Distributed Systems (COMP9243)

Lecture 9: Middleware

① Introduction

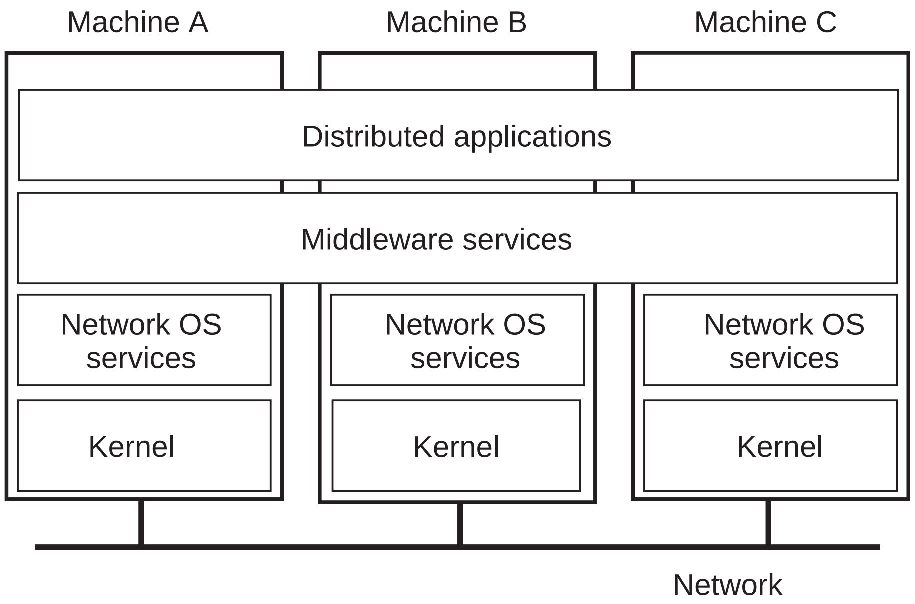
② Publish/Subscribe Middleware

③ Map-Reduce Middleware

④ Distributed Object Middleware

- Remote Objects & CORBA
- Distributed Shared Objects & Globe

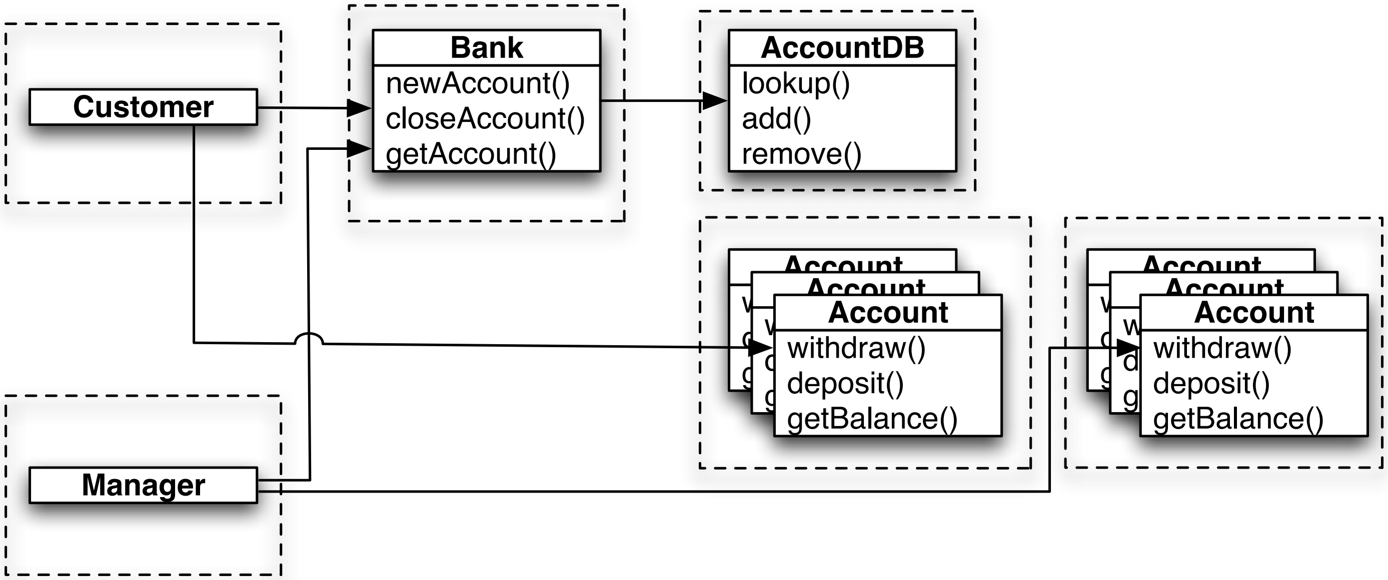
MIDDLEWARE


Machine A
Machine B
Machine C
Distributed applications
Middleware services
Network OS services
Network OS services
Network OS services
Kernel
Kernel
Kernel
Network

KINDS OF MIDDLEWARE

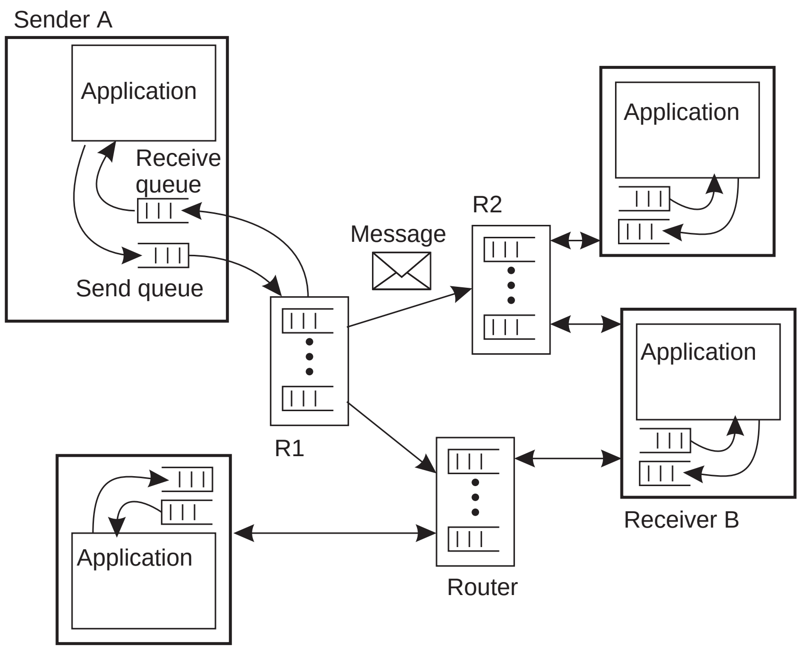
Distributed Object based:

➜ Objects invoke each other's methods



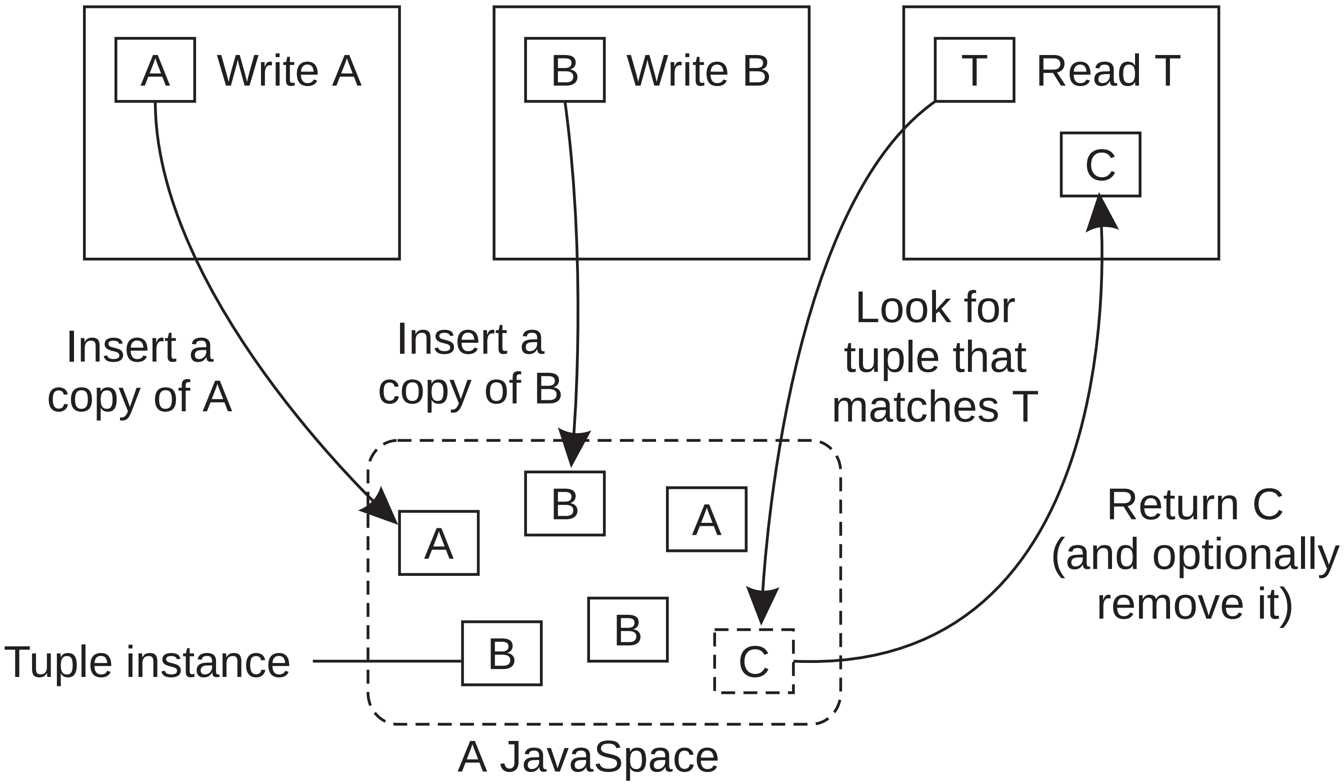
Message-oriented:

- ➜ Messages are sent between processes
- ➜ Message queues

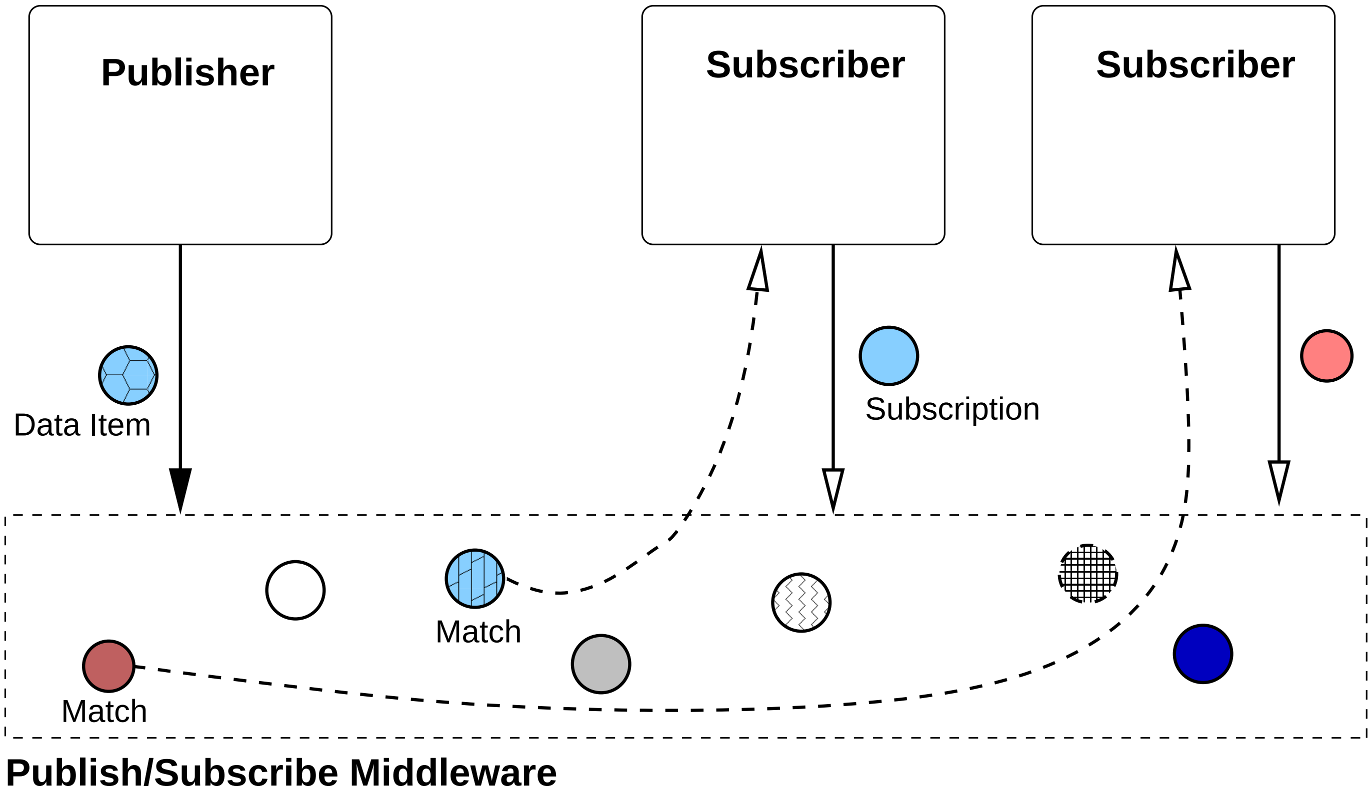


Coordination-based:

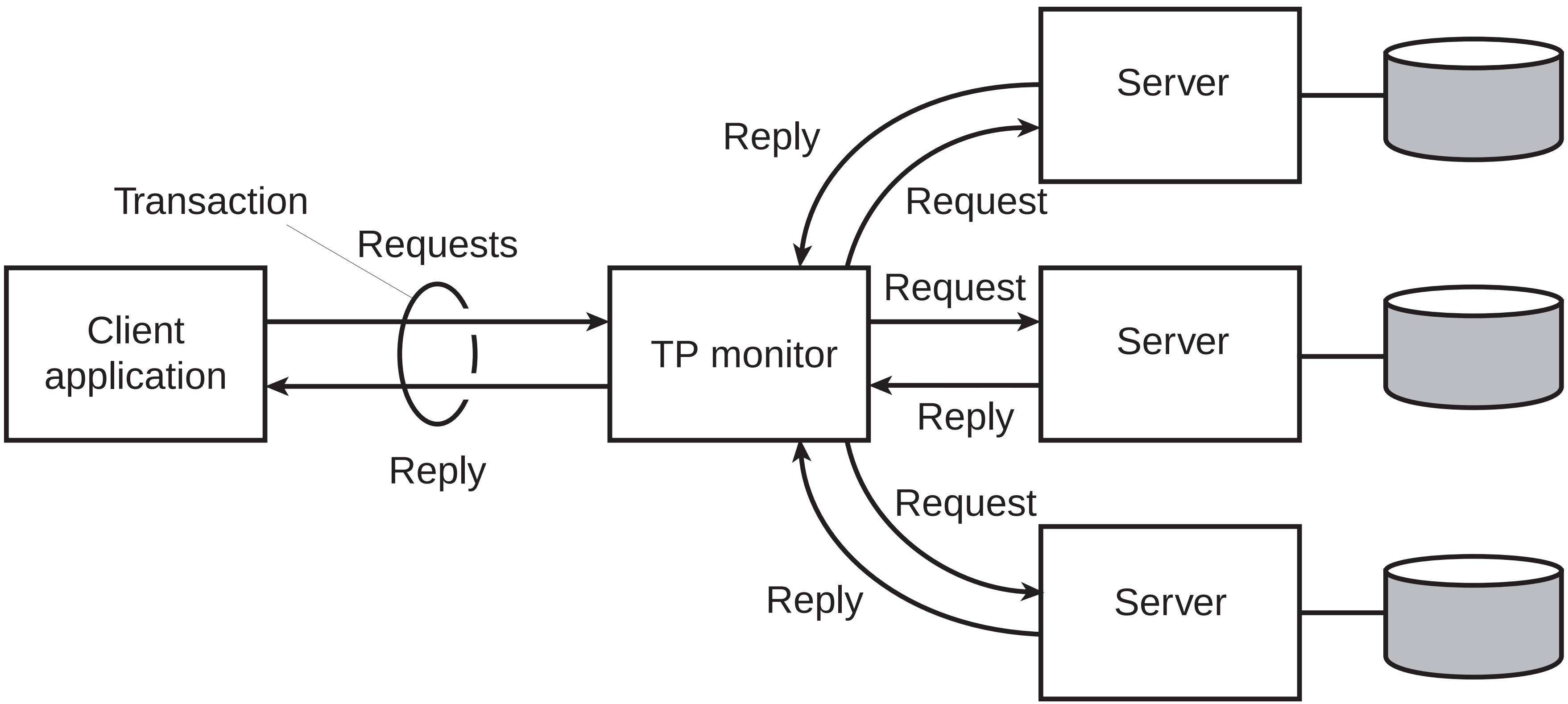
➜ Tuple space



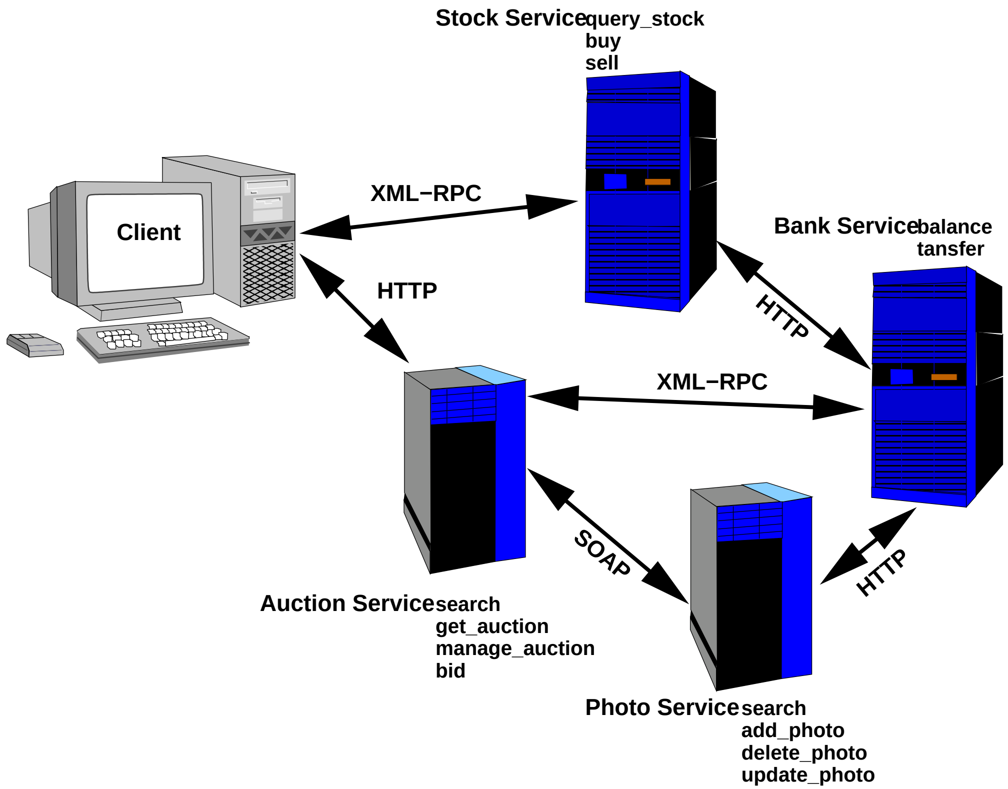
➜ Publish/Subscribe



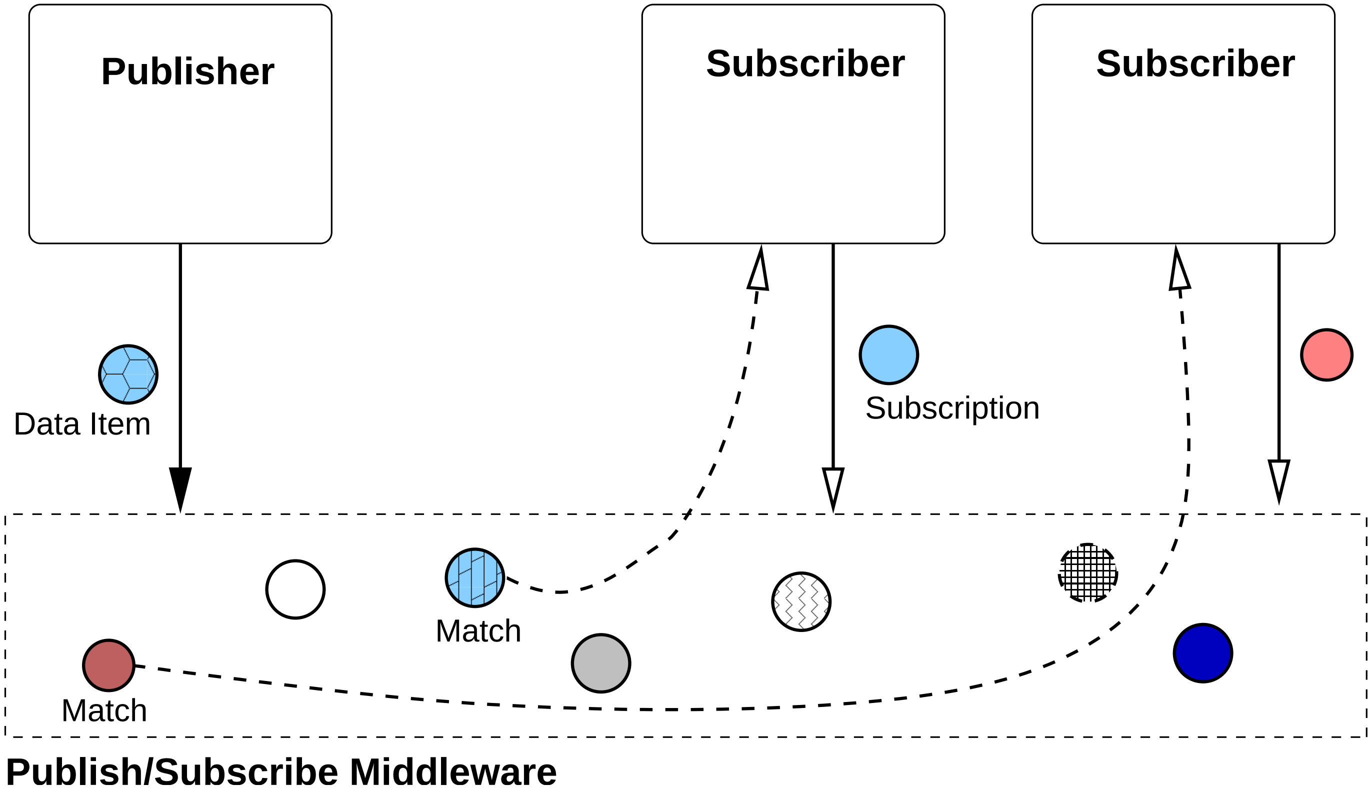
Transaction Processing Monitors:



Web Services:



Publish/Subscribe (Event-Based) Middleware



CHALLENGES

Transparency:

- ➜ loose coupling → good transparency

Scalability:

- ➜ Potentially good due to loose coupling
- ✗ In practice hard to achieve
- ➜ Number of subscriptions
- ➜ Number of messages

Flexibility:

- ➜ Loose coupling gives good flexibility
- ➜ Language & platform independence
- ➜ Policy separate from mechanism

Programmability:

- ➜ Inherent distributed design
- ➜ Doesn't use non-distributed concepts

EXAMPLES

Real-time Control Systems:

- External events (e.g. sensors)
- Event monitors

Stock Market Monitoring:

- Stock updates
- Traders subscribed to updates

Network Monitoring:

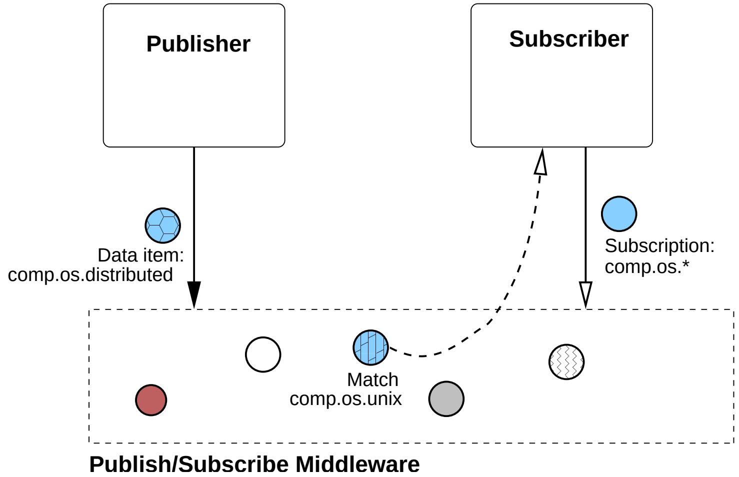
- Status logged by routers, servers
- Monitors screen for failures, intrusion attempts

Enterprise Application Integration:

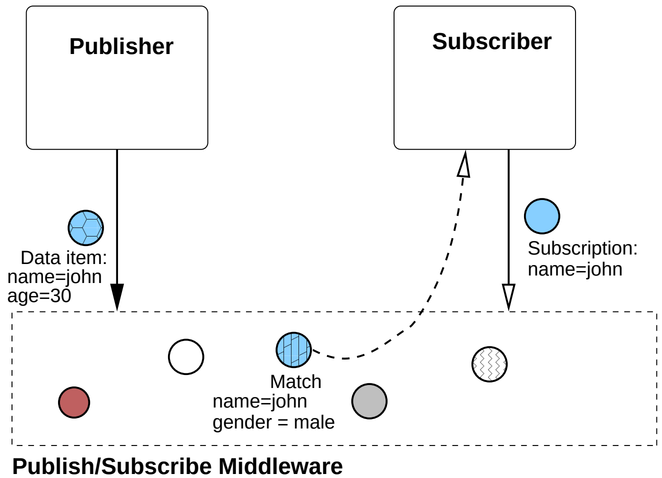
- Independent applications
- Produce output as events
- Consume events as input
- Decoupled

Message Filtering

Topic-based

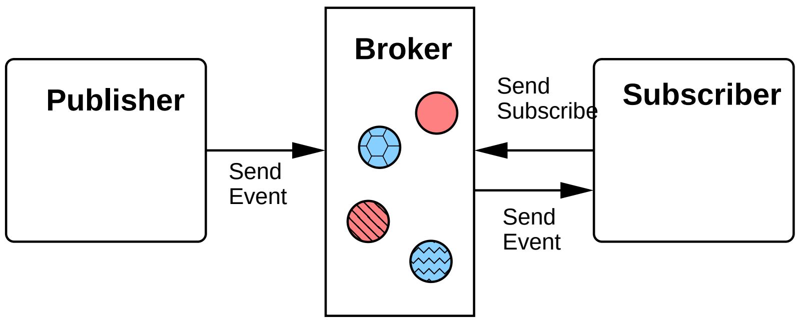


Content-based

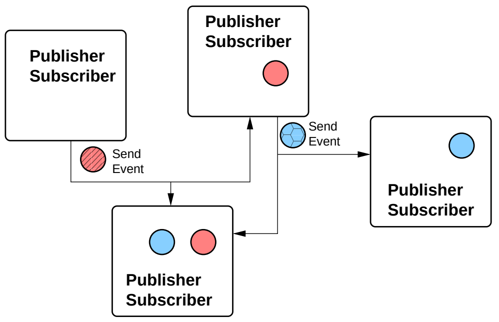


ARCHITECTURE

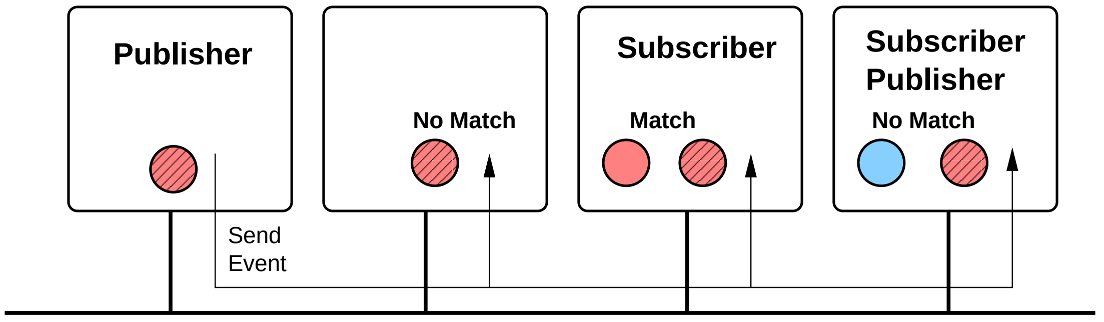
Centralised:



Peer-to-Peer:



Multicast-based:



COMMUNICATION

- ➜ Point-to-point
- ➜ Multicast
  - hard part is building appropriate multicast tree
- ➜ Content-based routing
  - point-to-point based router network
  - make forwarding decisions based on message content
  - store subscription info at router nodes

REPLICATION

Replicated Brokers:

- ➜ Copy subscription info on all nodes
- ➜ Keep nodes consistent
- ➜ What level of consistency is needed?
- ➜ Avoid sending redundant subscription update messages

Partitioned Brokers:

- ➜ Different subscription info on different nodes
- ➜ Events have to travel through all nodes
- ➜ Route events to nodes that contain their subscriptions

FAULT TOLERANCE

Reliable Communication:

➜ Reliable multicast

Process Resilience (Broker):

➜ Process groups

➜ Active replication by subscribing to group messages

Routing:

➜ Stabilise routing if a broker crashes

➜ Lease entries in routing tables

EXAMPLE SYSTEMS

TIB/Rendezvous:

- ➜ Topic-based
- ➜ Multicast-based

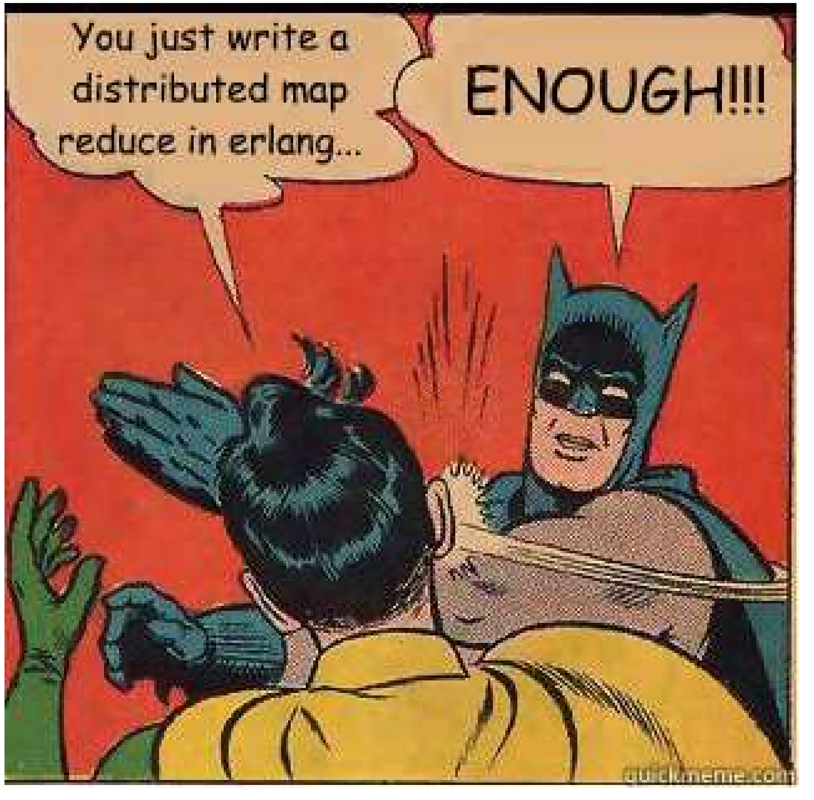
Java Message Service (JMS):

- ➜ API for MOM
- ➜ Topic-based
- ➜ centralised or peer-to-peer implementations possible

Scribe:

- ➜ Topic-based
- ➜ Peer-to-peer architecture, based on Pastry (DHT)
- ➜ Topics have unique IDs and map onto nodes
- ➜ Multicast for sending events
  - Tree is built up as nodes subscribe

Map-Reduce


You just write a distributed map reduce in erlang...
ENOUGH!!!
quickmeme.com

Context

Computations conceptually straightforward, but:

- ➜ Input data is usually large
- ➜ Need to finish in reasonable time
- ➜ Computations widely distributed (thousands of machines)

How to:

- ➜ Parallelize the computation?
- ➜ Distribute the data?
- ➜ Handle failures?
- ➜ Balance the load?

Solution

Map-Reduce:

- New abstraction for simple computations.
- Hide dirty details.
- Based on *map* and *reduce* primitives from Lisp (functional language).

Basic computation:

- Takes set of input <key, value> pairs
- Produces set of output <key, value> pairs

Implementation:

- Google's version: *MapReduce*
- Open source version: *Hadoop*

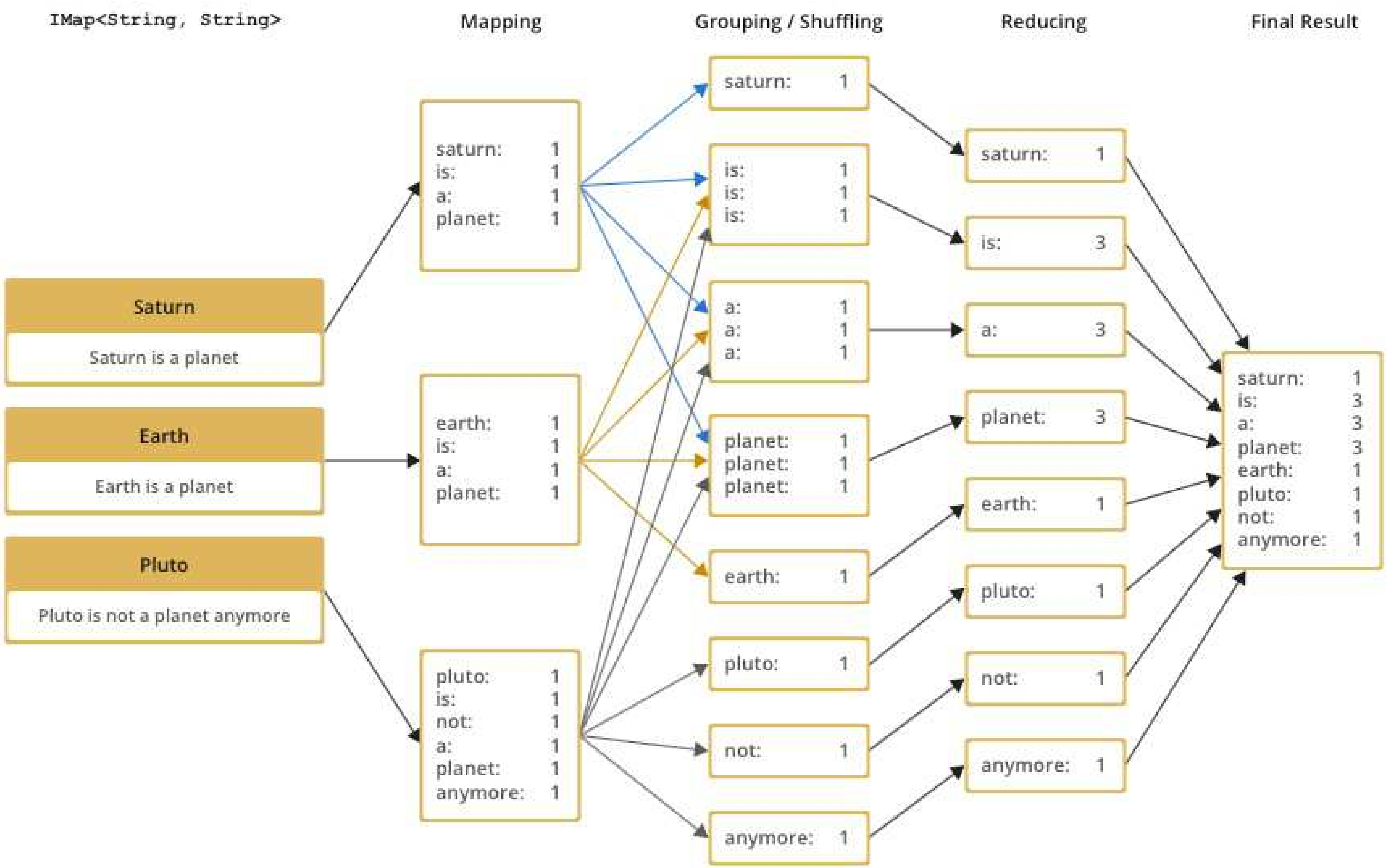
User supplied functions:

- **Map** Accepts: one input pair <key, value>
  Produces: a set of intermediate <key, value> pairs
- System groups intermediate values with same key together.
- **Reduce** Accepts: intermediate key, set of values for that key
  Produces: output list (typically small)

More formally:

- $map(k_1, v_1) \rightarrow list(k_2, v_2)$
- $reduce(k_2, list(v_2)) \rightarrow list(v2)$

Example: Word Count



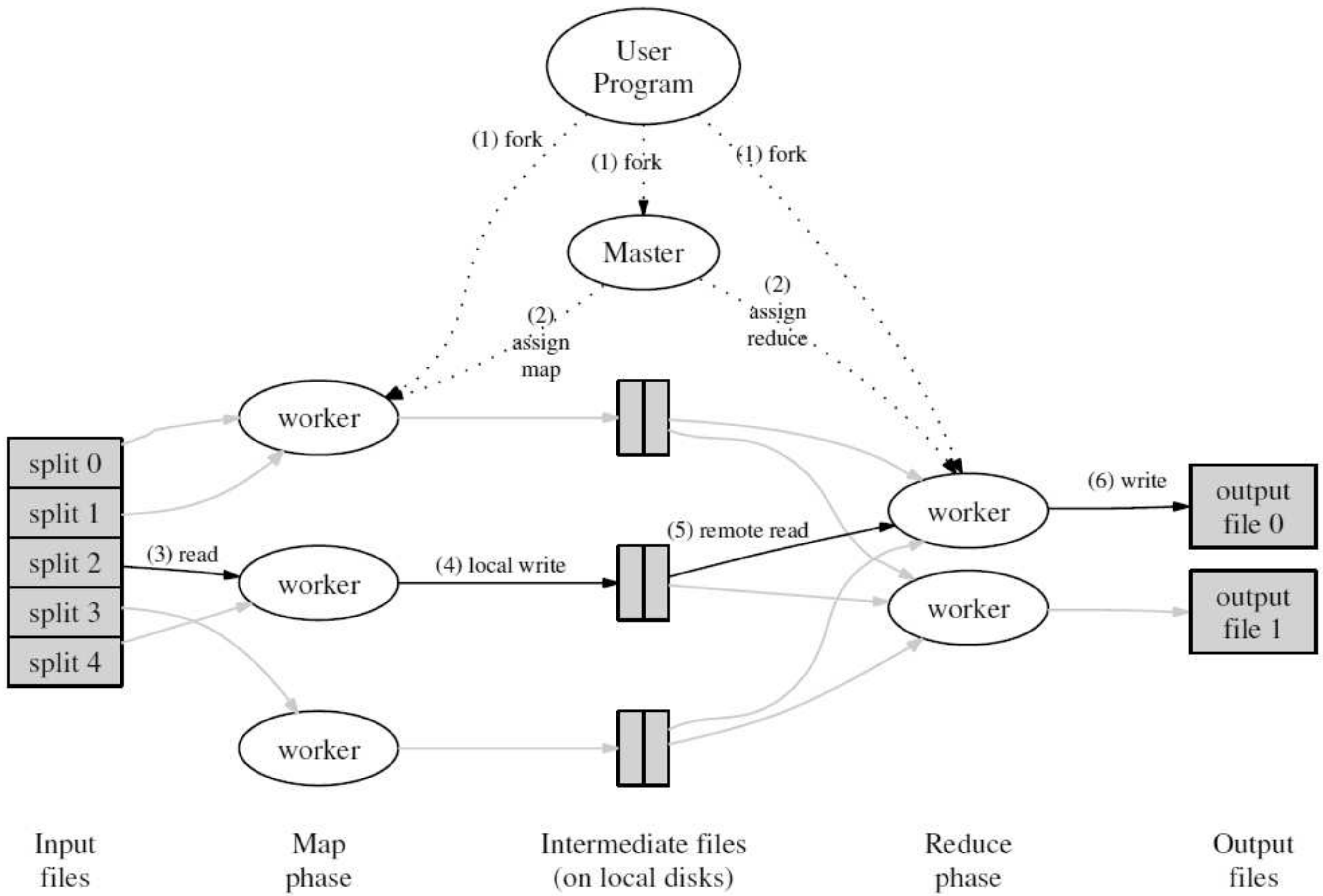
Example: Word Count

Count word occurances in in collection of documents:

```
map(String key, String value):
  // key:   document name
  // value: document contents
  for each word w in value:
    EmitIntermediate(w, "1");

reduce(String key, Iterator values):
  // key:    a word
  // values: a list of counts
  int result = 0;
  for each v in values:
    result += ParseInt(v);
  Emit(AsString(result));
```

Execution Overview



MASTER

Data structures:

- ➜ State of each map task and each reduce task
  (idle, in-progress, completed)
- ➜ Identity of worker machines
  (for non-idle tasks)
- ➜ Location of intermediate file regions
  (propagate from map to reduce tasks)

Fault tolerance:

- ➜ Data structures could be checkpointed to guard against failure
- ➜ In practice: Failure is unlikely
- ➜ On failure: Restart MapReduce

Worker Fault Tolerance

Unreachable workers:

- Master pings workers periodically
- Unreachable workers are marked as failed.
- Tasks from failed workers reset to idle and rescheduled
  - Completed map tasks need restart too (results on local disks)
  - Completed reduce tasks not rescheduled (results on GFS)
- Map task first executes on A, then fails, then executed on B:
  Notify workers.
- Works well according to paper:
  Network upgrade disabled 80 machines at a time, but
  MapReduce continued to make progress.

Bad code:

- ➜ Sometimes user code crashes
- ➜ Ideally: Fix bug and re-run, but not always feasible
- ➜ Signal handler in worker catches crashes and sends *last gasp* packet to master, with sequence number of record
- ➜ If master records multiple failures on same record, the record is skipped on re-execution

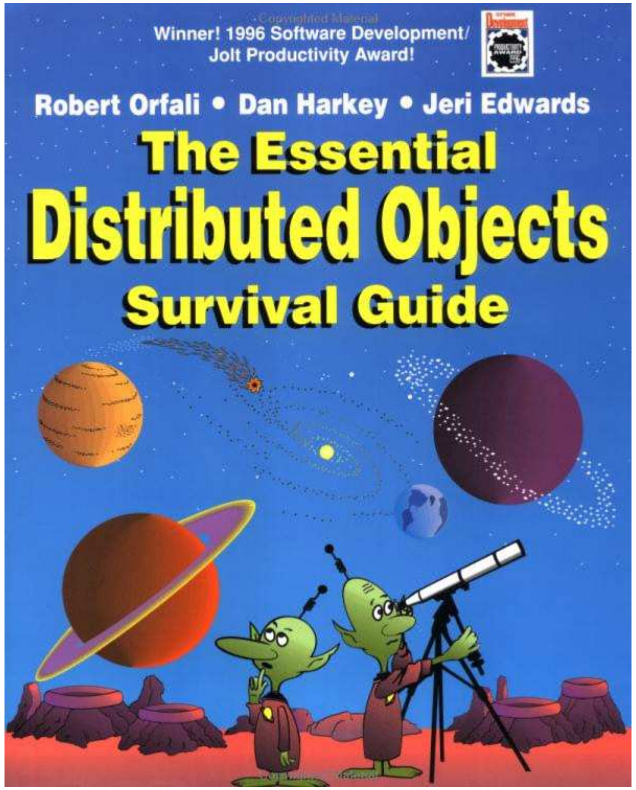
Locality

Network is scarce resource

- ➜ GFS divides files into blocks
- ➜ Each block is replicated (default: 3 replicas)
- ➜ MapReduce tries to schedule a map task on a machine that has a replica
- ➜ If that fails, schedule map task close to replica

Result: For large MapReduce operations, significant fraction of input data is read locally.

Distributed Objects



CHALLENGES

- ➜ Transparency
  - Failure transparency
- ➜ Reliability
  - Dealing with *partial failures*
- ➜ Scalability
  - Number of clients of an object
  - Distance between client and object
- ➜ Design
  - Must take distributed nature into account from beginning
- ➜ Performance
- ➜ Flexibility

OBJECT MODEL

➜ Classes and Objects

Class: defines a type

Object: instance of a class

➜ Interfaces

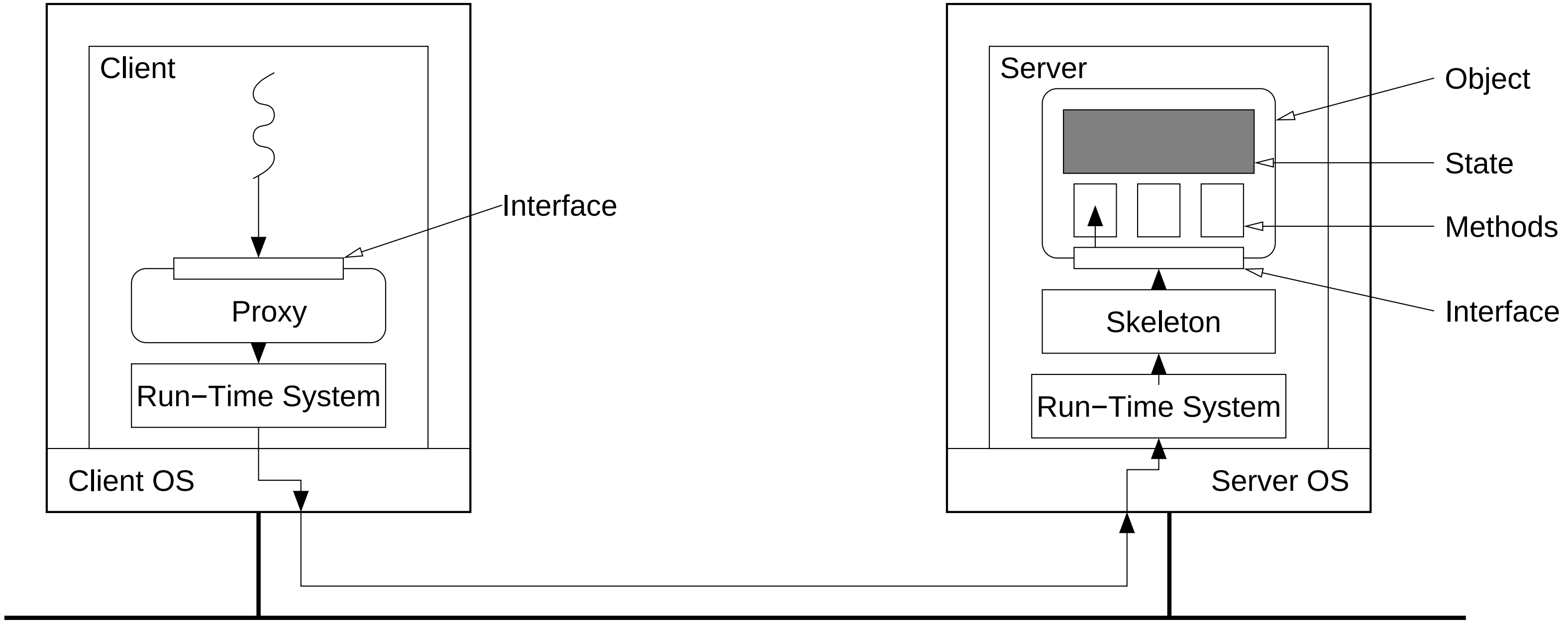
➜ Object references

➜ Active vs Passive objects

➜ Persistent vs Transient objects

➜ Static vs Dynamic method invocation

REMOTE OBJECT ARCHITECTURAL MODEL



Remote Objects:

- ➜ Single copy of object state (at single object server)
- ➜ All methods executed at single object server
- ➜ All clients access object through proxy
- ➜ Object's location is location of state

CLIENT

Client Process:

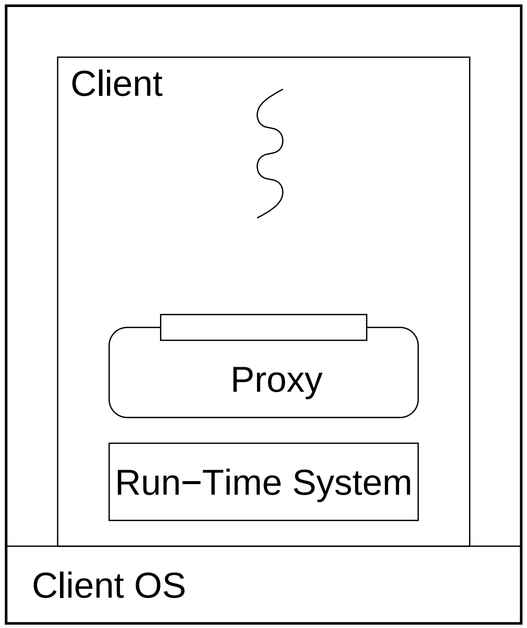
- ➜ Binds to distributed object
- ➜ Invokes methods on object

Proxy:

- ➜ Proxy: RPC stub + destination details
- ➜ Binding causes a proxy to be created
- ➜ Responsible for marshaling
- ➜ Static vs dynamic proxies
- ➜ Usually generated

Run-Time System:

- ➜ Provides services (translating references, etc.)
- ➜ Send and receive



Object Server

Object:

- ➜ State & Methods
- ➜ Implements a particular interface

Skeleton:

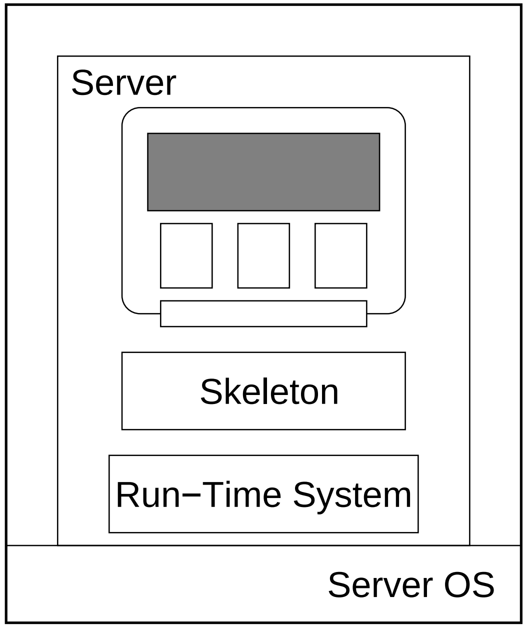
- ➜ Server stub
- ➜ Static vs dynamic skeletons

Run-Time System:

- ➜ Dispatches to appropriate object
- ➜ Invocation policies

Object Server:

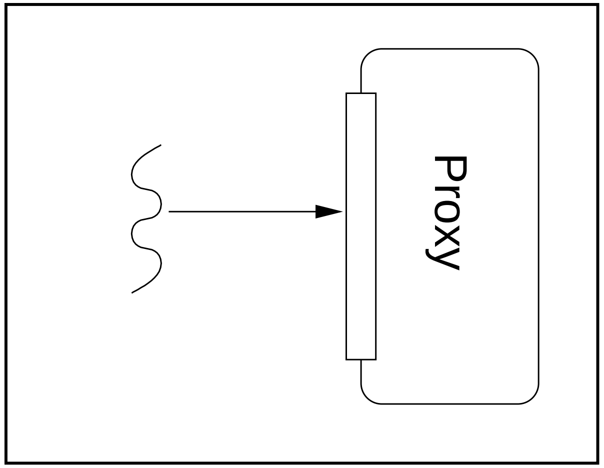
- ➜ Hosts object implementations
- ➜ Transient vs Persistent objects
- ➜ Concurrent access
- ➜ Support legacy code



OBJECT REFERENCE

Local Reference:

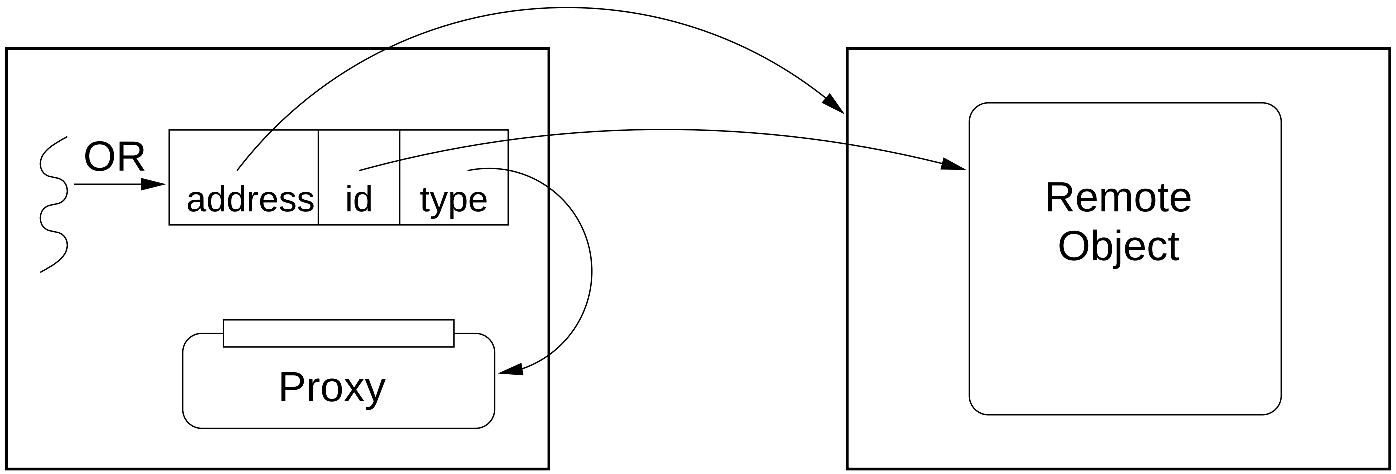
➜ Language reference to proxy



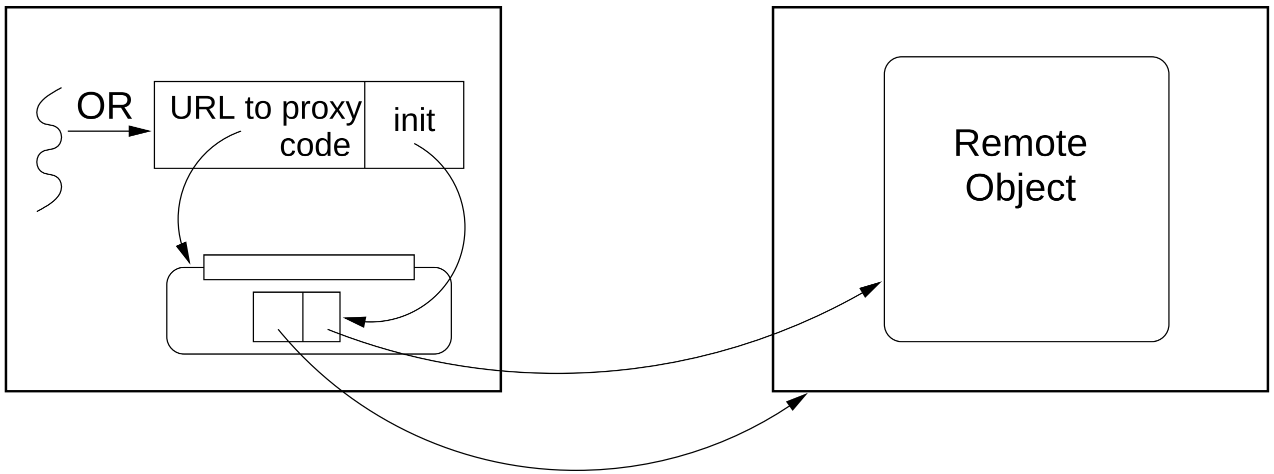
OBJECT REFERENCE

Remote Reference:

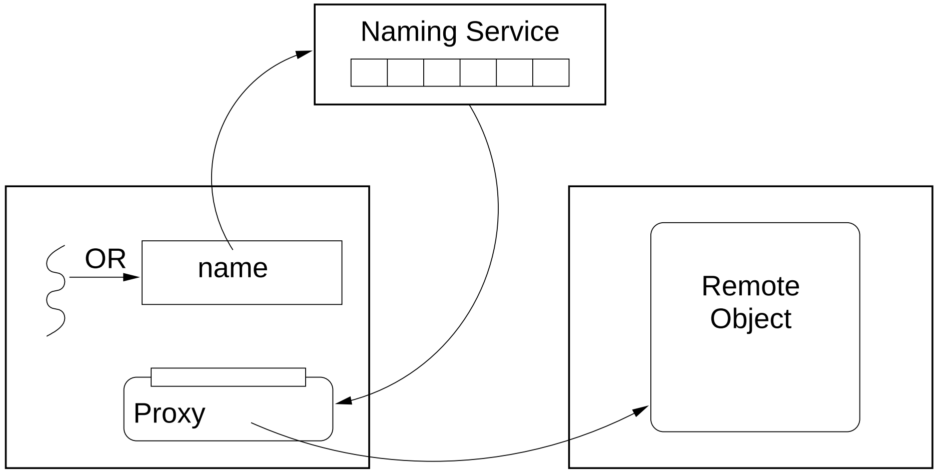
➜ Server address + object ID



➜ Reference to proxy code (e.g., URL) & init data



➜ Object name (human friendly, object ID, etc.)



What are the drawbacks and/or benefits of each approach?

Remote Method Invocation (RMI)

Standard invocation (synchronous):

- ➜ Client invokes method on proxy
- ➜ Proxy performs RPC to object server
- ➜ Skeleton at object server invokes method on object
- ➜ Object server may be required to create object first

Other invocations:

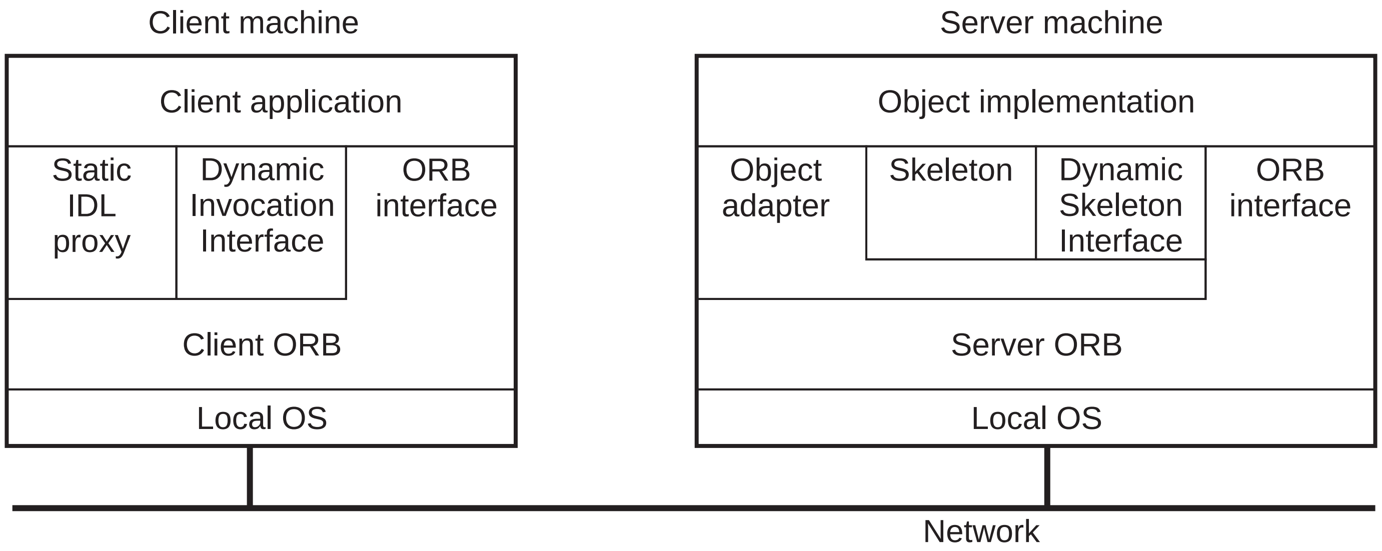
- ➜ Asynchronous invocations
- ➜ Persistent invocations
- ➜ Notifications and Callbacks

CORBA

Features:

- ➜ Object Management Group (OMG) Standard (version 3.1)
- ➜ Range of language mappings
- ➜ Transparency: Location & some migration transparency
- ➜ Invocation semantics: at-most-once semantics by default; maybe semantics can be selected
- ➜ Services: include support for naming, security, events, persistent storage, transactions, etc.

CORBA ARCHITECTURE



INTERFACES: OMG IDL

Example: A Simple File System:

```
module CorbaFS {
  interface File;       // forward declaration

  interface FileSystem {
    exception CantOpen {string reason;};
    enum OpenMode {Read, Write, ReadWrite};
    File open (in string fname, in OpenMode mode)
      raises (CantOpen);
  };

  interface File {   // an open file
    string read  (in long   nchars);
    void   write (in string data);
    void   close ();
  };
};
```

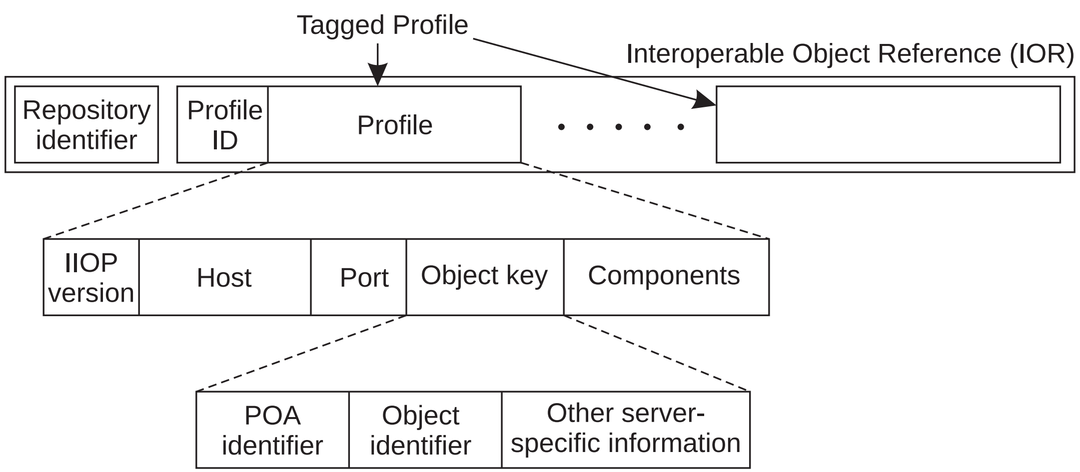
Object Reference (OR)

Object Reference (OR):

- ➜ Refers to exactly one object, but an object can have multiple, distinct ORs
- ➜ ORs are implementation specific

Interoperable Object Reference (IOR)

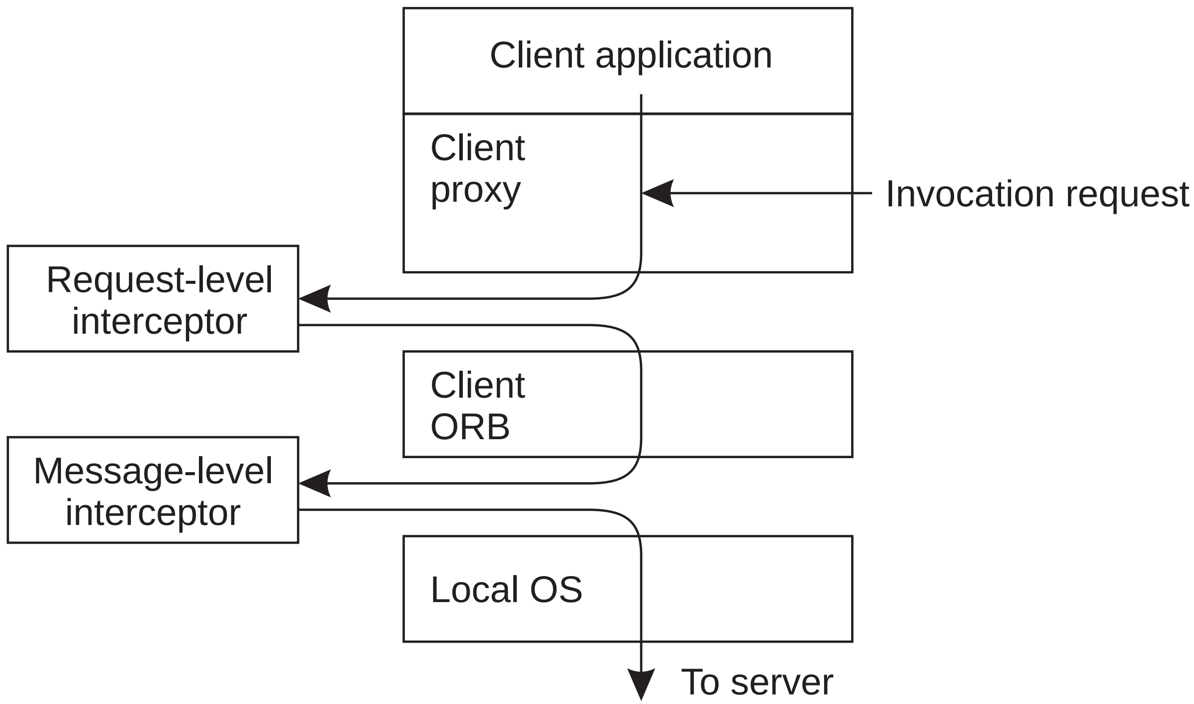
- ➜ Can be shared between different implementations



Object Request Broker (ORB)

- ➜ Provides run-time system
- ➜ Translate between remote and local references
- ➜ Send and receive messages
- ➜ Maintains interface repository
- ➜ Enables dynamic invocation (client and server side)
- ➜ Locates services

INTERCEPTORS

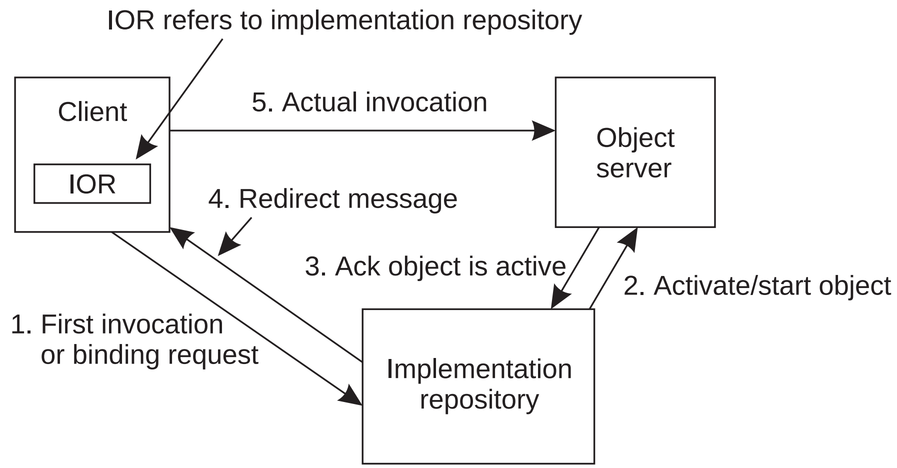


BINDING

Direct Binding:

- ➜ Create proxy
- ➜ ORB connects to server (using info from IOR)
- ➜ Invocation requests are sent over connection

Indirect Binding:



CORBA SERVICES

Some of the standardised services are the following:

- ➜ Naming Service
- ➜ Event Service
- ➜ Transaction Service
- ➜ Security Service
- ➜ Fault Tolerance

CORBA Bibliography

(1) *IIOP Complete*, W. Ruh, T. Herron, and P. Klinker, Addison Wesley, 1999.

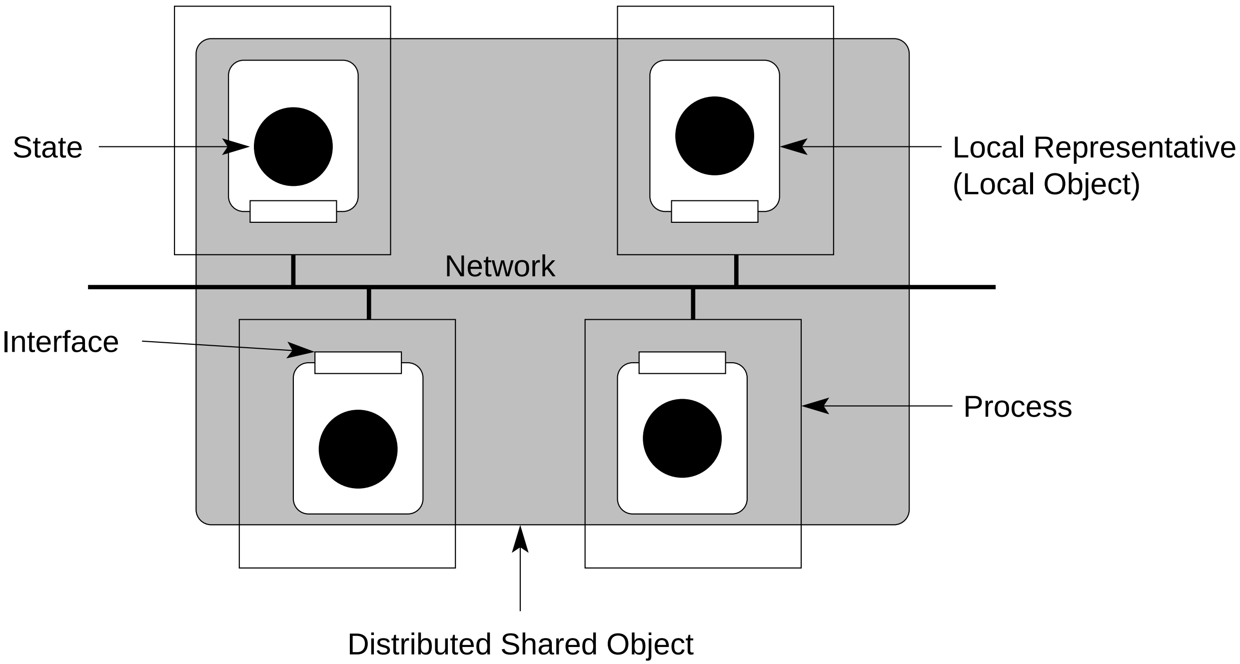
(2) *The Common Object Request Broker: Architecture and Specification (2.3.1)*, Object Management Group, 1999.

(3) *C Language Mapping Specification*, Object Management Group, 1999.

(4) *CORBAservices: Common Object Services Specification*, Object Management Group, 1998.

Play with CORBA. Many implementations available, including ORBit: `http://www.gnome.org/projects/ORBit2/`

DISTRIBUTED SHARED OBJECT (DSO) MODEL



Distributed Shared Objects:

- ➜ Object state can be replicated (at multiple object servers)
- ➜ Object state can be partitioned
- ➜ Methods executed at some or all replicas
- ➜ Object location no longer clearly defined

CLIENT

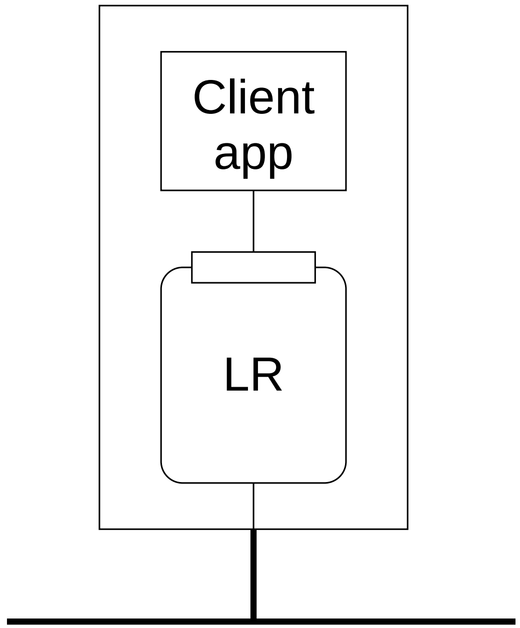
➜ Client has local representative (LR) in its address space

➜ Stateless LR

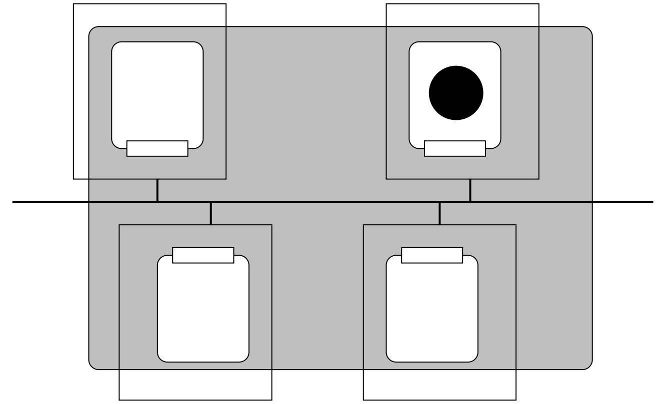
- Equivalent to proxy
- Methods executed remotely

➜ Statefull LR

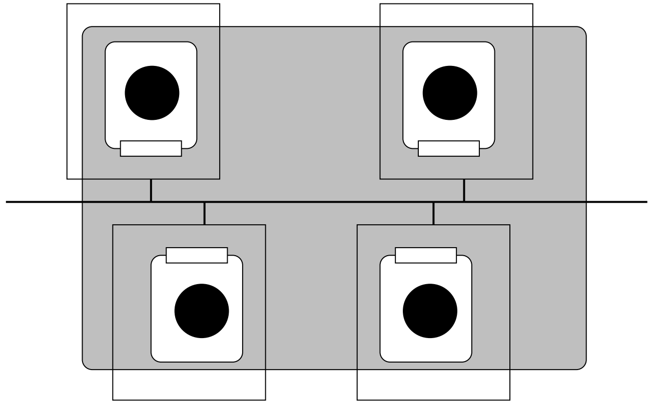
- Full state
- Partial state
- Methods (possibly) executed locally



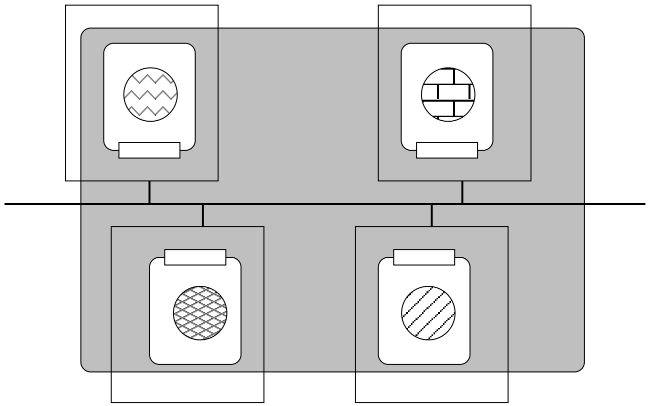
OBJECT



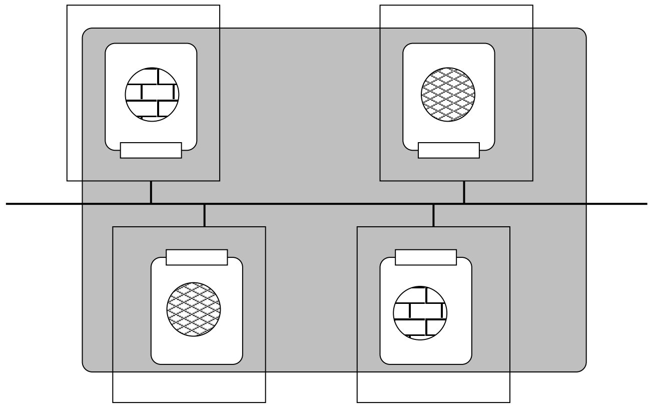
Remote Object



Replicated Object



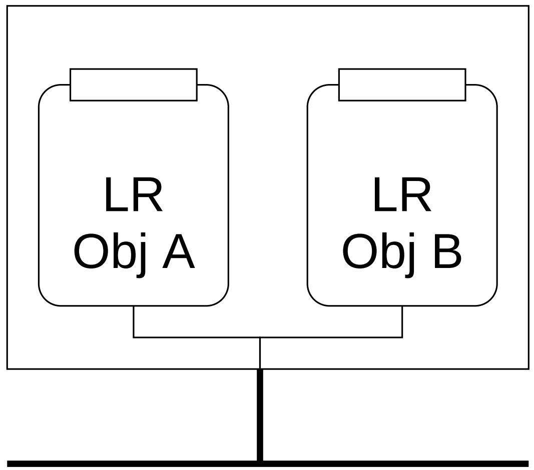
Partitioned Object



Replicated and Partitioned Object

Object Server

- ➜ Server dedicated to hosting LRs
- ➜ Provides resources (network, disk, etc.)
- ➜ Static vs Dynamic LR support
- ➜ Transient vs Persistent LRs
- ➜ Security mechanisms



Location of LRs:

- ➜ LRs only hosted by clients
- ➜ Statefull LRs only hosted by object servers
- ➜ Statefull LRs on both clients and object servers

GLOBE (GLOBAL OBJECT BASED ENVIRONMENT)

Scalable wide-area distributed system:

- ➜ Wide-area scalability requires replication
- ➜ Wide-area scalability requires flexibility

Features:

- ➜ Per-object replication and consistency
- ➜ Per-object communication
- ➜ Mechanism not policy
- ➜ Transparency (replication, migration)
- ➜ Dynamic replication

Homework

- Could you turn CORBA into a distributed shared object middleware using interceptors?

Hacker's edition:

- Implement the simple filesystem presented using a freely available version of CORBA (or other middleware if you prefer).

Reading List

Globe: A Wide-Area Distributed System An overview of Globe

CORBA: Integrating Diverse Applications Within Distributed Heterogeneous Environments An overview of CORBA

New Features for CORBA 3.0 More CORBA