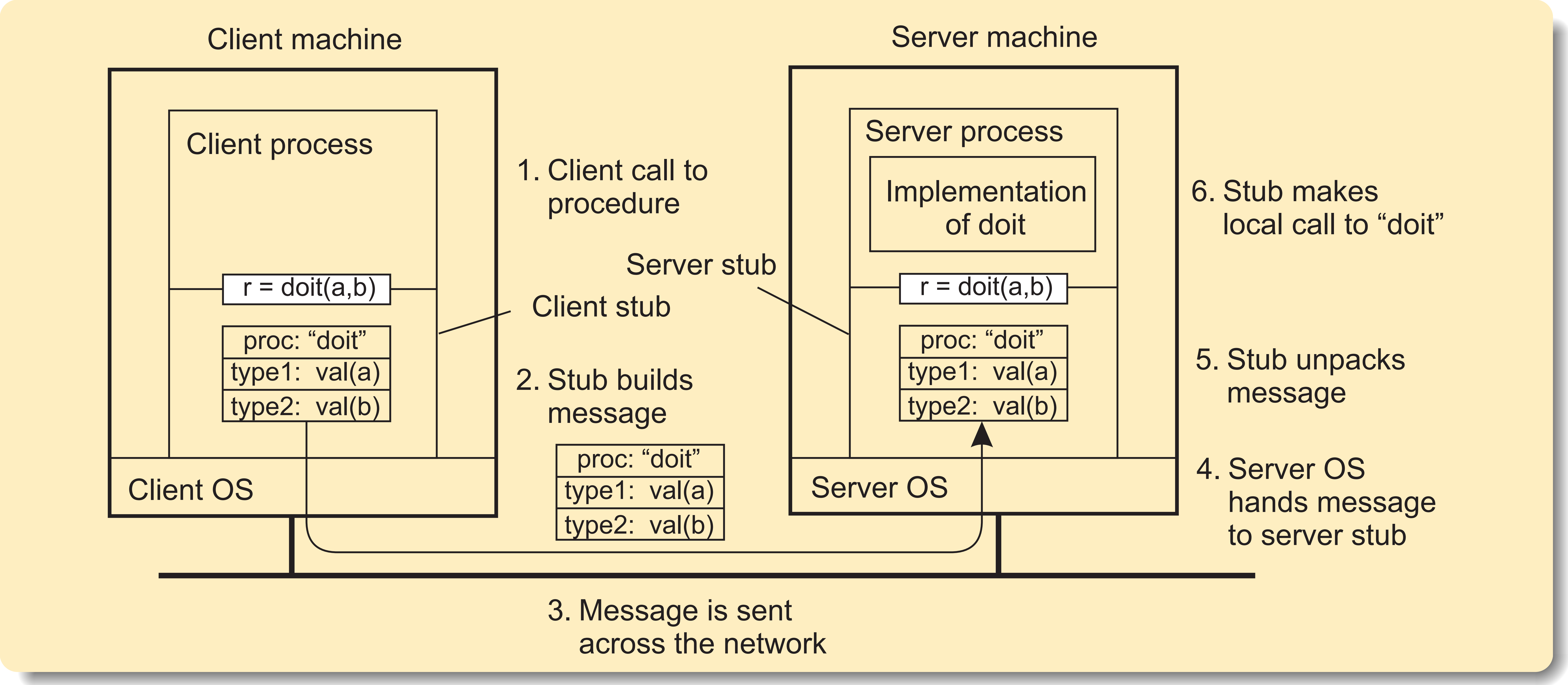
- Application developers are familiar with simple procedure model
- Well-engineered procedures operate in isolation (black box)
- There is no fundamental reason not to execute procedures on separate machine

Conclusion

Communication between caller & callee can be hidden by using procedure-call mechanism.



Basic RPC operation



1. Client procedure calls client stub.
2. Stub builds message; calls local OS.
3. OS sends message to remote OS.
4. Remote OS gives message to stub.
5. Stub unpacks parameters; calls server.
6. Server does local call; returns result to stub.
7. Stub builds message; calls OS.
8. OS sends message to client’s OS.
9. Client’s OS gives message to stub.
10. Client stub unpacks result; returns to client.

RPC: Parameter passing

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)

Conclusion

Client and server need to properly interpret messages, transforming them into machine-dependent representations.

RPC: Parameter passing

Some assumptions

- Copy in/copy out semantics: while procedure is executed, nothing can be assumed about parameter values.
- 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.

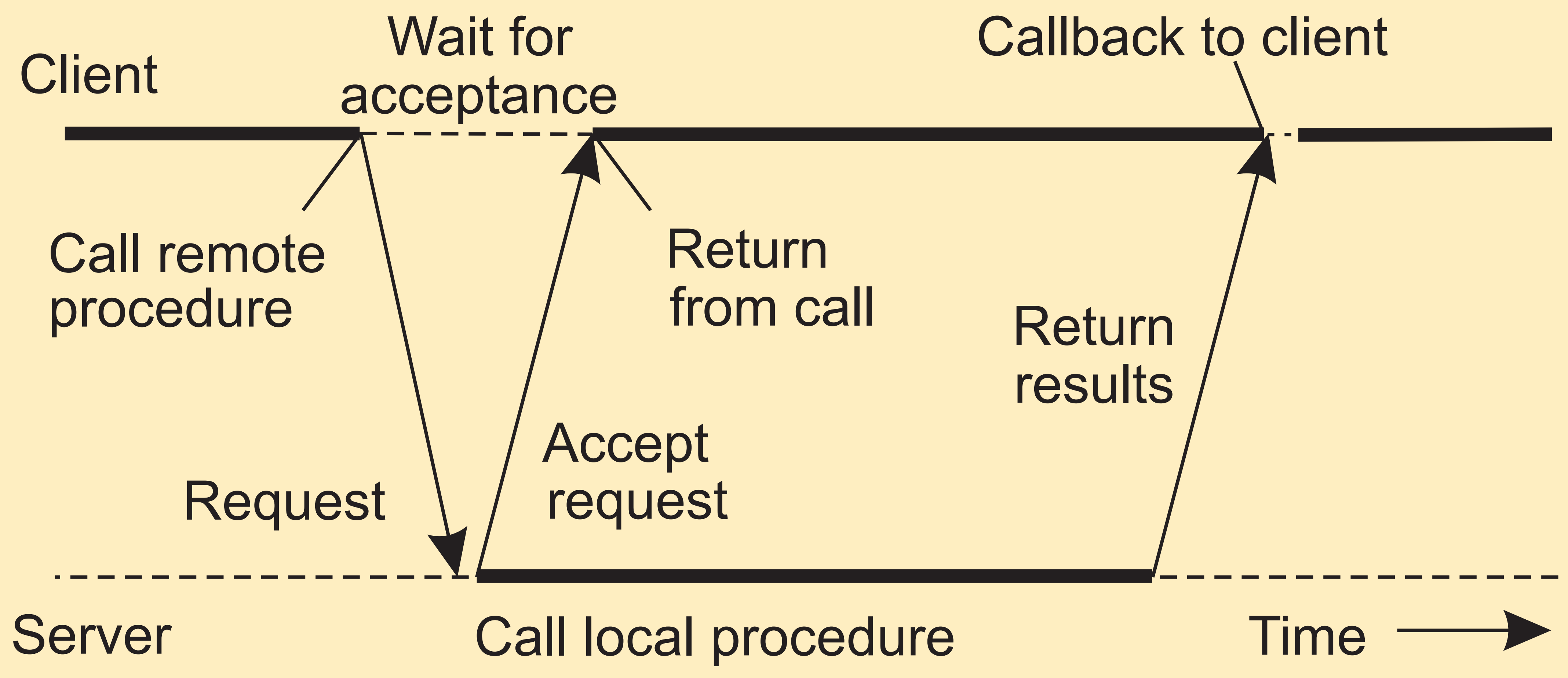
A remote reference mechanism enhances access transparency

- Remote reference offers unified access to remote data
- Remote references can be passed as parameter in RPCs
- Note: stubs can sometimes be used as such references

Asynchronous RPCs

Essence

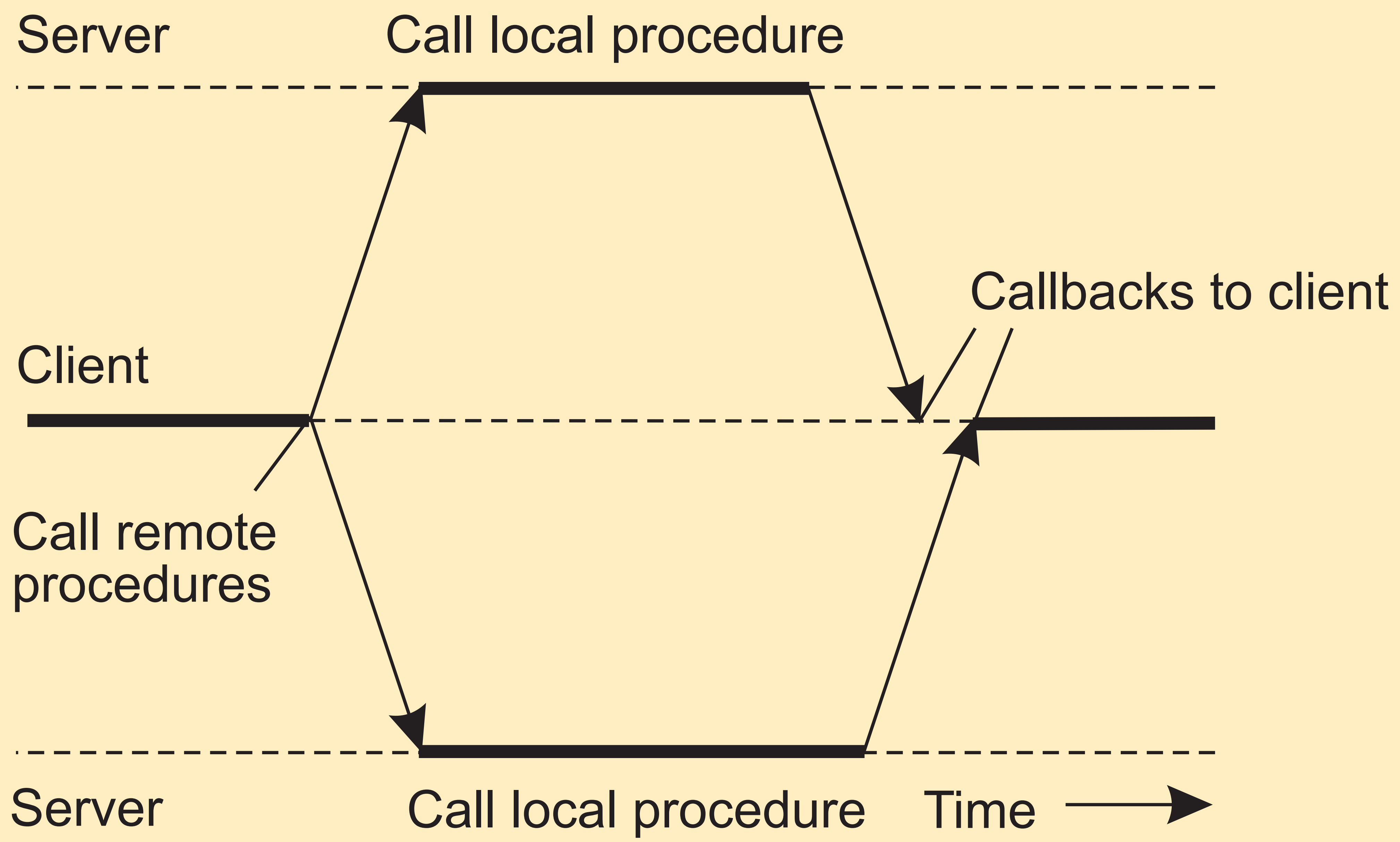
Try to get rid of the strict request-reply behavior, but let the client continue without waiting for an answer from the server.



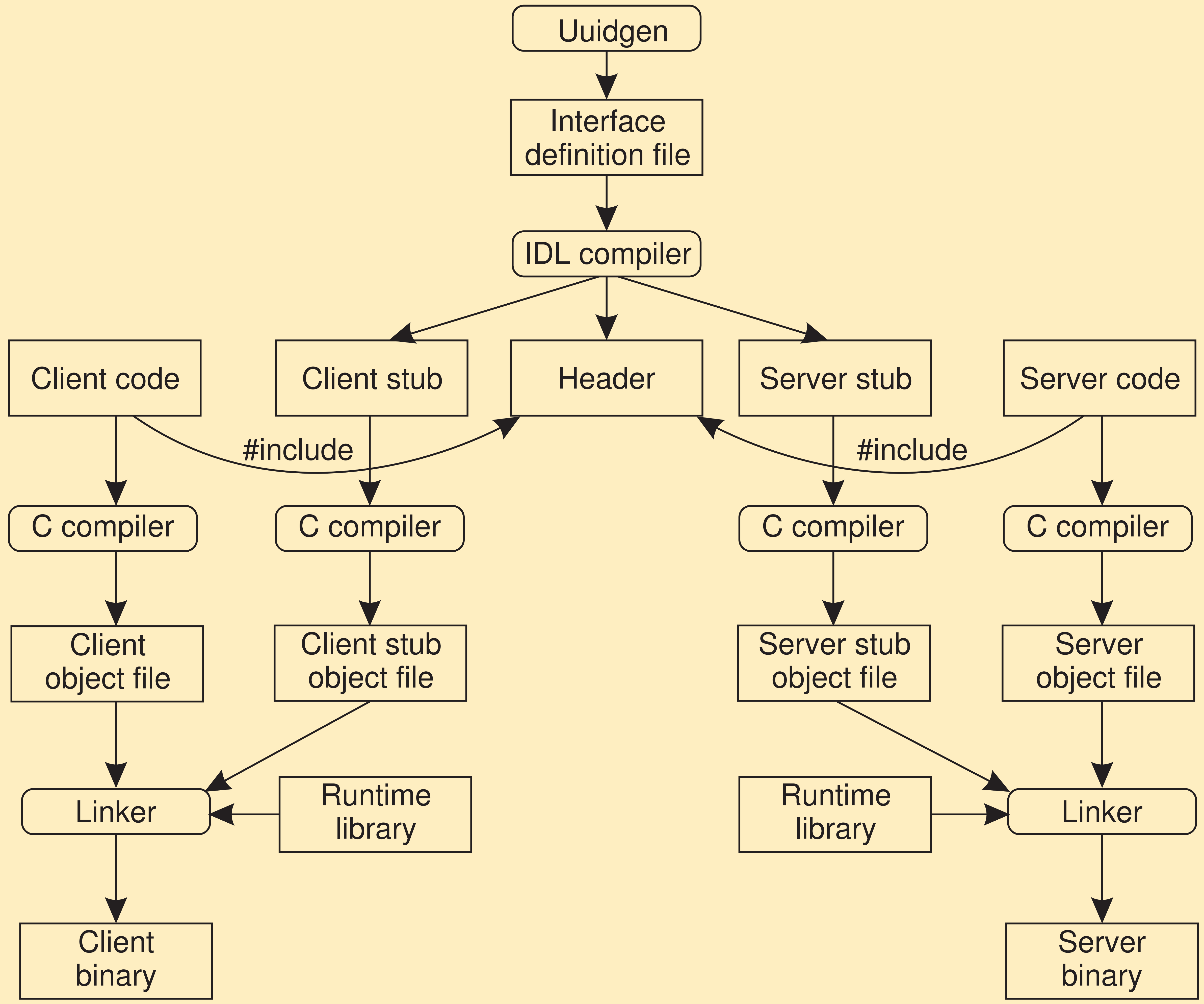
Sending out multiple RPCs

Essence

Sending an RPC request to a group of servers.



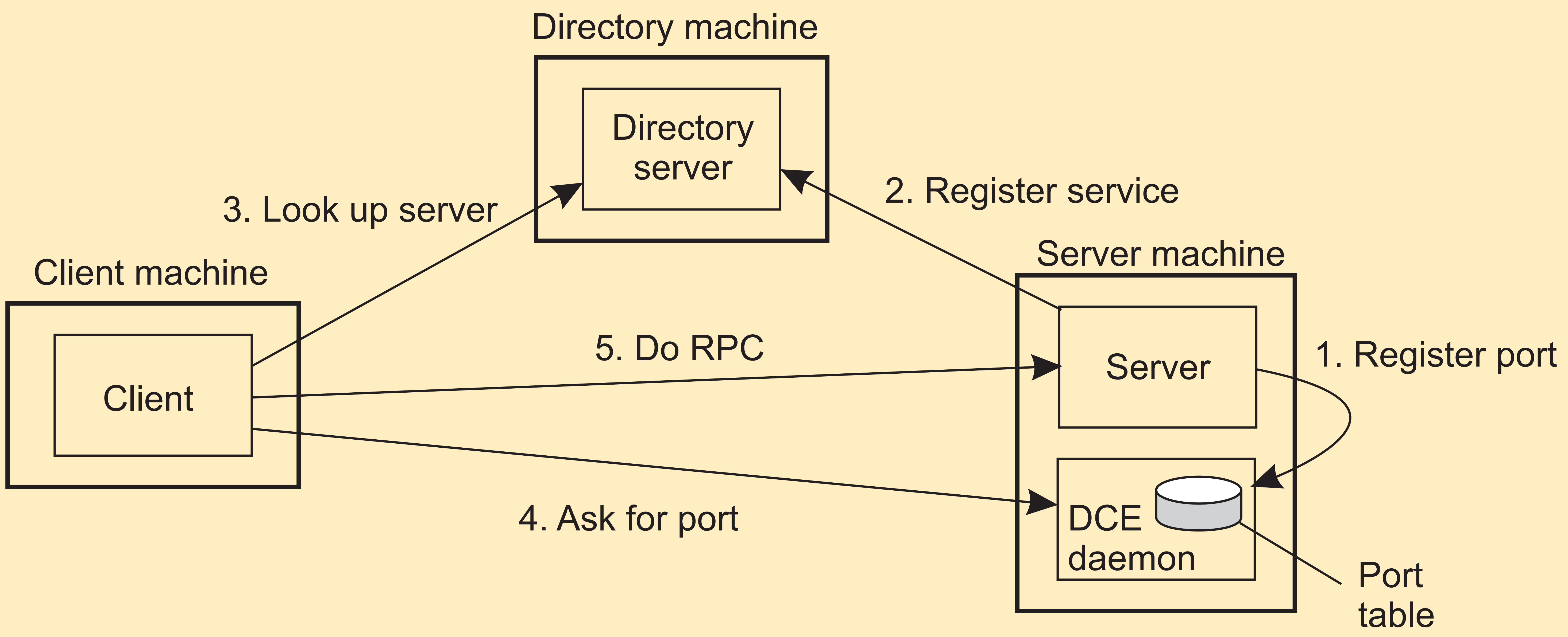
RPC in practice



Client-to-server binding (DCE)

Issues

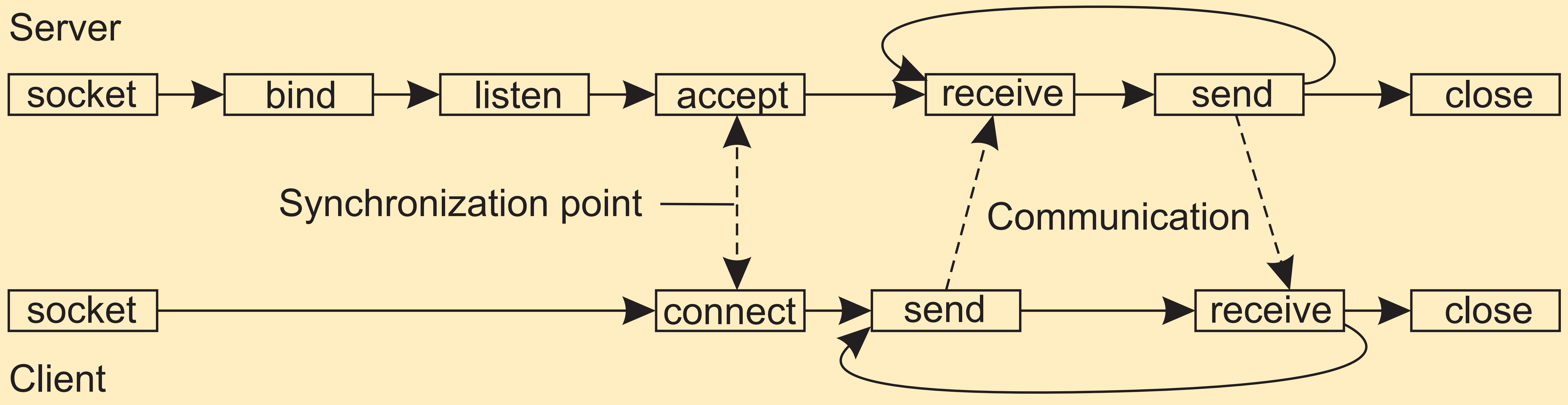
(1) Client must locate server machine, and (2) locate the server.



Transient messaging: sockets

Berkeley socket interface

Operation	Description
`socket`	Create a new communication end point
`bind`	Attach a local address to a socket
`listen`	Tell operating system what the maximum number of pending connection requests should be
`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



Sockets: Python code

Server

```
from socket import *
s = socket(AF_INET, SOCK_STREAM)
s.bind((HOST, PORT))
s.listen(1)
(conn, addr) = s.accept()  # returns new socket and addr. client
while True:                # forever
  data = conn.recv(1024)   # receive data from client
  if not data: break       # stop if client stopped
  conn.send(str(data)+"*") # return sent data plus an "*"
conn.close()               # close the connection
```

Client

```
from socket import *
s = socket(AF_INET, SOCK_STREAM)
s.connect((HOST, PORT)) # connect to server (block until accepted)
s.send('Hello, world')  # send same data
data = s.recv(1024)     # receive the response
print data              # print the result
s.close()               # close the connection
```

Making sockets easier to work with

Observation

Sockets are rather low level and programming mistakes are easily made. However, the way that they are used is often the same (such as in a client-server setting).

Alternative: ZeroMQ

Provides a higher level of expression by pairing sockets: one for sending messages at process *P* and a corresponding one at process *Q* for receiving messages. All communication is asynchronous.

Three patterns

- Request-reply
- Publish-subscribe
- Pipeline

Request-reply

Server

```
import zmq
context = zmq.Context()

p1 = "tcp://"+ HOST +":"+ PORT1 # how and where to connect
p2 = "tcp://"+ HOST +":"+ PORT2 # how and where to connect
s  = context.socket(zmq.REP)    # create reply socket

s.bind(p1)                      # bind socket to address
s.bind(p2)                      # bind socket to address
while True:
  message = s.recv()            # wait for incoming message
  if not "STOP" in message:     # if not to stop...
    s.send(message + "*")       # append "*" to message
  else:                         # else...
    break                       # break out of loop and end
```

Request-reply

Client

```
import zmq
context = zmq.Context()

php = "tcp://"+ HOST +":"+ PORT # how and where to connect
s   = context.socket(zmq.REQ)    # create socket

s.connect(php)                   # block until connected
s.send("Hello World")            # send message
message = s.recv()               # block until response
s.send("STOP")                   # tell server to stop
print message                    # print result
```

Publish-subscribe

Server

```
import zmq, time

context = zmq.Context()
s = context.socket(zmq.PUB)          # create a publisher socket
p = "tcp://"+ HOST +":"+ PORT        # how and where to communicate
s.bind(p)                            # bind socket to the address
while True:
  time.sleep(5)                      # wait every 5 seconds
  s.send("TIME " + time.asctime())  # publish the current time
```

Client

```
import zmq

context = zmq.Context()
s = context.socket(zmq.SUB)            # create a subscriber socket
p = "tcp://"+ HOST +":"+ PORT          # how and where to communicate
s.connect(p)                           # connect to the server
s.setsockopt(zmq.SUBSCRIBE, "TIME")   # subscribe to TIME messages

for i in range(5):   # Five iterations
  time = s.recv()    # receive a message
  print time
```

Pipeline

Source

```
import zmq, time, pickle, sys, random

context = zmq.Context()
me  = str(sys.argv[1])
s   = context.socket(zmq.PUSH)        # create a push socket
src = SRC1  if me == '1' else SRC2    # check task source host
prt = PORT1 if me == '1' else PORT2   # check task source port
p   = "tcp://"+ src +":"+ prt         # how and where to connect
s.bind(p)                             # bind socket to address

for i in range(100):                  # generate 100 workloads
  workload = random.randint(1, 100)   # compute workload
  s.send(pickle.dumps((me,workload))) # send workload to worker
```

Pipeline

Worker

```
import zmq, time, pickle, sys

context = zmq.Context()
me = str(sys.argv[1])
r  = context.socket(zmq.PULL)      # create a pull socket
p1 = "tcp://"+ SRC1 +":"+ PORT1    # address first task source
p2 = "tcp://"+ SRC2 +":"+ PORT2    # address second task source
r.connect(p1)                      # connect to task source 1
r.connect(p2)                      # connect to task source 2

while True:
  work = pickle.loads(r.recv())    # receive work from a source
  time.sleep(work[1]*0.01)         # pretend to work
```

MPI: When lots of flexibility is needed

Representative operations

Operation	Description
`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 transmission 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

Message-oriented middleware

Essence

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

Operations

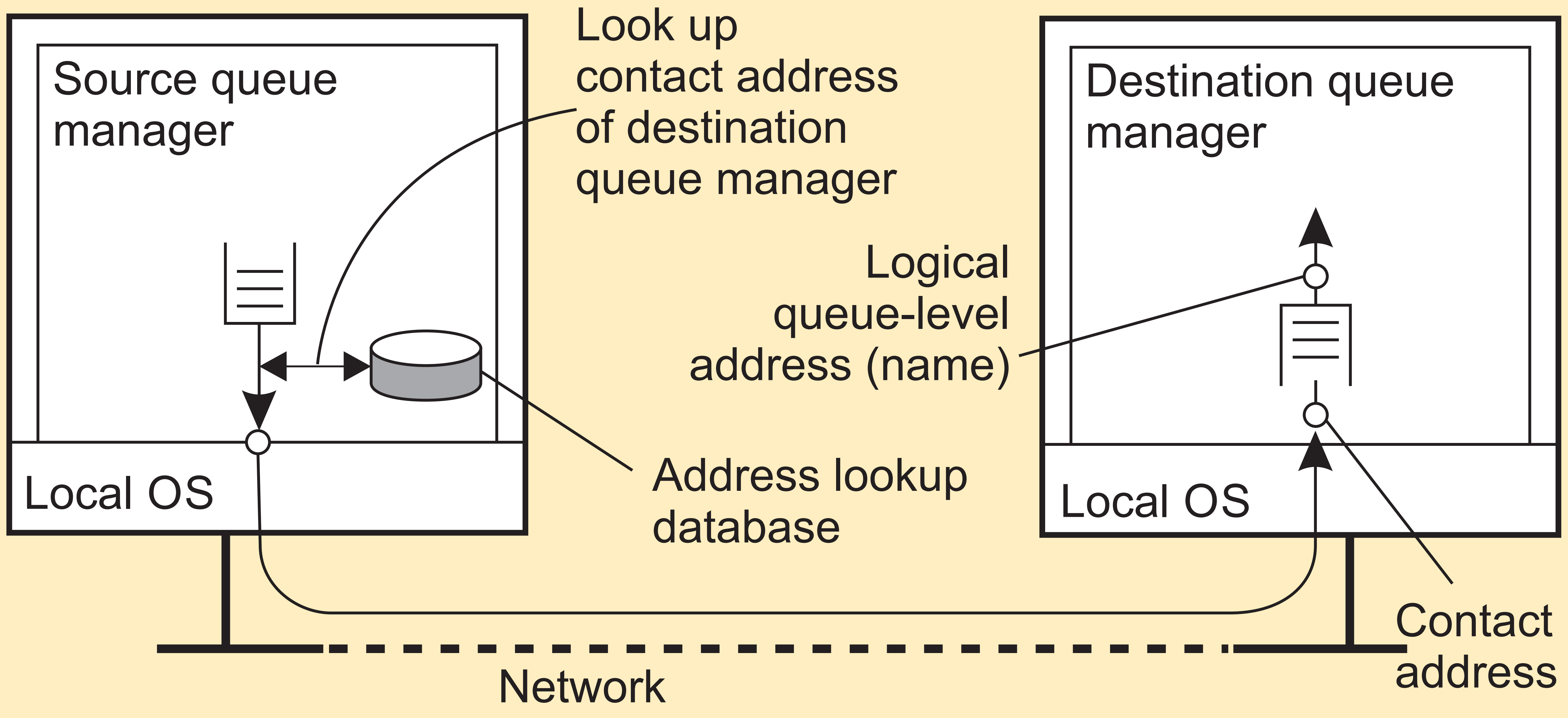
Operation	Description
`put`	Append a message to a specified queue
`get`	Block until the specified queue is nonempty, and remove the first message
`poll`	Check a specified queue for messages, and remove the first. Never block
`notify`	Install a handler to be called when a message is put into the specified queue

General model

Queue managers

Queues are managed by queue managers. An application can put messages only into a local queue. Getting a message is possible by extracting it from a local queue only $\Rightarrow$ queue managers need to route messages.

Routing



Message broker

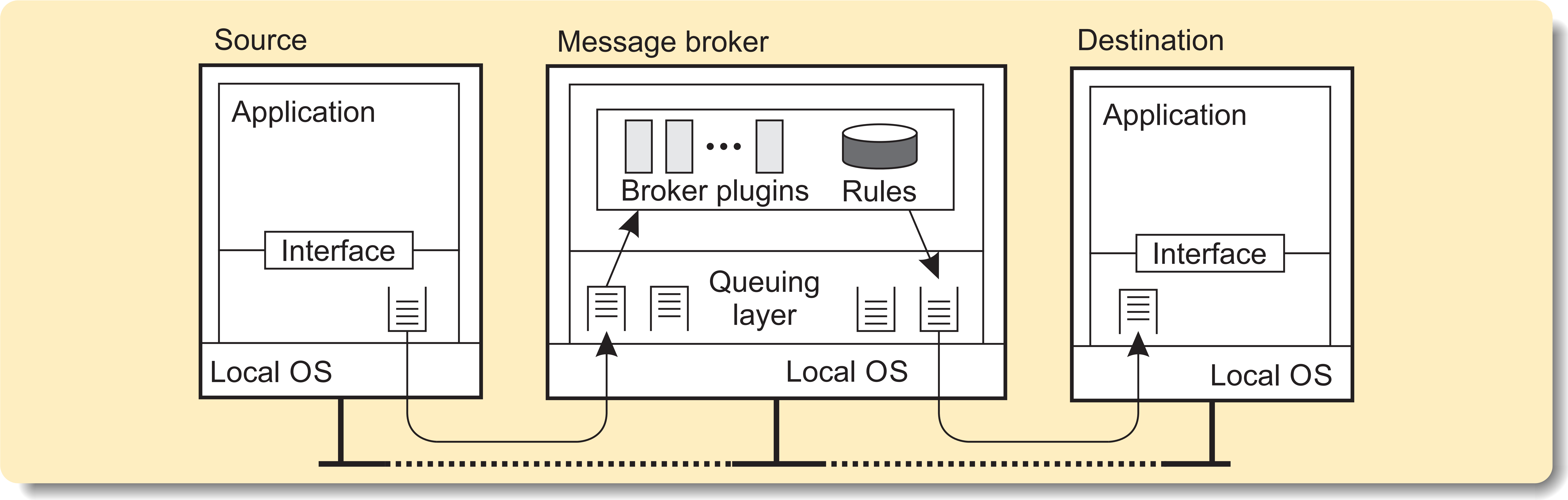
Observation

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

Broker handles application heterogeneity in an MQ system

- Transforms incoming messages to target format
- Very often acts as an application gateway
- May provide subject-based routing capabilities (i.e., publish-subscribe capabilities)

Message broker: general architecture



IBM's WebSphere MQ

Basic concepts

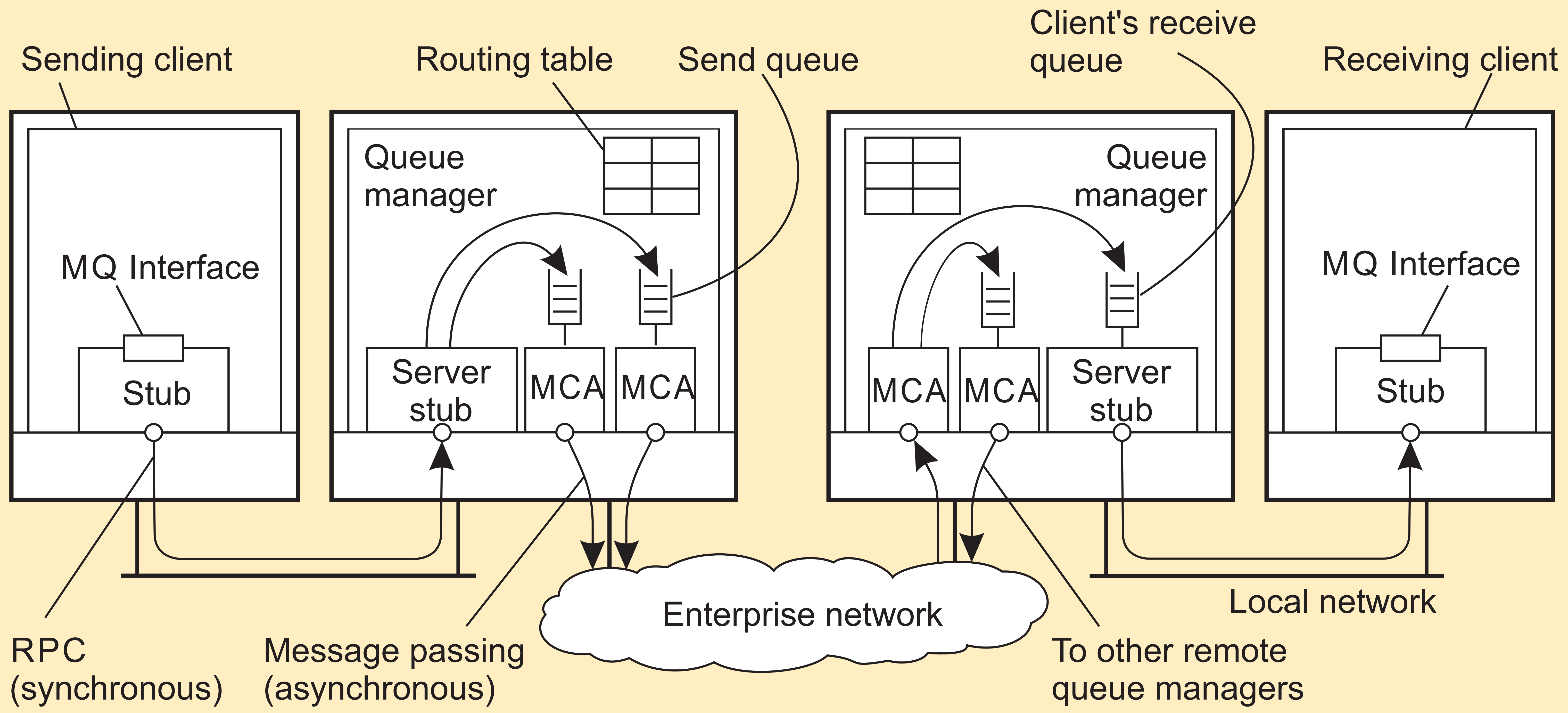
- Application-specific messages are put into, and removed from queues
- Queues reside under the regime of a queue manager
- Processes can put messages only in local queues, or through an RPC mechanism

Message transfer

- Messages are transferred between queues
- Message transfer between queues at different processes, requires a channel
- At each end point 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's WebSphere MQ

Schematic overview



- Channels are inherently unidirectional
- Automatically start MCAs when messages arrive
- Any network of queue managers can be created
- Routes are set up manually (system administration)

Message channel agents

Some attributes associated with message channel agents

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

IBM's WebSphere MQ

Routing

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