University of Bologna

Dipartimento di Informatica –

Scienza e Ingegneria (DISI)

Engineering Bologna Campus

Class of

Infrastructures for Cloud Computing and Big Data M

Dependability and new replication strategies

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Academic year 2018/2019

Replication to tolerate faults

Models and some definitions related to faults

failure any behavior not conforming with the requirements

error any problem that can generate an incorrect behavior or a *failure (unsafety)*

fault set of events in a system that can cause *errors*

An application can fail and it can cause a wrong update on a database

fault is the concrete causing occurrence (several processes entering at the same time), **error** is the sequence of events (mutual exclusion has not been enforced)

these can generate the visible effect of **failures (to be prevented)**

fault ⇨ transient, intermittent, permanent ones

Bohrbug repeatable, neat failures, and often easy to be corrected

Eisenbug less repeatable, hard to be understood failures, hard to correct

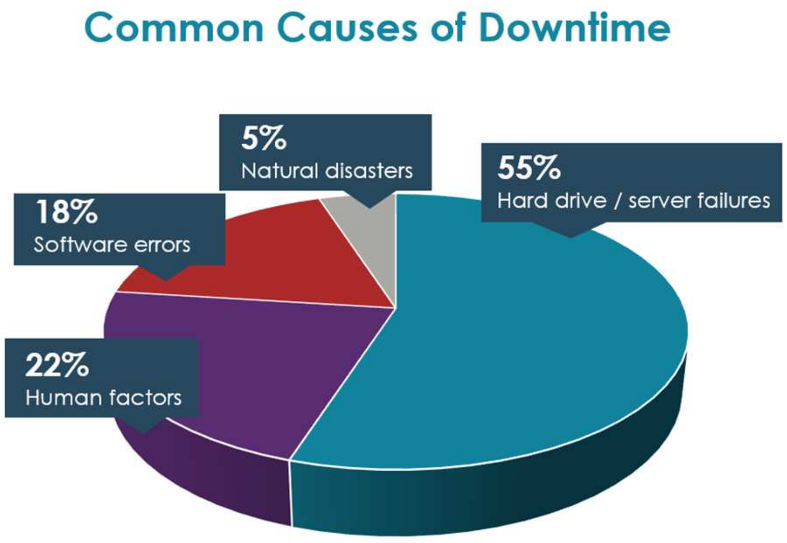
Eisenbug often tied to specific runs and events, so not easy to be corrected

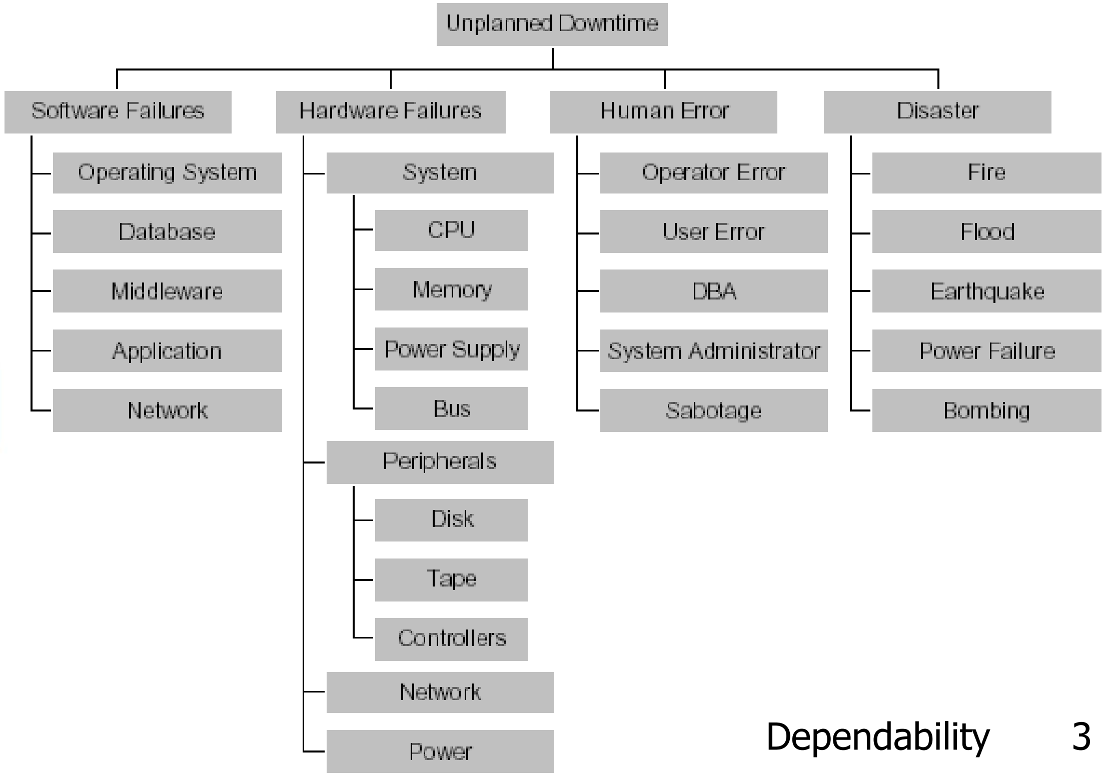
SERVICE UNAVAILABILITY

Any system can crash and may become unavailable some time, for several reasons, so it must recover to work safely again

Causes of unavailability can stem from many different reasons, either planned ones or not planned

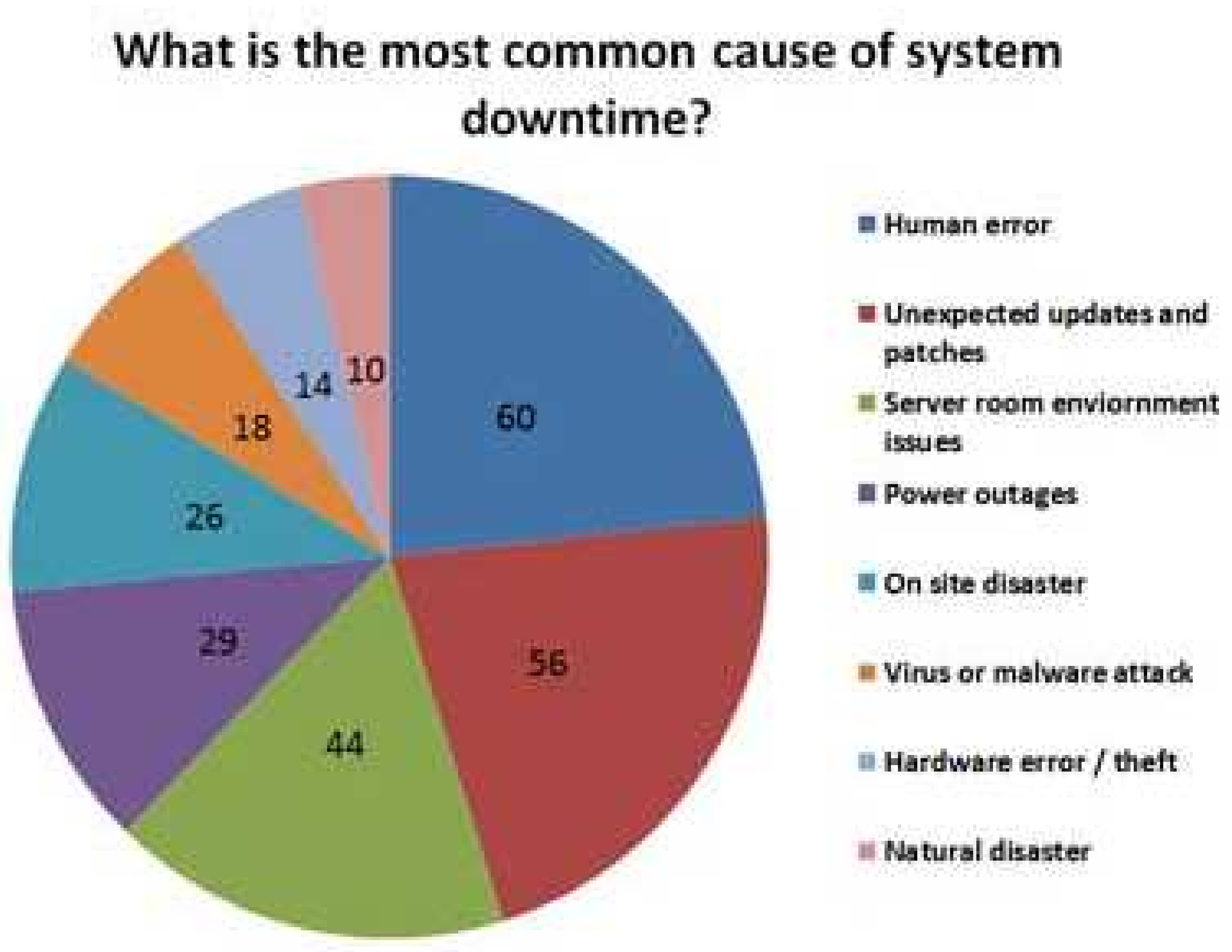
We need **phases of fault/error IDENTIFICATION** and **RECOVERY** to go back to normal operations and requirement conformance





- Unplanned Downtime
  - Software Failures
    - Operating System
    - Database
    - Middleware
    - Application
    - Network
  - Hardware Failures
    - System
      - CPU
      - Memory
      - Power Supply
      - Bus
    - Peripherals
      - Disk
      - Tape
      - Controllers
    - Network
    - Power
  - Human Error
    - Operator Error
    - User Error
    - DBA
    - System Administrator
    - Sabotage
  - Disaster
    - Fire
    - Flood
    - Earthquake
    - Power Failure
    - Bombing

DOWNTIME CAUSES

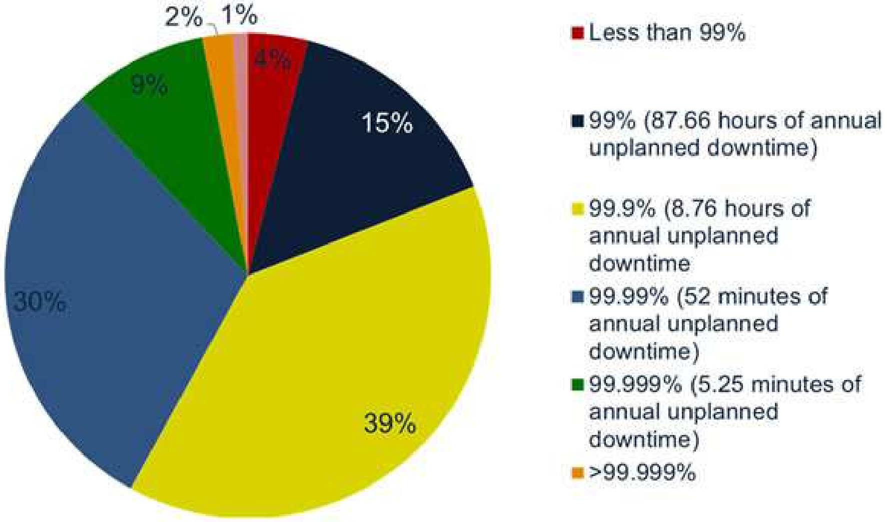


SERVICE UNAVAILABILITY INDICATORS

If a system crashes with a specified probability, at those times we experience unavailability periods (**downtime**) that may be very different and must be measured

Often we use the ***number of 9s*** to measure availability
That indicator expresses not only the *frequency of crashes* and the *percentage of uptime*, but also the *capacity of fast recovery*, because the **uptime depends not only from fatale failure occurrences but also from the capacity of recovering**
The indicators averaged over one year time

Uptime (%)	*Downtime (%)*	*Downtime (year)*
98%	2%	7.3 days
99%	1%	3.65 days
99.8%	0.2%	17h,30’
99.9%	0.1%	8h, 45’
99.99%	0.01%	52,5’
99.999%	0.001%	5.25’
99.9999%	0.0001%	31.5”

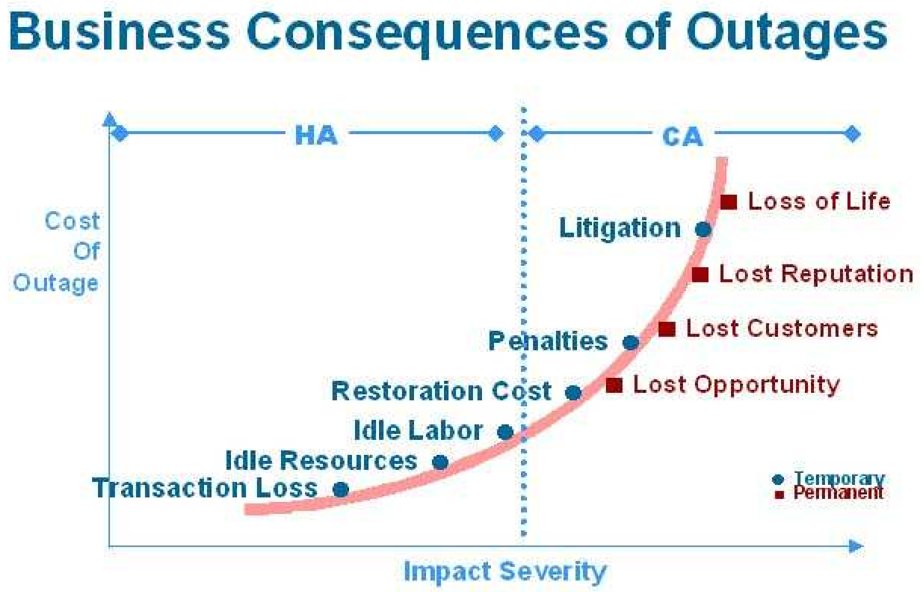


FAILURE COSTS

Again any area has **downtime costs, very different** because of the different impact on the society or on the customers, due to the importance and the interests in the service

Of course a true and precise evaluation is very difficult

Industrial Area	Loss/h
Financial (broker)	$ 6.5M
Financial (credit)	$ 2.6M
Manufacturing	$ 780K
Retail	$ 600K
Avionic	$ 90K
Media	$ 69K



HA High availability – **CA** Continuous availability

More Definitions

DEPENDABILITY ***FAULT TOLERANCE* (FT)**

The customer has a complete confidence in the system

Both in the sense of hardware, software, and in general any aspect

Complete confidence in any design aspect

RELIABILITY ***(reliance on the system services)***

The system must provide **correct answers**

(the stress is on correct responses)

A disk can save any result ⇨ but cannot grant a fast response time

AVAILABILITY ***(continuity of services)***

The system must provide **correct answers in a limited time**

(the stress is on correct response timing)

Replication with active copies and service always available

RECOVERABILITY ***(recovery via state persistency)…***

Consistency, Safety, Security, Privacy, ...

Fault Identification & Recovery in C/S

C/S play a reciprocal role in control & **identification**

the client and the server control each other

- **the client waits for the answer from the server synchronously**
- **the server waits for the answer delivery verifying it**
  - **messages have timeout and are resent**

Fault identification and **recovery** strategies

Faults that can be tolerated without causing failure

(at any time, all together and during the recovery protocol)

Number of repetitions ⇨ possible fault number

The design can be vary hard and intricate →

Fault assumptions simplify the complex duty

SINGLE FAULT ASSUMPTION

Fault assumptions simplify the management and system design

Single Fault assumption (**one fault at a time**)

The **identification** and **recovery** must be less than

(**TTR T**ime **T**o **R**epair and **MTTR Mean TTR**)

the interval between two faults

(**TBF T**ime **B**etween **F**ailure and **MTBF Mean TBF**)

In other words, during recovery we assume that no fault occurs and the system is safe

With **2** copies, we can **identify one fault** (identification *via some invariant property*), and, even if fault caused the block, we can continue with the residual correct copy (in a degraded service) with single fault assumption

With **3** copies, we can **tolerate one fault**, and **two can be identified**

In general terms,

with **3t copies**, we can tolerate **t** faults for a replicated resource

(**without any fault assumption**)

SINGLE POINT OF FAILURE!!!!

To make systems more viable

Avoid single points of failure

SPoF in an architecture

single fault assumption

After tandem

RAID

In general terms,

with **3t copies**, we can tolerate **t** faults for a replicated resource

(**without any fault assumption**)

FAULT ASSUMPTIONS FOR COMMUNICATING PROCESSORS

We can work with computing resources, with executing and **communicating processors**

FAIL-STOP

one processor fails by stopping (halt) and all other processors can verify its failure state

FAIL-SAFE (CRASH or HALT assumption)

one processor fails by stopping (halt) and all other processors **cannot** verify its failure state

BYZANTINE FAILURES

one processor can fail, by exhibiting any kind of behavior, with passive and active malicious actions (see byzantine *generals and their baroque strategies*)

DISTRIBUTED SYSTEMS ASSUMPTIONS

More advanced fault assumptions

SEND & RECEIVE OMISSION

one processor fails by receiving/sending only some of the messages it should have worked on correctly

GENERAL OMISSION

one processor fails by receiving/sending only some of the messages it should have worked on correctly or by halting

NETWORK FAILURE

the whole interconnection network does not grant correct behavior

NETWORK PARTITION

the whole interconnection network does not work by partitioning the systems in two parts that cannot communicate with each other

Replication as a strategy to build dependable components

HIGH LEVEL GOALS

Availability and Reliability measured in terms of

MTBF	**M**ean **T**ime **B**etween **F**ailures	system availability
MTTR	**M**ean **T**ime **T**o **R**epair	system unavailability

Availability **A = MTBF / (MTBF + MTTR)**

It defines the percentage of **correct services** in time (number of 9s)

It can also be different for read and write operations

If we consider more copies, the read can be answered also if only one copy is available, and others ones are not (action that does not modify)

Reliability probability of an available service depending on time and based on a period of Δt

R (Δt) = reliable over time Δt

R(0) = A, as a general limit

RELATED PROPRIETIES

Formal properties

Correctness - Safety guarantees that there are no **problems**
all invariants are always met

Vitality - Liveness achieving goals with **success**
the goal is completely reached

A system without safety & liveness does give any guarantee for any specific fault (no tolerance)

A system with safety e liveness can tolerate occurring faults

A system with **safety** without **liveness** operates **always correctly and can give results, without guarantee of respecting timing constraints**

A system without **safety** with **liveness** always provides a **result in the required time**, even if the results maybe **incorrect** (e.g., an exception)

In any case, to grant any of those the solutions should consider replication either in time or space

FAULT-TOLERANCE ARCHITECTURES

Use of replicated components that introduce added costs and require new **execution models**

Hw replication, but replication also propagates at any level

Differentiated execution: several copies either **all active** or **not**, over the same service, or working on different operations

- **One component only** executes and produces the result, all the others are there as **backups**
- **All components are equal and play the same role,** by executing different services at the same time and give out different answers (max throughput)
- **All components are equal in role** and **execute the same operation** to produce a **coordinated unique result** (maximum guarantee of correctness: algorithm diversity)

Those architectures are typically metalevel organizations, because they introduce **parts that control the system behavior** and **manage replication**

STABLE MEMORY

Stable Memory uses replication strategies (persistency ***on disk***) to grant not to lose any information

Limiting fault assumption: *we consider a support system in which there is a low and negligible probability of multiple faults over related memory components (single fault over connected blocks of memory)*

In general, the fault probability during a possible recovery must be minimal, to mimic the **single fault assumption**

Memory with correct blocks

any error is converted in an **omission** (a control *code is associated to the block and the block is considered correct or faulty, in a clear way)*

Blocks are organized in **two different** copies over different disks, with a really low *probability of simultaneous* ***fault (or conjunct fault)***: the two copies contain the same information

Replication in degree of two

STABLE MEMORY - SUPPORT PROTOCOLS

Any operation (either **read** or **write**) operates on both copies: if one is incorrect, a recovery protocol starts

Any **action** proceeds starting from one of the copies and then to the other one

Any **action** from an **incorrect block** is considered an omission fault and starts a recovery protocol

The **recovery** protocol has the goal of recovering both copies to a safe state, even by working for a long time…. repeating actins

*if both copies are **equal and consistent**, no action*

*If only **one** of the copies is **correct**, the protocol copies the correct value over the wrong copy*

if both copies are correct but inconsistent, the consistency is established (one content is enforced)

(if copies have a time/version indicator it is used to choose the correct)

High cost of implementation, especially in terms of timing

(how to limit the recovery time?)

TANDEM

Special-purpose system with online data (not disk)

TANDEM (bought and adopted by Compaq e HP)

- **replication via two copies of any system component** (two processors, two buses, two disks, …) and the system works in a perfectly synchronous approach
- The goal: **fail-safe** system dependable with **single fault assumption**
  - *Any error is identified via component replication and the **double** approach can tolerate it*
  - *The stable memory approach is implemented via the access to the double bus to a doubled disk with double data replicated*
  - **The system cost is high and makes it special purpose (banks)**

Replicated copies can push to two strategies

- to make the actions twice, in any **component** or
- to make actions only **once** and use the other copy as a back up

Tandem has a high cost, both in terms of resources and timing

Redundant Array of Inexpensive Disks

General-purpose organization of disks with a replication goal but low-cost intention

well spread and used market solution

RAID **R**edundant **A**rray of **I**nexpensive **D**isk

A set of **low cost** disks coordinated toward common actions with different goals in shared common actions to achieve different standard objectives

Commercial low cost off the shelf systems

The initial goal of RAID was to offer **low response time,** via **data striping,** so that a content is **split among different disks** to be **read** / **written in parallel**

Then **some standards** extended to consider **data replication**

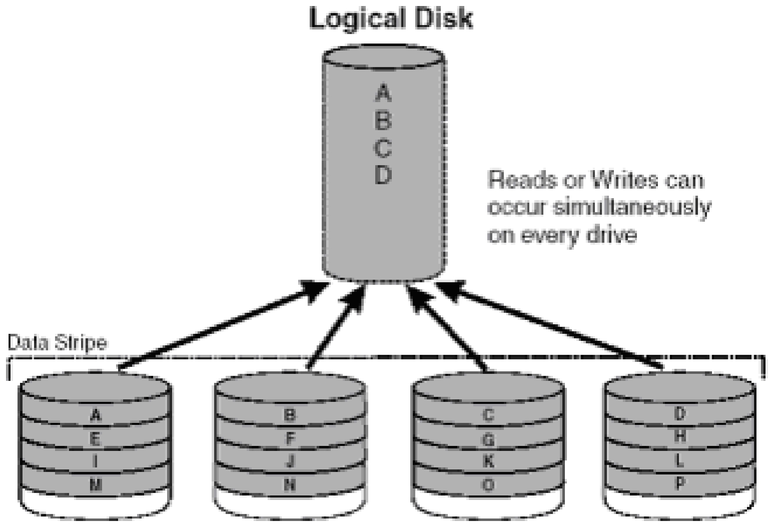
Some classes consider different organizations for different standard goal

RAID

Raid 0: simple striping

parallel I/O but no redundancy, suitable for I/O intensive applications

but worse **MTBF**

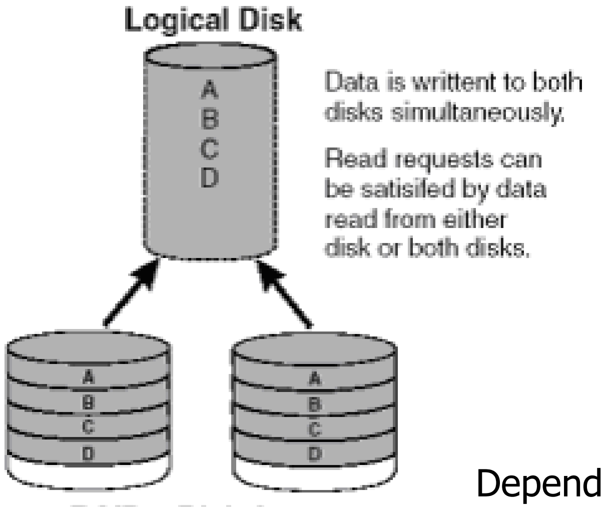


RAID 0 Disk Array

Raid 1: mirroring – maximum **redundancy**

for high availability even if higher cost

good performances in reading and less in writing


Logical Disk
A
B
C
D
Data is writtent to both disks simultaneously.
Read requests can be satisifed by data read from either disk or both disks.
A
B
C
D
A
B
C
D

RAID 1 Disk Array

RAID

Raid 3 & 4: striping with dedicated parity disk

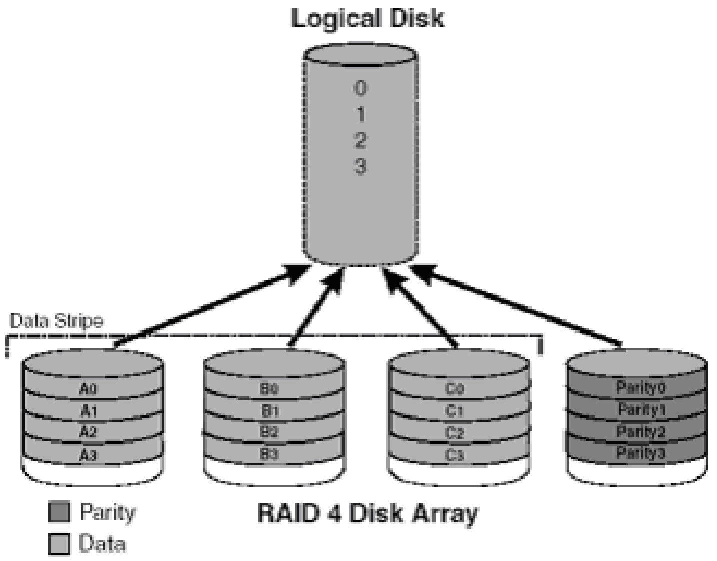
High speed to support operations on large contents (images)

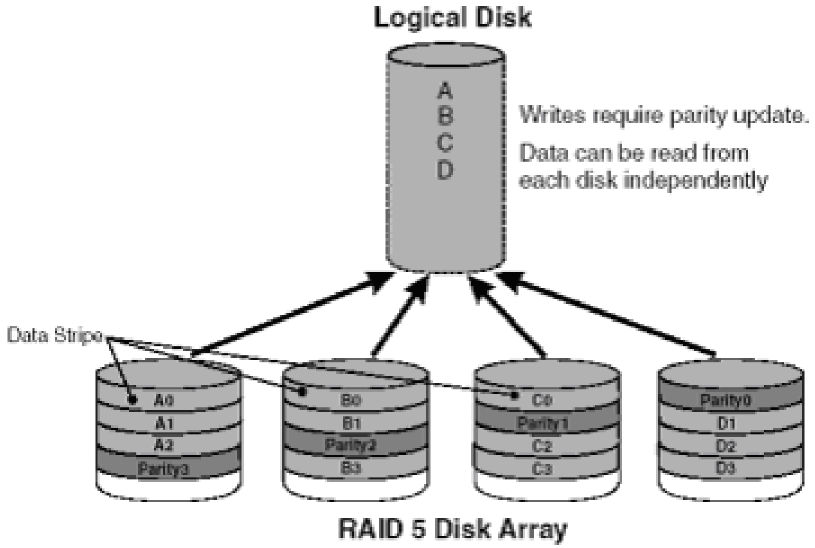
one I/O operation at a time, for the contention on the parity disk

Raid 5: striping without dedicated parity disk

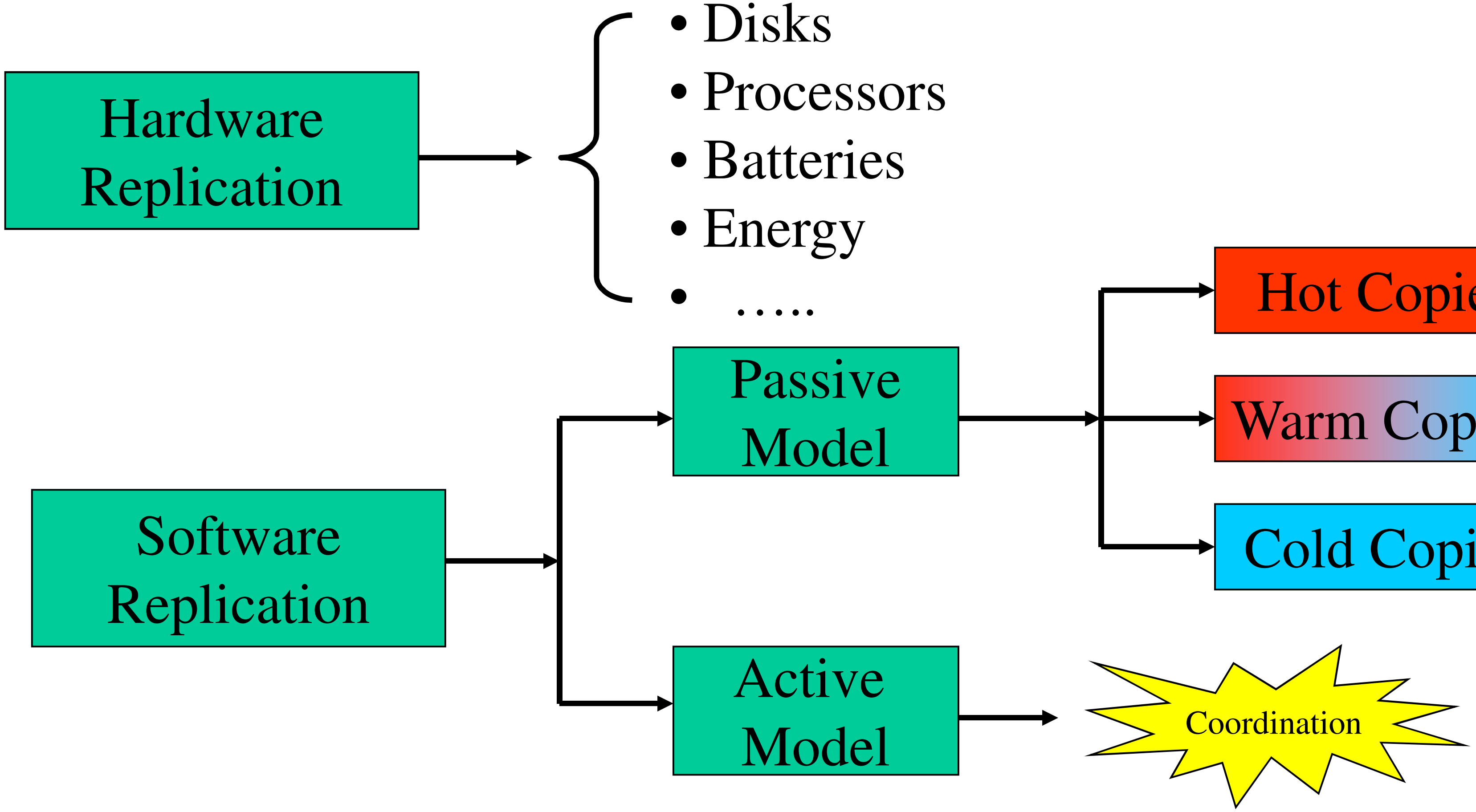
the distributed parity check achieves good speed in case of many readings for small contents and

good writing operations for large contents





REPLICATION FORMS



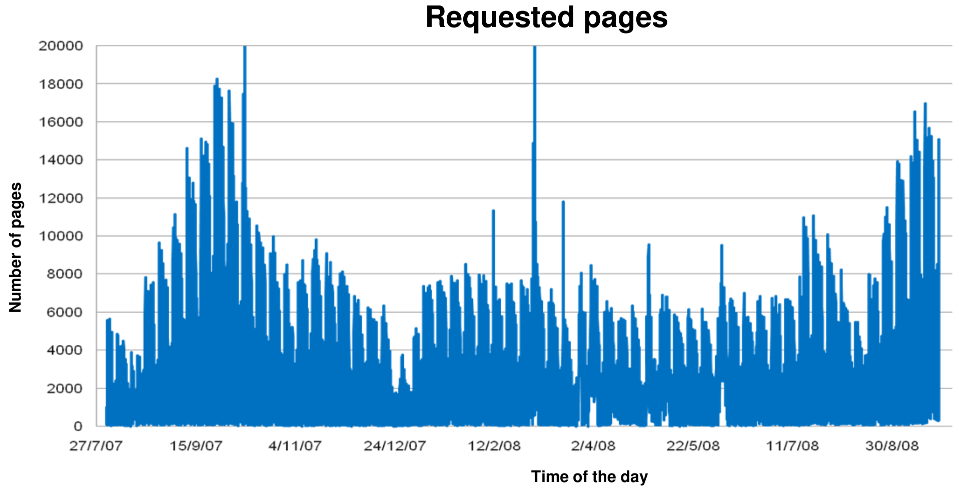
Hot copies, continuous updating
Cold copies, no update actions
Warm copies, some update actions, but not continuous

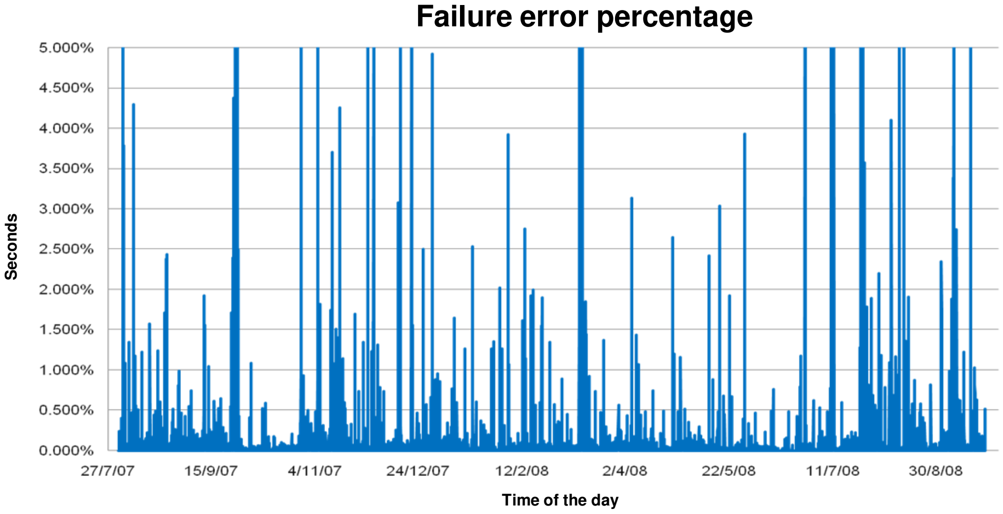
A SMALL SCALE EXAMPLE

Alma ICT has a small problem in answering many requests in a short time for a specific Web Service

A better solution than a **simple server** has to be devised to grant **limited answer times with no errors**

and some fault tolerance to single fault occurrence





ALMA WEBSERVICE ARCHITECTURE

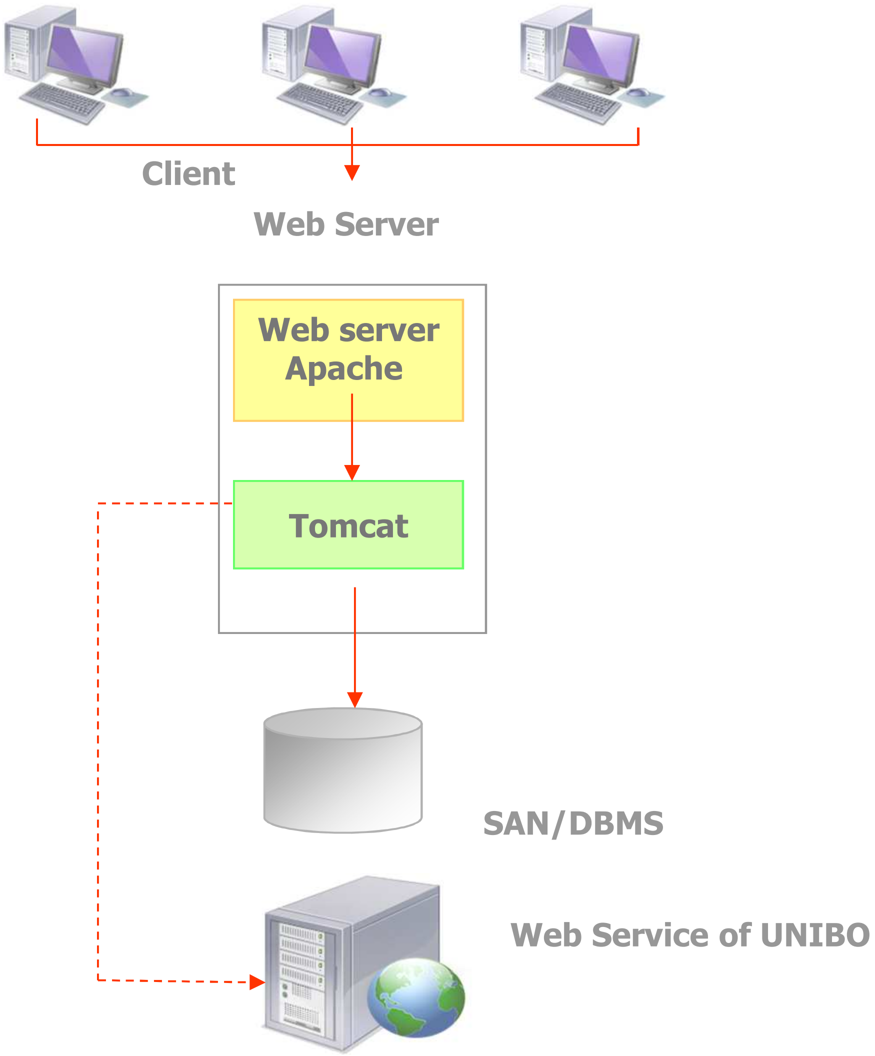
Devise a minimal cost solution

Users are interested in **getting Web server answers**

after invoking a Web service **that interacts asking to a back end database**

Requests arrive both from **final portal users** and also from external **programs** and other **internal UNIBO applications**

The correct answers are **very crucial**



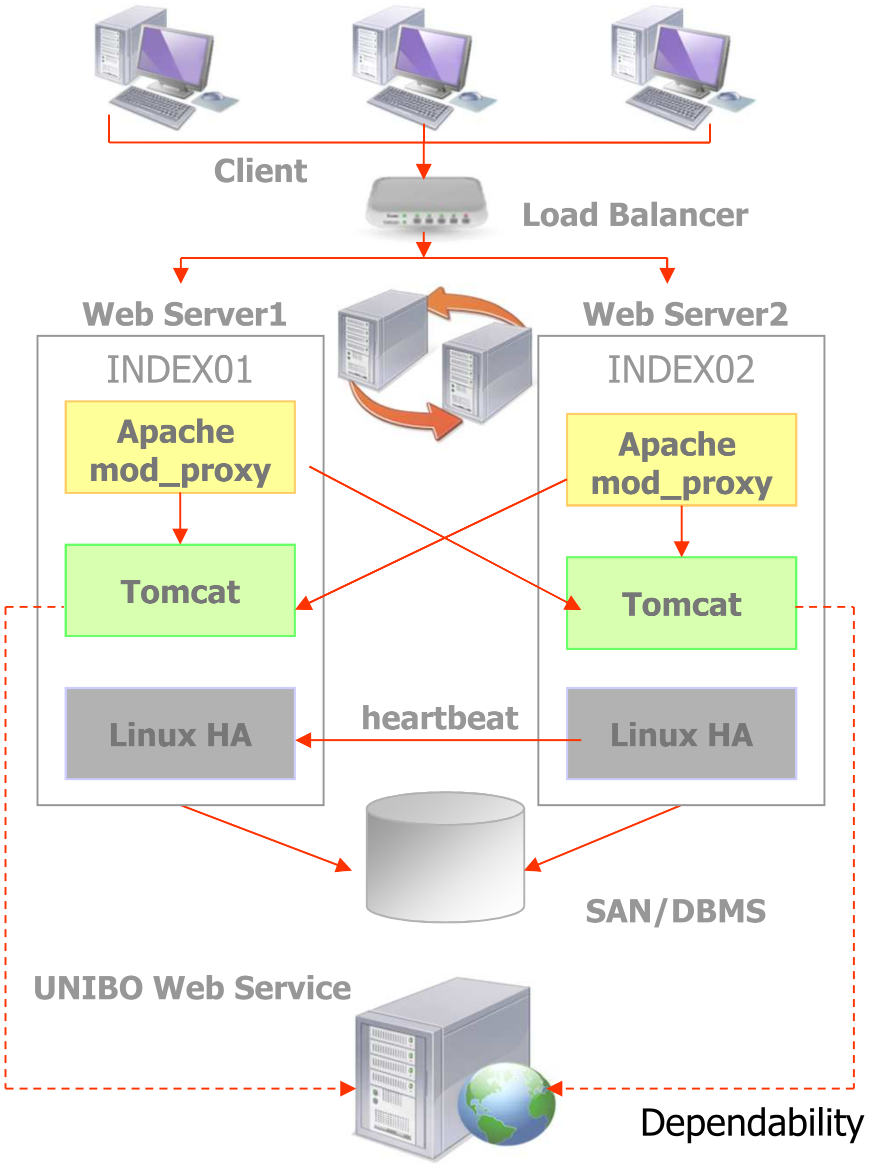
PROTOTYPE ARCHITECTURE

- Load balancing via a hardware balancer as a front end of the two main servers

- INDEX01 & INDEX02: two Web Servers in a cluster
- two Tomcat instances managed by an Apache proxy

Reliability granted by a module of High Availability Linux

master-slave with a heartbeat

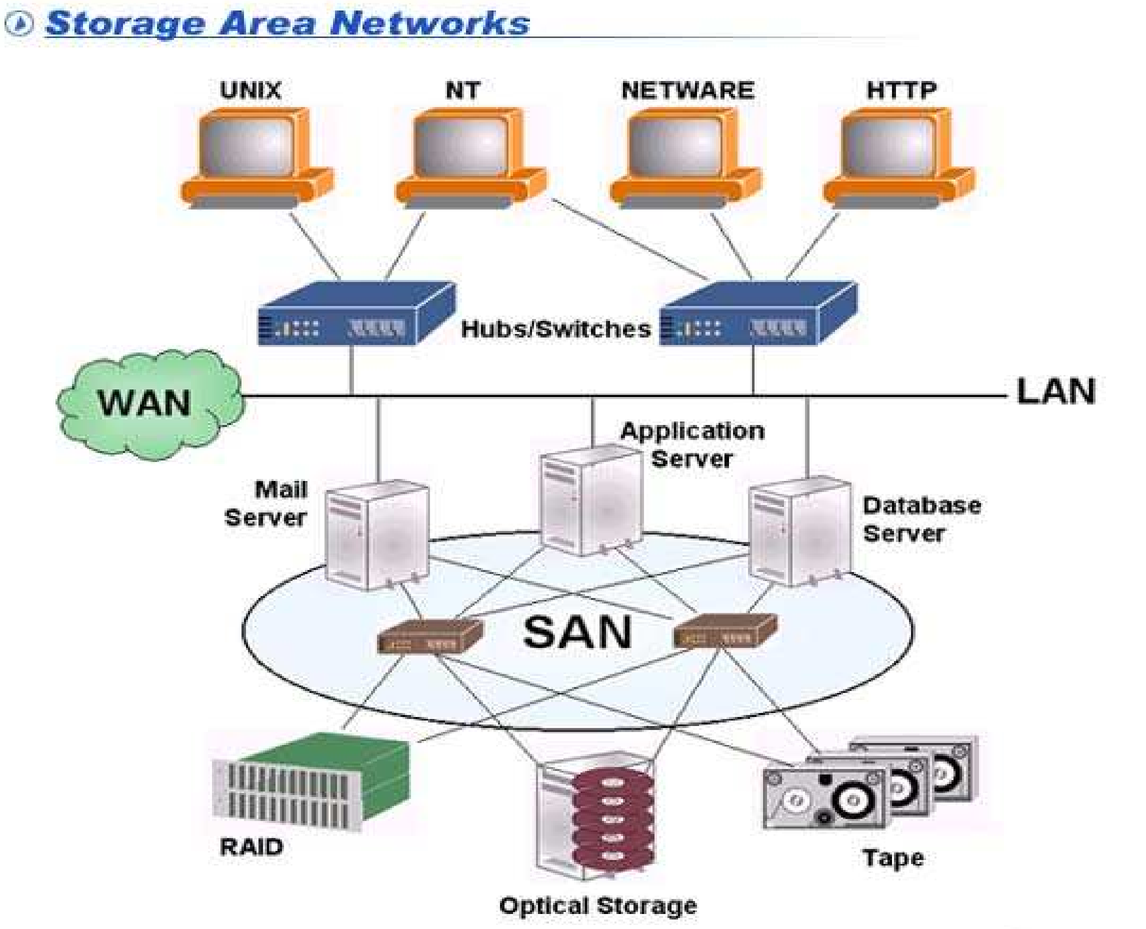


STORAGE AREA NETWORK (SAN)

A Storage Area Network is a **set of interconnected resources with several QoS** to grant the storage service with the best suitability for different users

Users can employ SAN to get the **storage resource** they need **without any interference** and ideally **without any capacity limit** and with **minimal delay**

In Cloud, *the SAN can offer* ***Storage as-a-Service***



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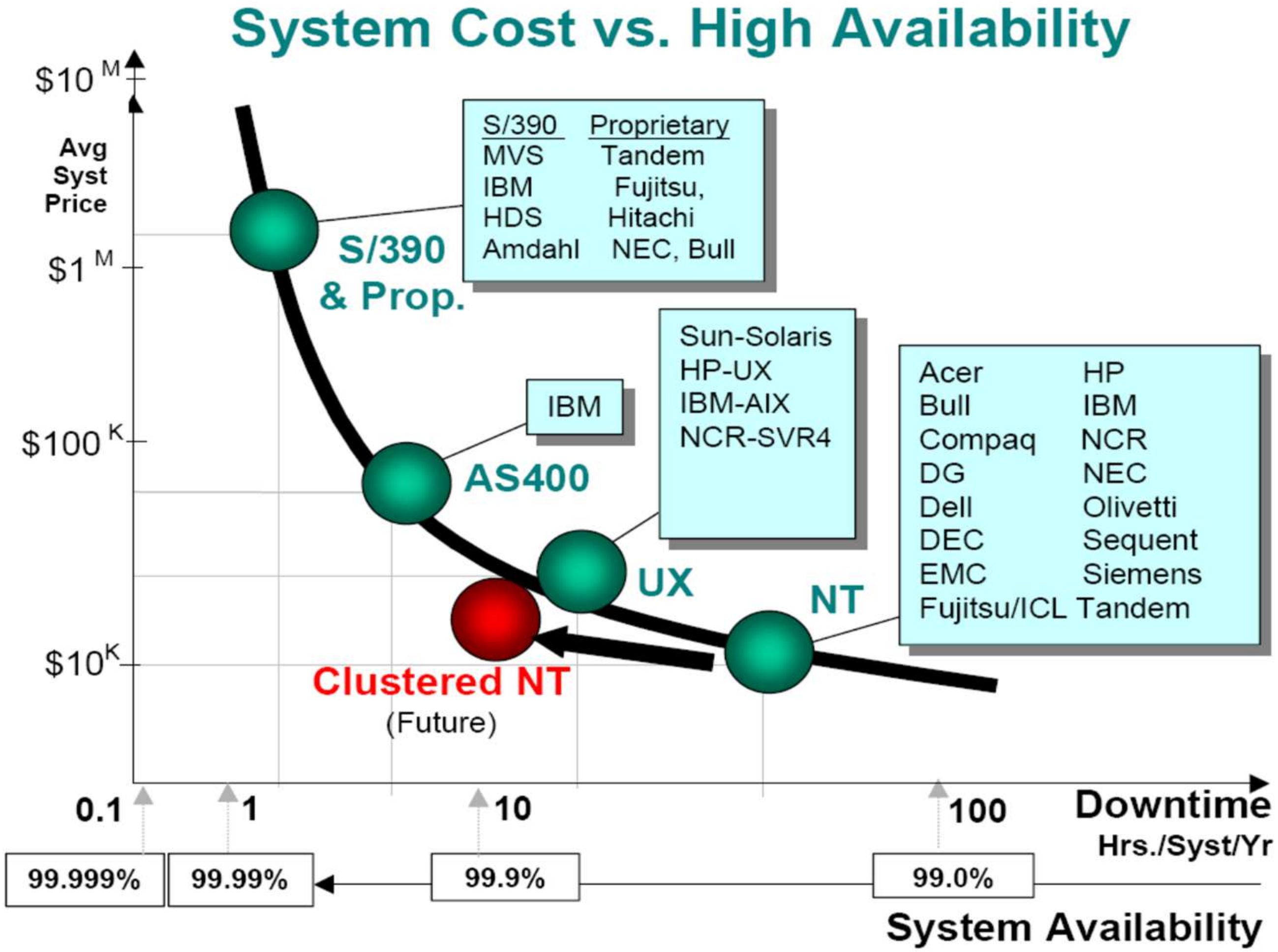
HIGH AVAILABILITY (HA)

High availability costs tend to decrease and to get better service

Low cost solutions are more and more **common** with a **better QoS** and **better dependability**

Solutions are more and more **off-the-shelf**

System Cost vs. High Availability



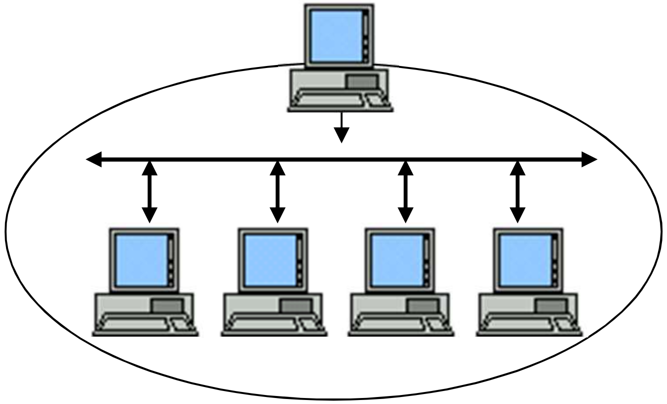
HIGH AVAILABILITY CLUSTERS

Cluster have different motivations

- **high availability**
- **high performance**
- **load balancing**

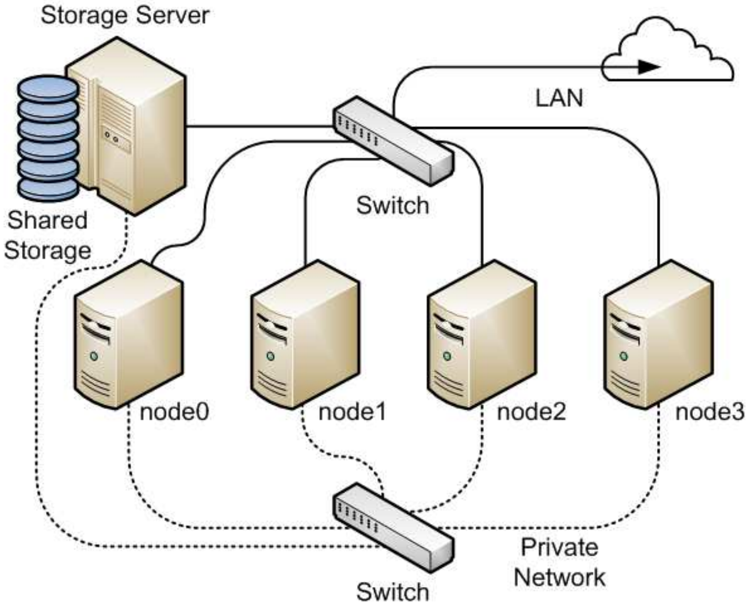
A cluster for **high availability**

Consists of a **set of independent nodes** that cooperate to provide a dependable **service, always on 24/7**



The cluster are a good off-the-shelf solution for **high availability**:

- **robust** and **reliable**
- **cost-effective** (easy to buy off-the-shelf hardware and support)
- **typically one Front-end**



CLUSTER SUPPORT OPERATIONS

The cluster support must provide:

- Service **monitoring**

  To dynamically ascertain the current QoS (***final and perceived***)

- **Failover** (**service migration**)

  the failover is a hot migration of a service immediately after the crash, whichever the cause. The failover must take place very fast to limit service unavailability

  Typically should automatic, fast, and transparent (the sooner the better)

- **Heartbeat** (**node state monitoring**)

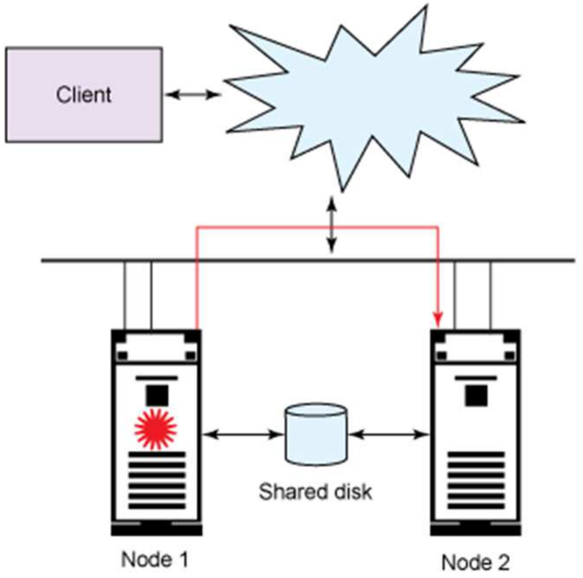
  The heartbeat is the protocol to check node state to monitor and ascertain any copy failure

  Exchange of are-you-alive messages with low intrusion

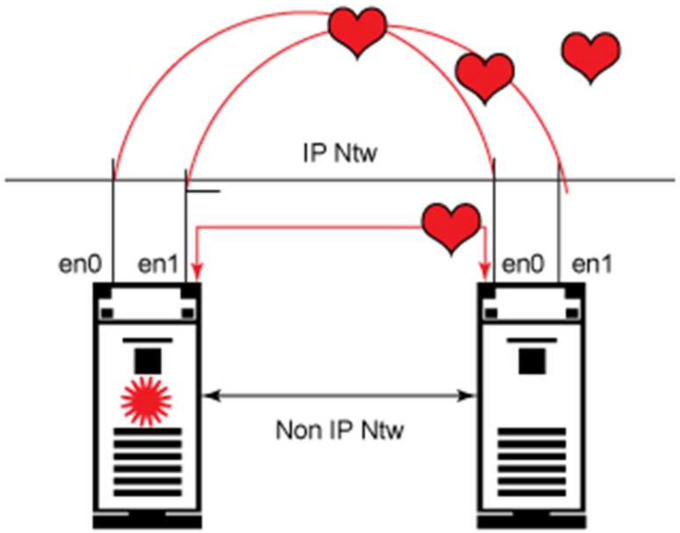
  Some cluster can also work in case of partitioning and allows to go on and support reconciliation when reconnected

CLUSTER: FAILOVER & HEARTBIT

In case of failover, the data must be available to the new node of the cluster via **shared component** over the cluster



The detection of problem is via a **lightweight heartbeat protocol**

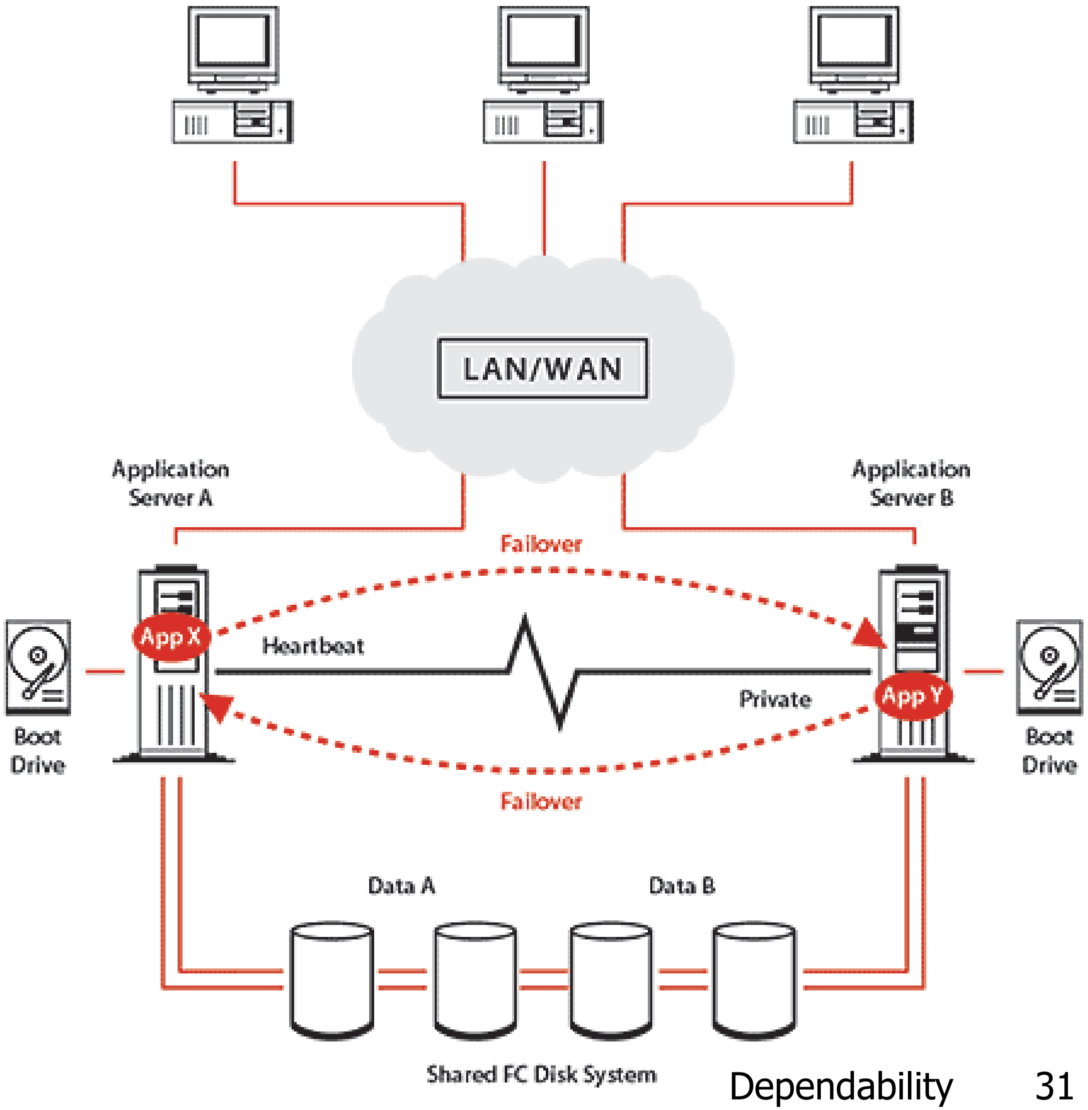


Red Hat CLUSTER

Red Hat Cluster suite (open source)

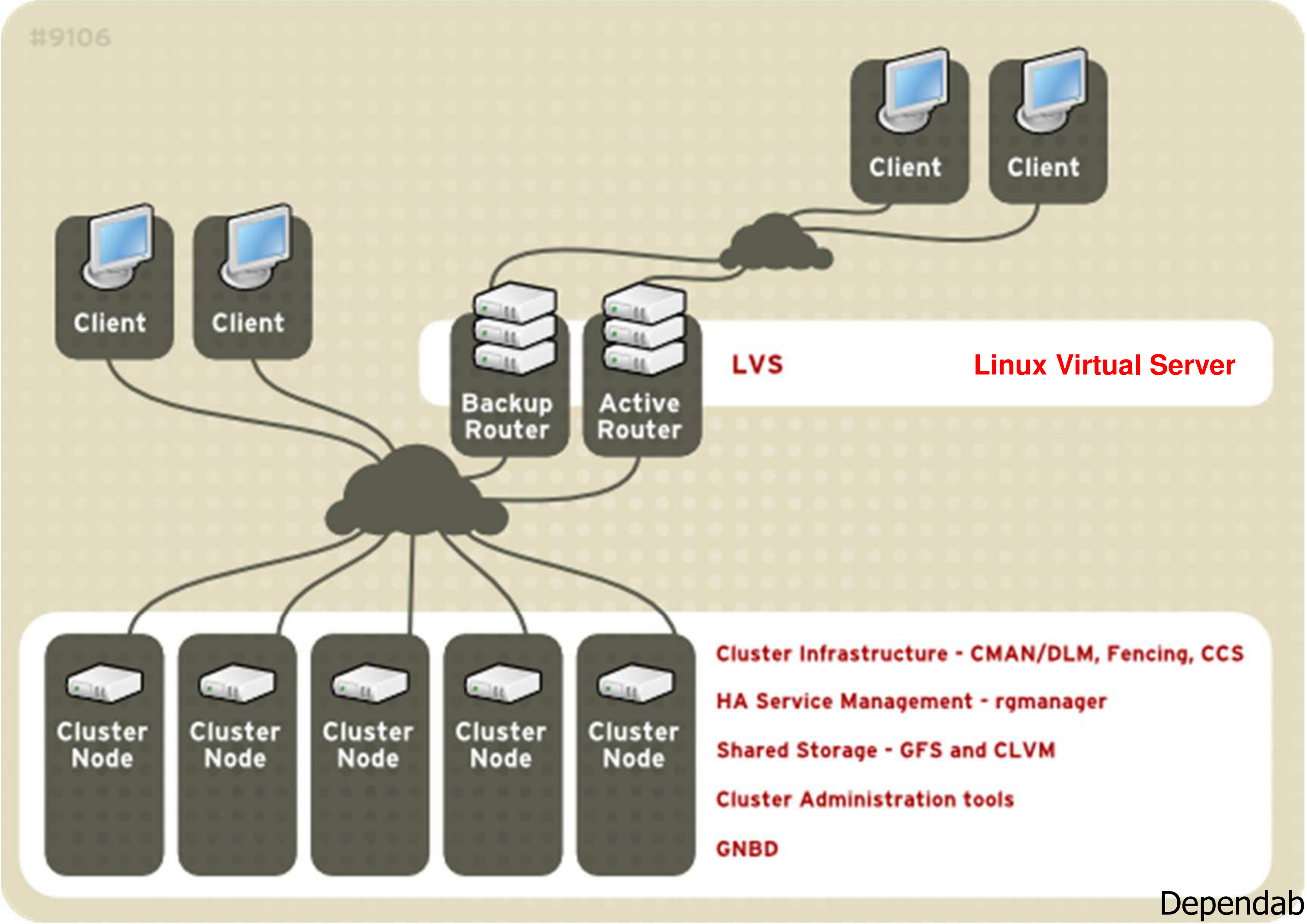
The figure has a replication degree of two

It comprises also some shared disks to share data



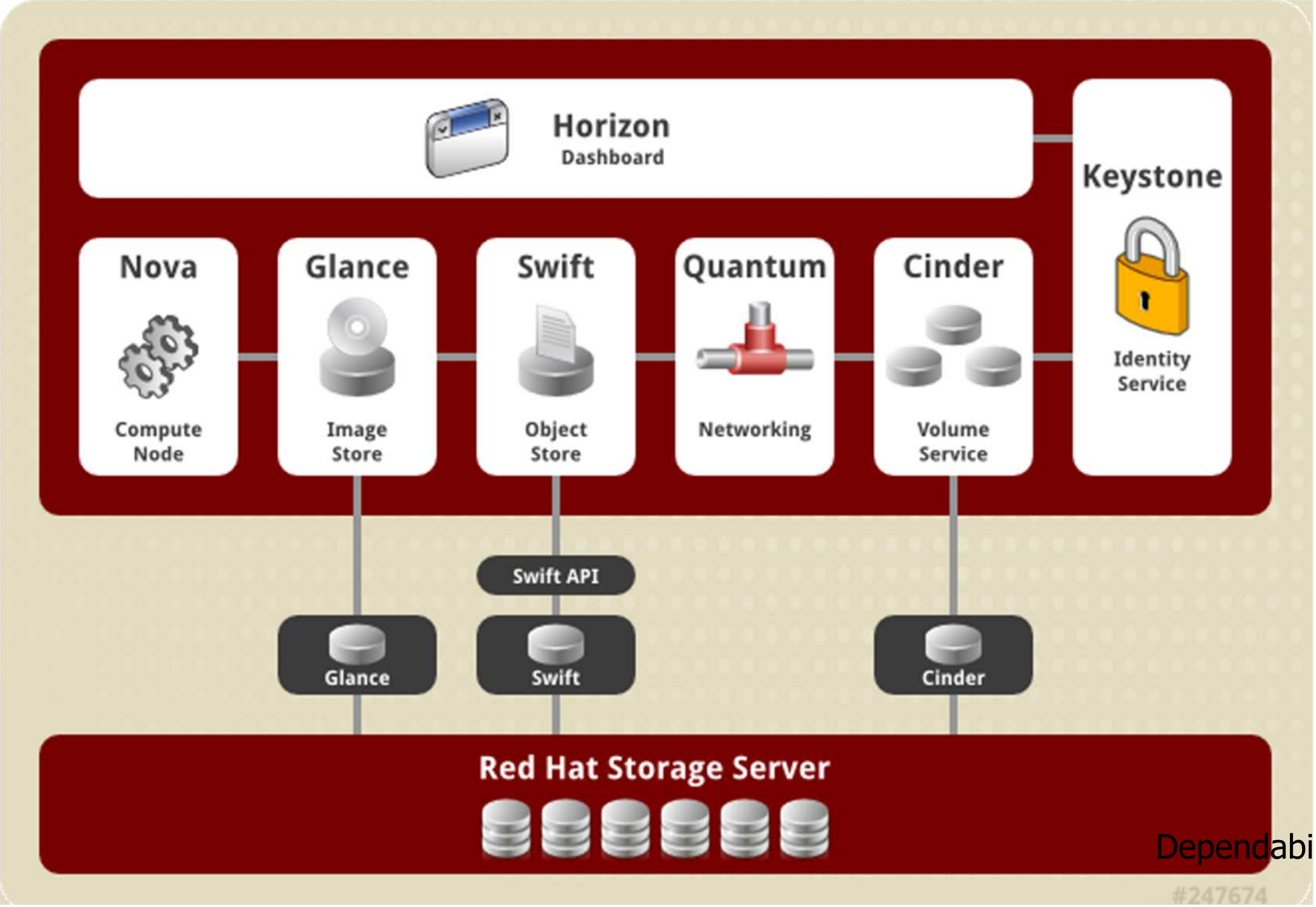
Red Hat CLUSTER

Red Hat Cluster suite evolved a lot and is off-the-shelf



Red Hat CLUSTER & …

Red Hat Cluster can coexist with most widespread architectures… Here Openstack



FAULT-TOLERANT SUPPORT

FAULT TOLERANCE requires support, resources, protocols

Protocols are expensive in term of required resources

complexity and length of the algorithms
implementation of the algorithm (and their correctness)

The **(hw & sw) support to grant dependability** is a challenge to be answered

There is no **unique strategy** for always **accepted solutions** because it is strictly interconnected with system requirements and dependability is a non functional property with many facets

In general terms, the recovery protocol must be more reliable than the application itself *(it is a problem how to grant it)*

Special-purpose systems ⇨

ad hoc resources even with better QoS

General-purpose systems ⇨

fault tolerance support insists on user resources

FAULT-TOLERANT ARCHITECTURES

Minimal intrusion principle applies to any solution

To limit **the cost of the dependability support, by organizing the resource engagement** (*overhead*) at any support and system level

The minimal intrusion principle is an engineering one, so it should be considered in any design of systems, to answer with the requested SLA any need

Special-purpose systems ⇨

These systems can achieve dependability via an added ad-hoc architecture completely separated from the application one

Costs are high and the design is complex (formal proofs?)

General-purpose systems ⇨

User resources are the only one available. The fault tolerance support must economize on its design so not to get too much from the resources for the application levels

HIGH REPLICATION COSTS

Dependability costs are generally high in the two senses and dimensions

space in terms of required **resource** available (multiple copies)

time in terms of **time, answer and service timing**

Often the fault assumptions can make the system more or less complex and viable the cost of solutions

Cost may depend on many different factors

- ***Memory and persistency costs***
- ***Communication overhead***
- ***Implementation complexity***
  what to replicate, how many copies, where to keep them, how to coordinate? etc.

The general trend is in the sense of optimizing protocols, supports, infrastructures

RESOURCE MANAGEMENT

We can consider **replicated resources in distributed systems** with an obvious **need of coordination of them toward a common goal (also software fault-tolerance)**

Replicated resources

Multiple resource copies on different nodes with several replication degrees

Partitioned resources

Multiple resource copies on different nodes (without any replication degree) to work independently

Redundancy can suggest architectures to get a better QoS

replication of processes and data

AN ABSTRACT UNIQUE RESOURCE

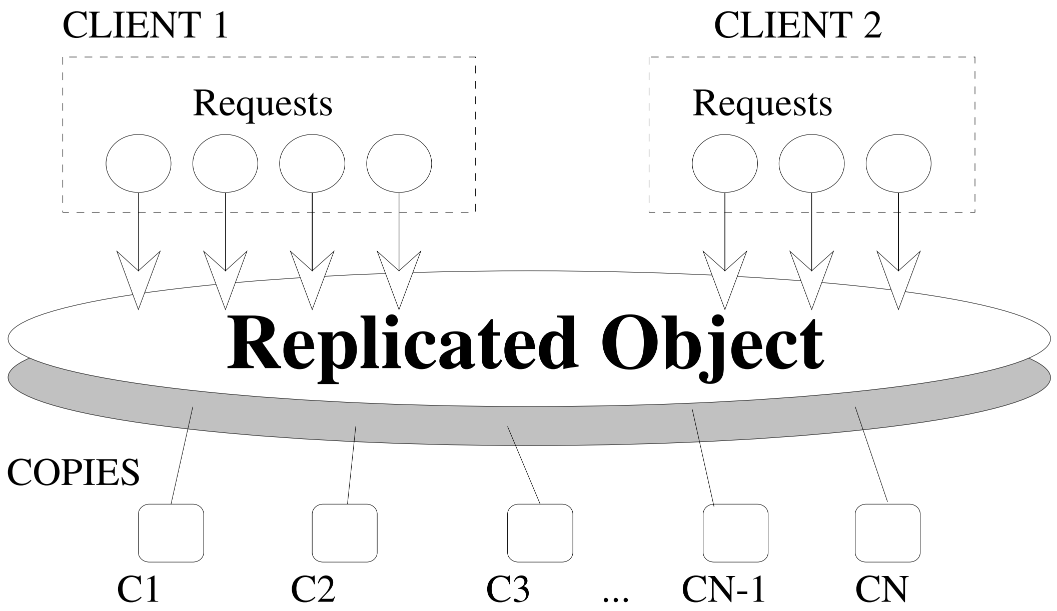
Replication degree and FT models

Number of copies of the entity to replicate

The greater the **number** of **copies,** the greater the **redundancy**

The better the **reliability & availability**

The greater the cost and the overhead



Two extreme models of FT architectures

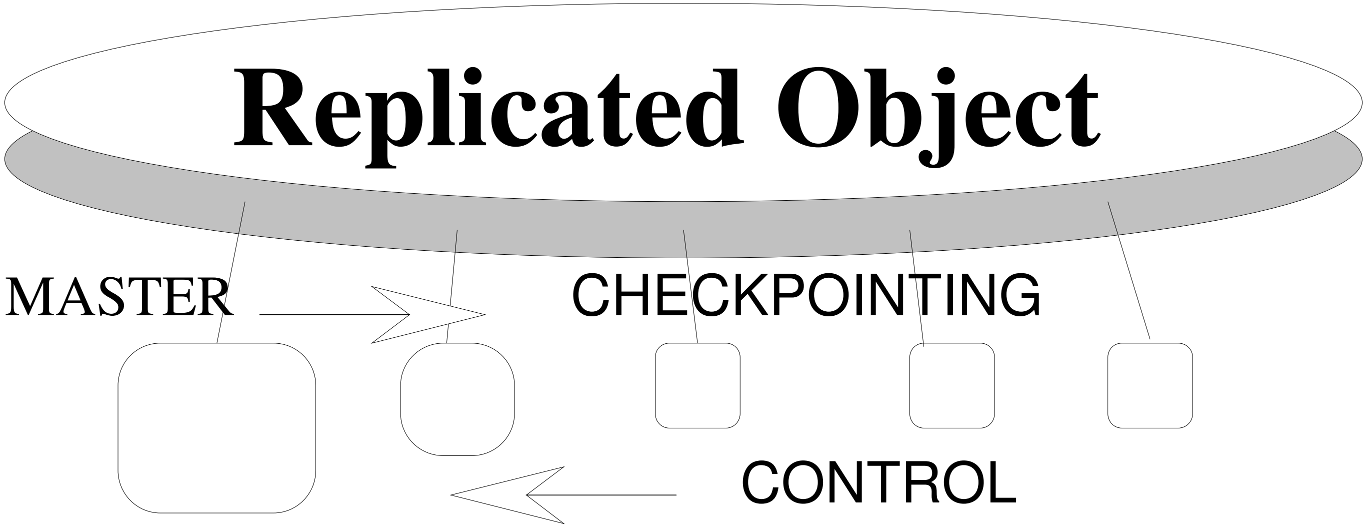
- **One only** executes (master-slave)
- **All** execute (copies are active and peer)

With variations

REPLICATION ARCHITECTURES

Passive model ***(also called Master-Slave)***
Only one copy executes, the others are back-ups

This is the first replication model well spread in industrial plants
*The **master** is externally visible and manages the whole resource*
The slaves must control the master for errors and faults



ACTIVE REPLICATION

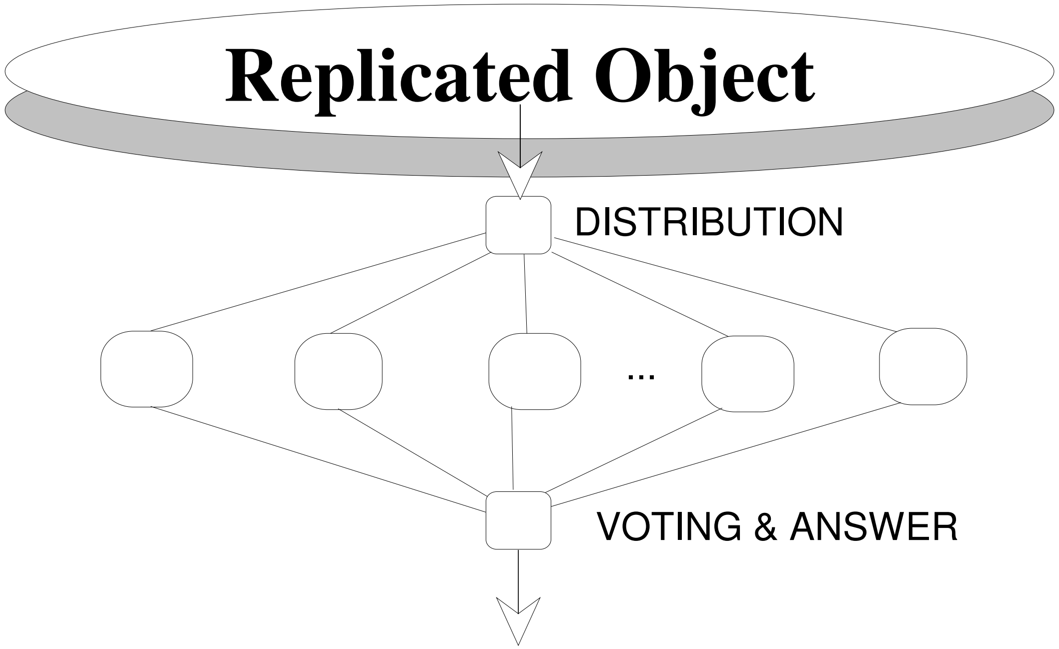
Active Model

***All copies* execute all operations in a more or less synchronous way and with some forms of coordination among copies**

In **TMR** (Triple Modular Redundancy) **three** copies

We can tolerate on faults and can identify up to two faults

In software FT different copies can use different algorithms toward the goal



PASSIVE REPLICATION MODEL

The two extreme FT models are

Master Slave	***(passive model)***
Active Copies	***(active model)***

The passive model or **master/slave** or **primary/backup**

Has one **active process only (the master or primary) actively executes over data,** the other copies (passive ones or back-ups) become operating only in case of failure of the master

*only one copy is fresh and updated, the other can also be obsolete in state and not updated (***cold*** or ***hot copies****)*

This mode can produce a possible conflict between the state of the **master** and the state of the **slaves**

In case of a failure and cold copies, one must start repeating from the previous state, to produce the updated state

CHECKPOINT - SLAVE UPDATE

In general, the master updates the slave states via **checkpointing** ⇨ ***the updating action also made in a chain:*** *the master updates the first slave that updates the second, …*

The **management policies** can distinguish

the required actions to grant a correct response

update of the **primary** copy (first slave)

from successive actions (less crucial)

update of the **secondary** copies (other slaves)

Those strategies can achieve different policies and different state updating costs and quality

the client gets the answer with **less delay** if the master answers before the state has been **updated in all copies** (but only a part) or even in **no slave copy** at all (prompt but not safe)

In the other case, the **delay is more**, but we grant more **consistency on the internal resource state** (safe less prompt)

Master – Slave: CHECKPOINT

CHECKPOINT

The update of the state and its establishment over the slaves

• **Periodic action**	**time-driven**
• **Event action**	**event-driven**

When to do it?

In case of a **sequential** resource,

the state is more clear and easy to identify and establish

In case of a **parallel** resource, all the parallel actions should be taken into account and considered toward the state saving

the state subjected to more **concurrent actions is less easy to isolate** and the state is harder to identify and distinguish

*In other words, the **checkpoint of a resource with several operations going on at the same time** is more complex to deal with and to complete correctly, **because of the sharing of data between concurrent activities***

Checkpoint at **entrance/exit** and in **specific decision points**

MASTER - SLAVE: FAILURE RECOVERY

Who identifies the fault and when: which roles?

Fault Recovery

Secondary copies (slaves) must identify the fault of the master by observing its activity

by using application messages coming from the master and by keeping the timing into account

Even ad-hoc management messages can be used and exchanged

The organization can use

- **one slave** for the control protocol (***if single fault***)
- **a hierarchy of slaves** and more complex protocols (***for multiple faults***)

The entire **resource**, from an external perspective, can tolerate a different number of errors depending on internal strategies and can still provide correct services in case of errors (**fault transparency**)

ACTIVE REPLICATION MODEL

Active copies - **all copies are active and consistent in executing all operations**

An activity executes the operation for any private data copy

Client external requests to the server can have an either **explicit** or **implicit approach** related to **replication**

If the client has an ***explicit*** *FT ⇨* ***no abstraction***

This organization lacks abstraction because all clients has too much visibility of internal FT details of servers

If the client has an ***implicit*** *FT ⇨* ***FT transparency***

Need of a support that is capable of getting the request and distributing them to server copies and vice versa for results

ACTIVE COPIES REPLICATION

Usually the FT is an **implicit private strategy of resources**

either there exists **one manager only** (**static organization**)

centralized **farm** that received the request and commands the operations, collects the answer and gives it back to the client

or there exist **several managers** (**dynamic**)

Any operation gets a different manager in charge of it, with no central role and also balancing of requests

Policy for choosing the manager: decision

Static or

Dynamic by **locality** / by **rotation**

If several operations are alive at the same time, we need to avoid any interference among the different concurrent managers

ACTIVE COPIES COORDINATION

Active models can decide different coordination models

perfect synchrony (full consistency)

all copies should agree and produce a **completely synchronized view**, with the same internal copy scheduling for all copies (difficult for nested actions or external actions)

different approaches to the synchrony (less consistency)

Even if some minimal threshold can be considered, actions can complete before **all copies agrees on the final outcome**, and the final agreement can take place later (also it does not apply even eventually)

Less synchronous strategies costs less in time, mainly client service time, and makes protocols easier and more viable but grant less in operation ordering and release some *semantic properties*

Some **modern Cloud systems** decide of abandoning **perfect synchronicity in favor of an eventual synchronicity**

COPIES COORDINATION

Also different actions on active copies can have different requirements and management

reading actions typically **actions that can occur easily in parallel** and accessing to a limited number of copies

writing actions those intrinsically require **coordination among copies**

Any action that can change the state

Implies more coordination to propagate such a change

In case of a clean state partitioning, where any change applies to different partitions, those actions can proceed independently in parallel without any coordination

Eventually, some actins can require a copy reconciliation of actions that could have been interfering

There are also actions with very specific intrinsic semantics

For instance, the actions on a directory can proceed with some more parallelism

Add/delete of a file, read /write of a file, directory listing

Even semantics properties can distinguish operations and can make possible more efficient behavior and greater parallelism

ACTIVE COPIES UPDATING

Any action requires to update the state of any copy

The ***update action*** must occur **before delivering the answer** to grant a **complete consistency** but that impacts on response time (more delay in case of failures) (**eager policies vs lazy**)

If the component employs **different managers for any operation,** it is a manager duty to command the internal actions

If the component defines **parallel operations,** all manager must negotiate and conciliate their decisions, causing also some conflict to be solved and some actions in incorrect order to be undone or redone

Strategies for the operation maximum duration

*In case of **failure during one operation and before its correct completion,** there should exist the feature of giving an answer anyway, because of the excess of accumulated delay in finishing internal agreement protocols*

ACTIVE COPIES AGREEMENT

Copies can reach an agreement before giving the answer

- ***All* copies should agree** on the specific action (**full agreement**)
- ***Majority voting*** (not all copies must agree) **with a quorum** (also weighted)
  - correct copies can go on freely
  - other copies must agree on it and then reinserted in the group (recovery)

Failure detection: who is in charge? when?
Reinsertion detection: who is in charge? when?

There is a strict need of monitoring and **execution control**

Group semantics

In a group, depending on agreed semantics of actions, there may be also less expensive and less coordinated actions on execution orders

The less the coordination, the less is the cost

WIDESPREAD REPLICATION MODELS

Which is the FT replication model more common and widespread?

the Master-Slave model is simpler and with only one execution point

the Active Copies is more complex and implies more coordination

In any model, the cost is influenced by the group replication degree, i.e., the **number of copies**, *either working or not*

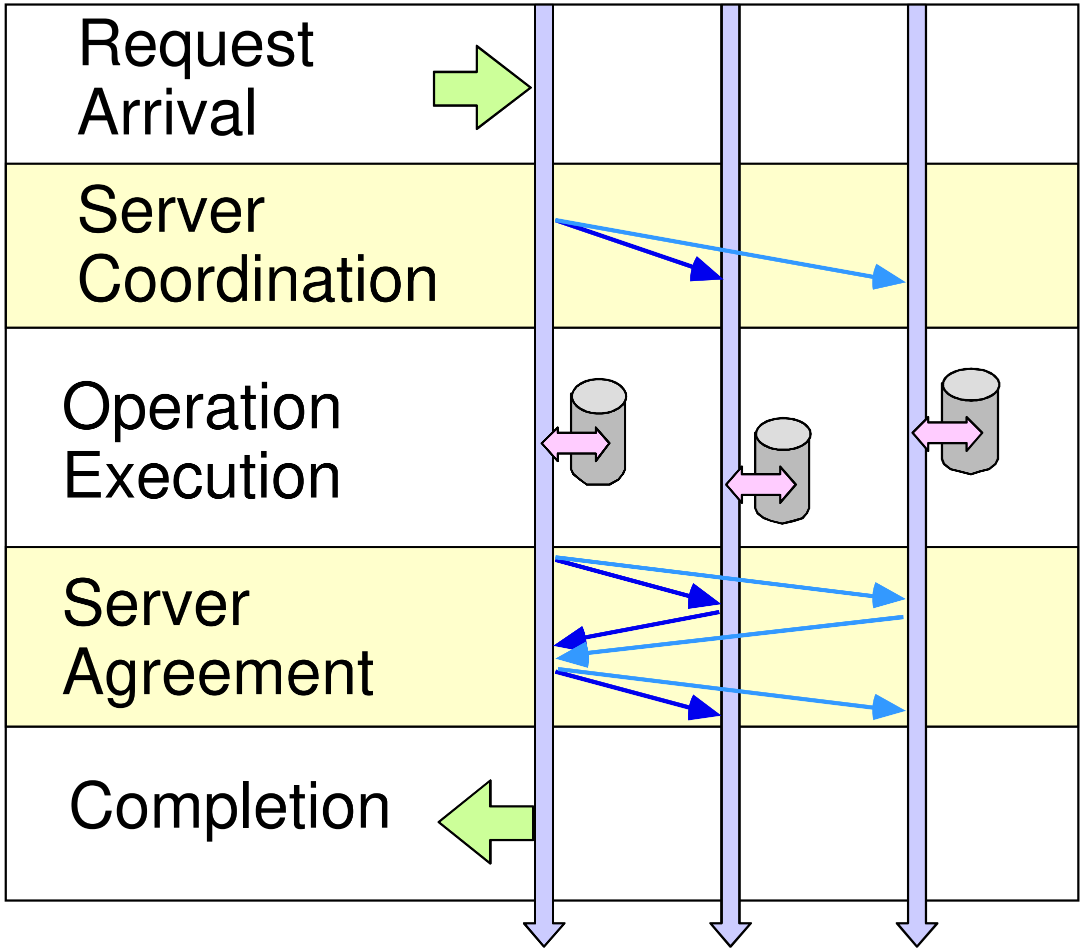
A search on the most common applications and more widespread ones, the **replication degree is typically very limited** (no more than a few copies)

There are also **intermediate replication models**, non FT oriented, with ***a set of resources*** that are able **to work independently** on the same kind of operations, and they operate on different service at the same time, and they can share the responsibility of being a back-up of each other (throughput driven and load balancing)

ACTIVE COPIES OPERATIONS

To make more clear the needs of different steps and one general workflow, we can model the group operation as a sequence of five phases:

1) **Request Arrival**
2) **Copy coordination**
3) **Execution**
4) **Copy agreement**
5) **Response delivery**



Request Arrival

Server Coordination

Operation Execution

Server Agreement

Completion

PHASE 1: CLIENT REQUESTS

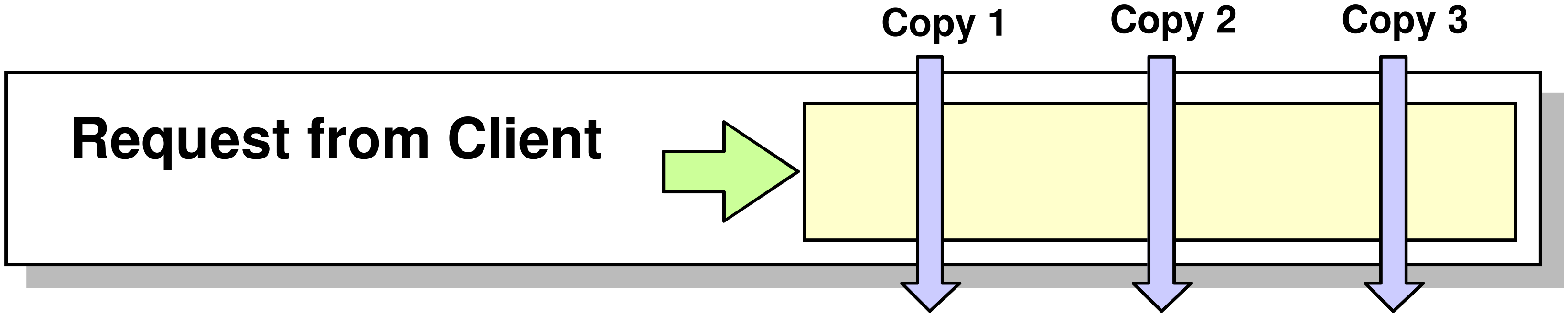
the client can send the request of an operation

- *Only to one of the copies*
- *to all copies*

In case of a delivery to copy only, it is that copy that should propagate the requests to all other ones

The manager is in charge of re-bouncing the first phase

The specific copy con be decided either dynamically or statically



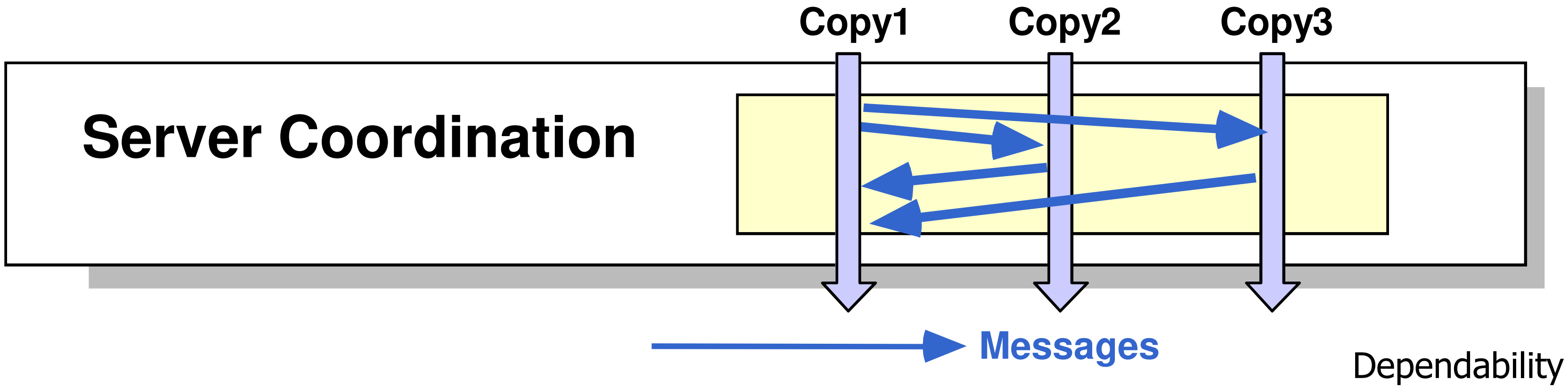
PHASE 2: COPY COORDINATION

The **copies** must coordinate with each other, to define a negotiated policy in scheduling

One **master copy** can become the manager of that operation

- **All copies** must decide how and when to execute the operation to prepare the correct execution
- Different **copies may have different weight** in the gruop and a different role

First coordination phase



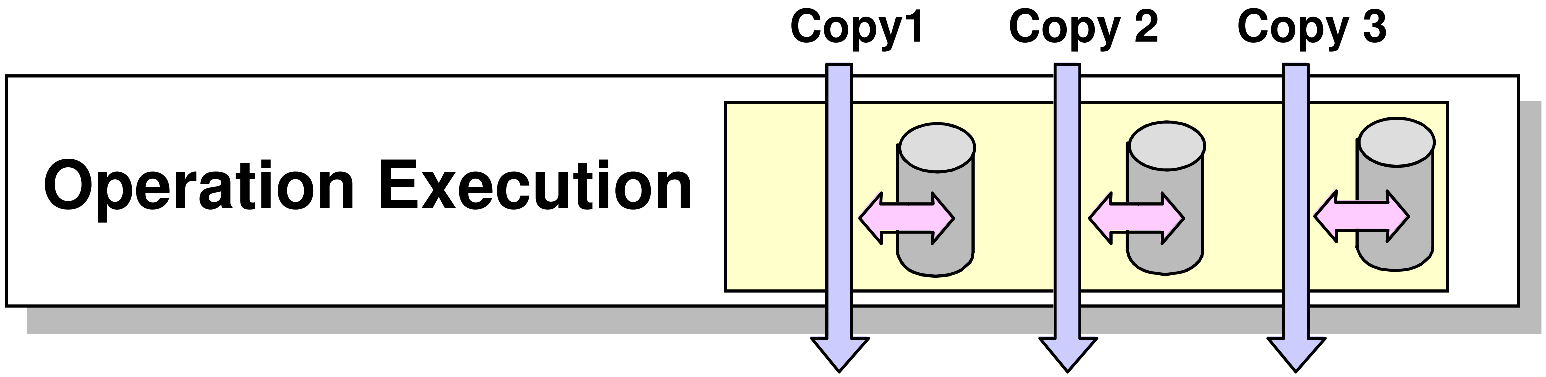
PHASE 3: COPY EXECUTION

The **coordination phase** influences the execution and some **scheduling can be avoided or prevented**

In general, some degree of freedom can be still left to individual decisions

Depending on agreed policy and general scheduling

- All copies execute with proper decision (some copies maybe prevented, up to a master slave case)
- Clashing executions may require coordination o posteriori

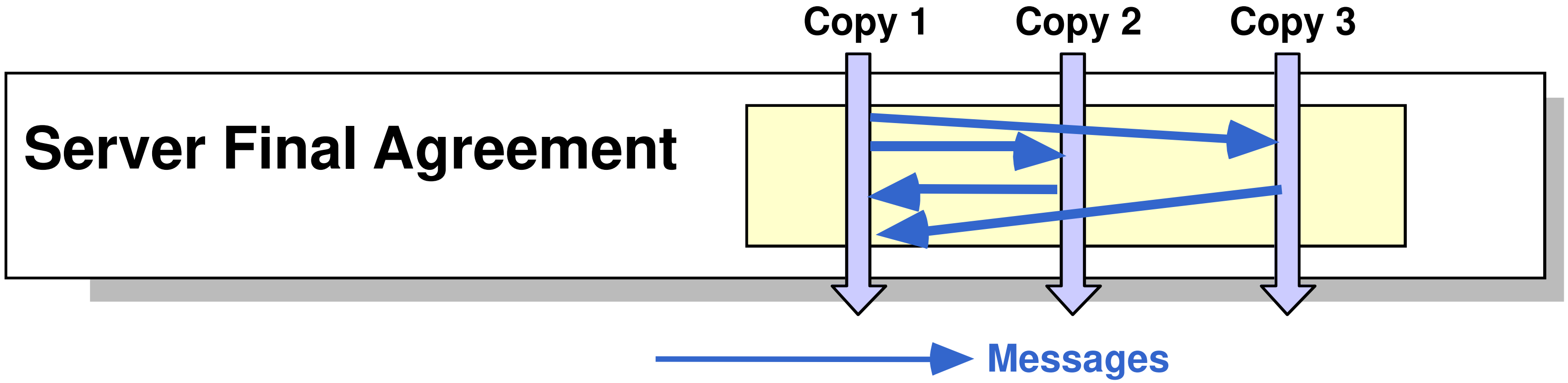


PHASE 4: COPY AGREEMENT

All copies (some are out of the group) must agree on the result to be given back: some results are not conformant to the group whole decision

The group must decide either the commit or also some undo on some actions and the exclusion of related devergent copies from the group for incorrectness

***Second* coordination phase**

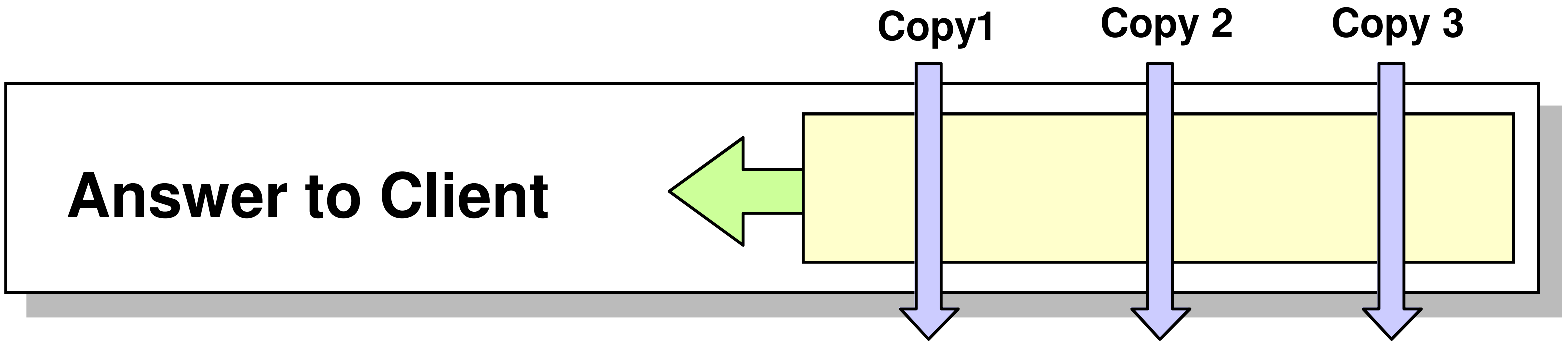


PHASE 5: RESULT DELIVERY

This phase has the goal of delivering the correct result to the waiting client

the client gets **the operation result**

- One unified **answer** form the copy he has sent the request
- **Answers from all copies separately** (overhead of handling all responses)

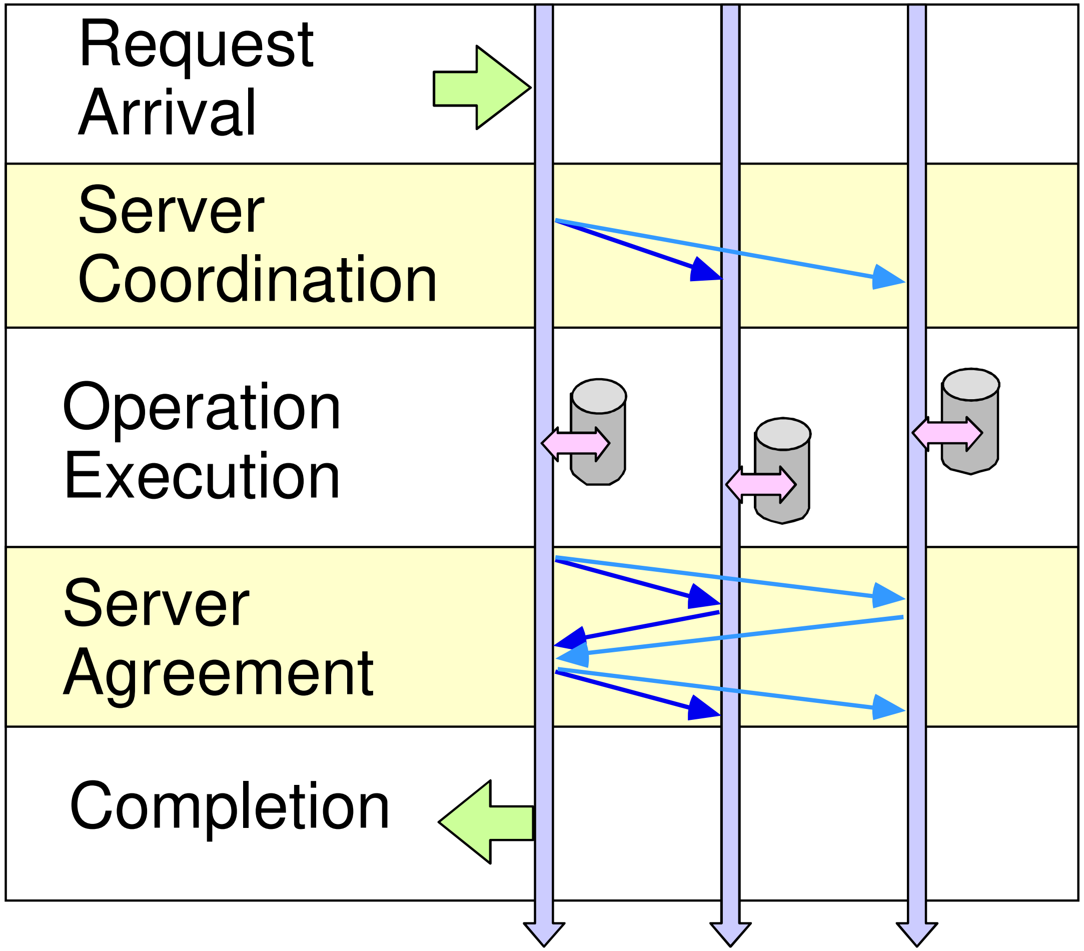


ACTIVE COPIES OPERATIONS

The sequence of the five phases gives a first idea of the complexity of an active copy replication

The coordination among copies tends to induce a high overhead to be limited

So the **replication degree must be kept low** and **replication policies are to be kept simple**



UPDATING POLICIES

To classify some FT **resources** replication, we can use two significant directions

- **who decides the updating**
  only the **primary** copy or **all copies**
- **when to propagate and take the updates**
  eager (immediate and before the answer) **pessimistic** or
  lazy (delayed after the propagation) optimistic

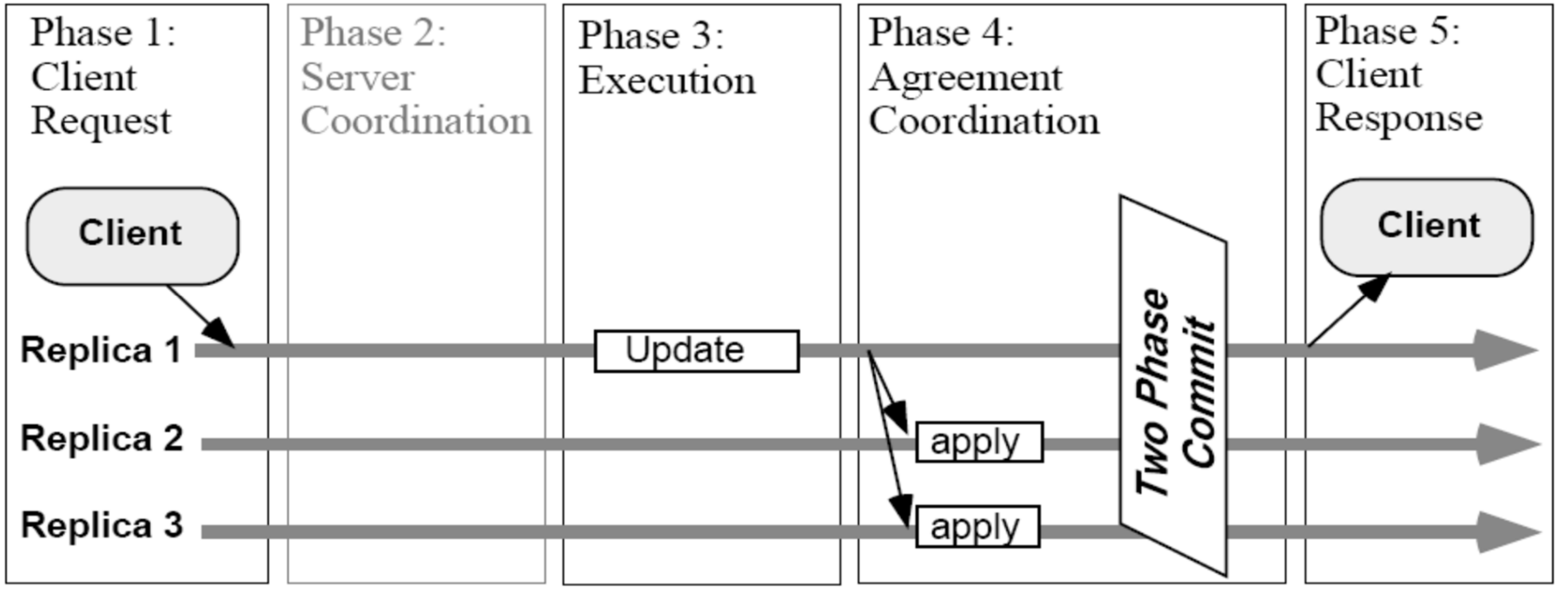
(*we can reverse the terms for the client perspective*)

For the updating we can distinguish:

- ***Eager primary copy*** ***vs*** ***Lazy primary copy***
- ***Eager*** *updating* ***for all copies*** ***vs***
  Lazy *updating* ***for all copies***

EAGER PRIMARY COPY

Sticking to one primary, that copy executes and **gives back** the answer only after **having updated the state** of all copies in a pessimistic approach (*one operation at a time with faults*)

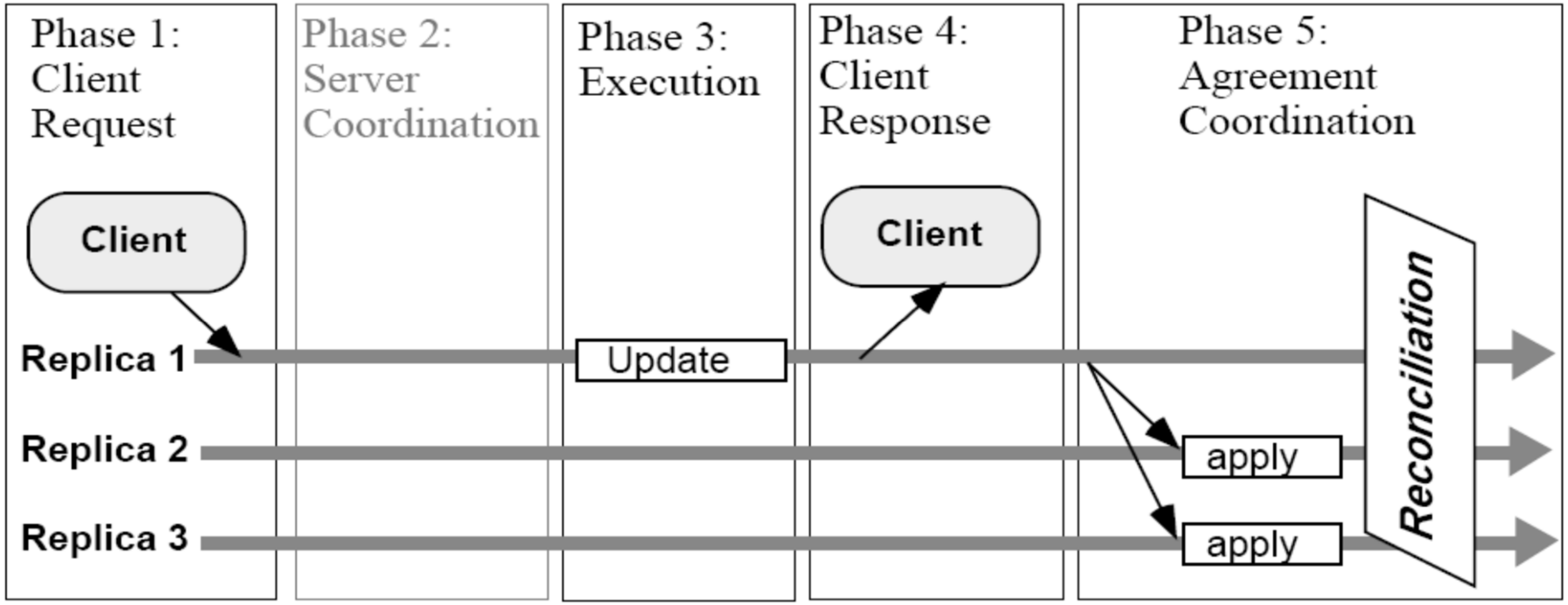


In that case, the manager is in charge of the whole coordination, but the client receives a deferred answer (for correctness sake)

If more operations are active over the replicated object that does not change

LAZY PRIMARY COPY

On the opposite, the manager can first answer to the client and afterwards it updates the copies with an optimistic approach (***also several operations can go on at the same time***)



In this case, the manager must also be able to control the possible reconciliation of the state of the copies … and some problems may occur if there is a manager crash

UPDATE OF ACTIVE COPIES

Eager policies favor **consistency** and **correctness** of the operations, instead of the promptness of the answer to the client

- The goal is **not very fast precocious answers**, because that can lead to undo actions, that are not easy to be done, and, in some cases, impossible to backtrack

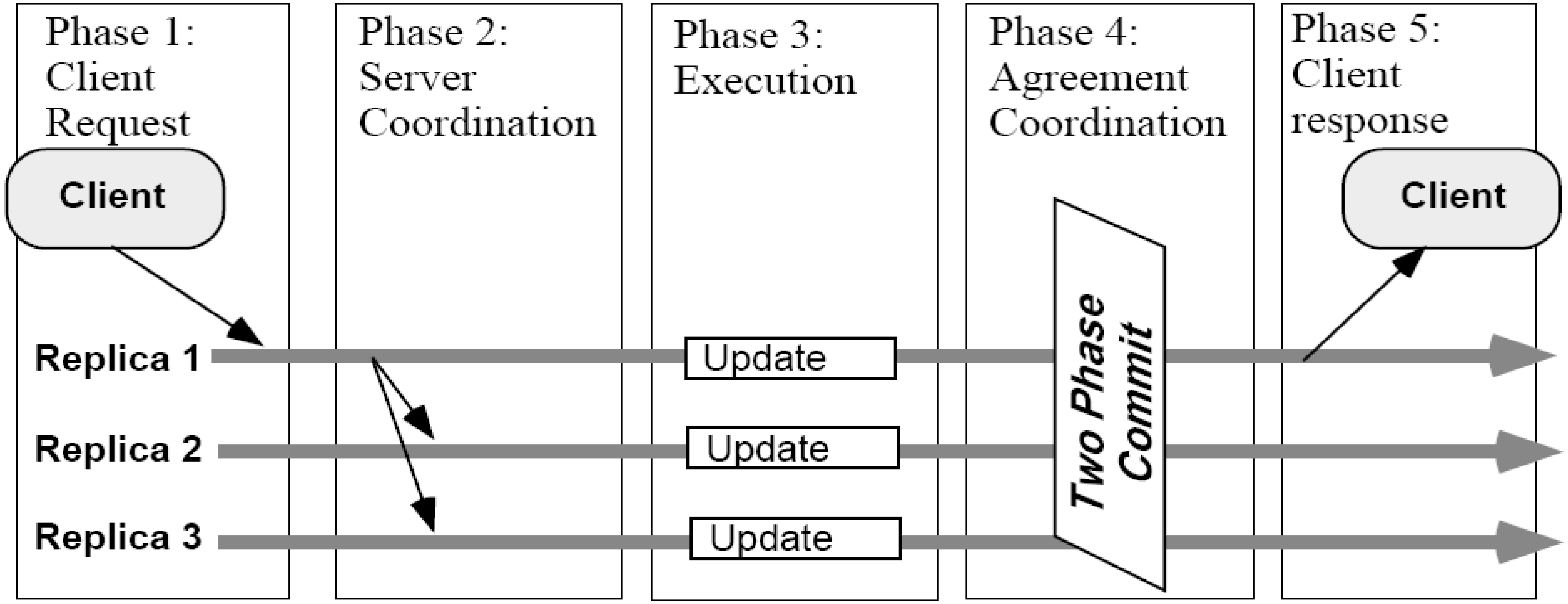
Copy coordination are **two phases toward consistency granting** (specially in case of **concurrent actions**)

Let us stress that those two phases are not always necessary but they can obtain the necessary coordination among copies and operations

- **A posteriori coordination** to **verify consistency.** If it is not verifies, some **undo** must be considered (two phase protocol and roll back)
- **A priori coordination** can ensure that all **correct copies receive all correct messages** and the **right schedule** is automatically enforced (e.g., atomic multicast)

OPTIMISTIC EAGER UPDATE

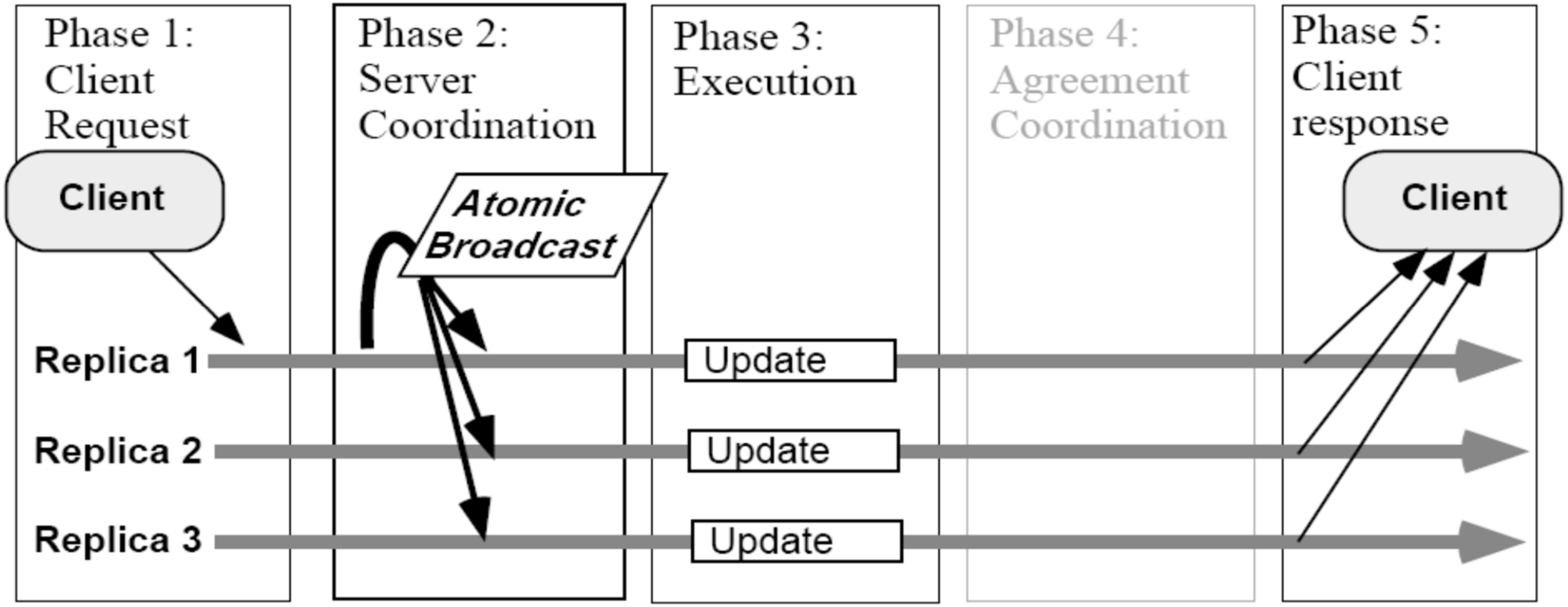
All copies are updated with some enforcing policies in a **optimistic approach** (**two-phase commit**), only afterwards the answer is provided to the client



After copy independent executions, the final coordination ensure an agreement, otherwise some backtracking is commanded (*possible* ***undo***)

PESSIMISTIC EAGER UPDATE

A different approach for eager update implies coordination but tends to save the final phase of it. The agreement of results is granted via a delivery protocol **in a pessimistic approach**



An **atomic multicast can ensure** that any message is correctly sent to all copies in the same order, so that there is no need for a final check (*no undo*)

OPTIMISTIC LAZY POLICIES

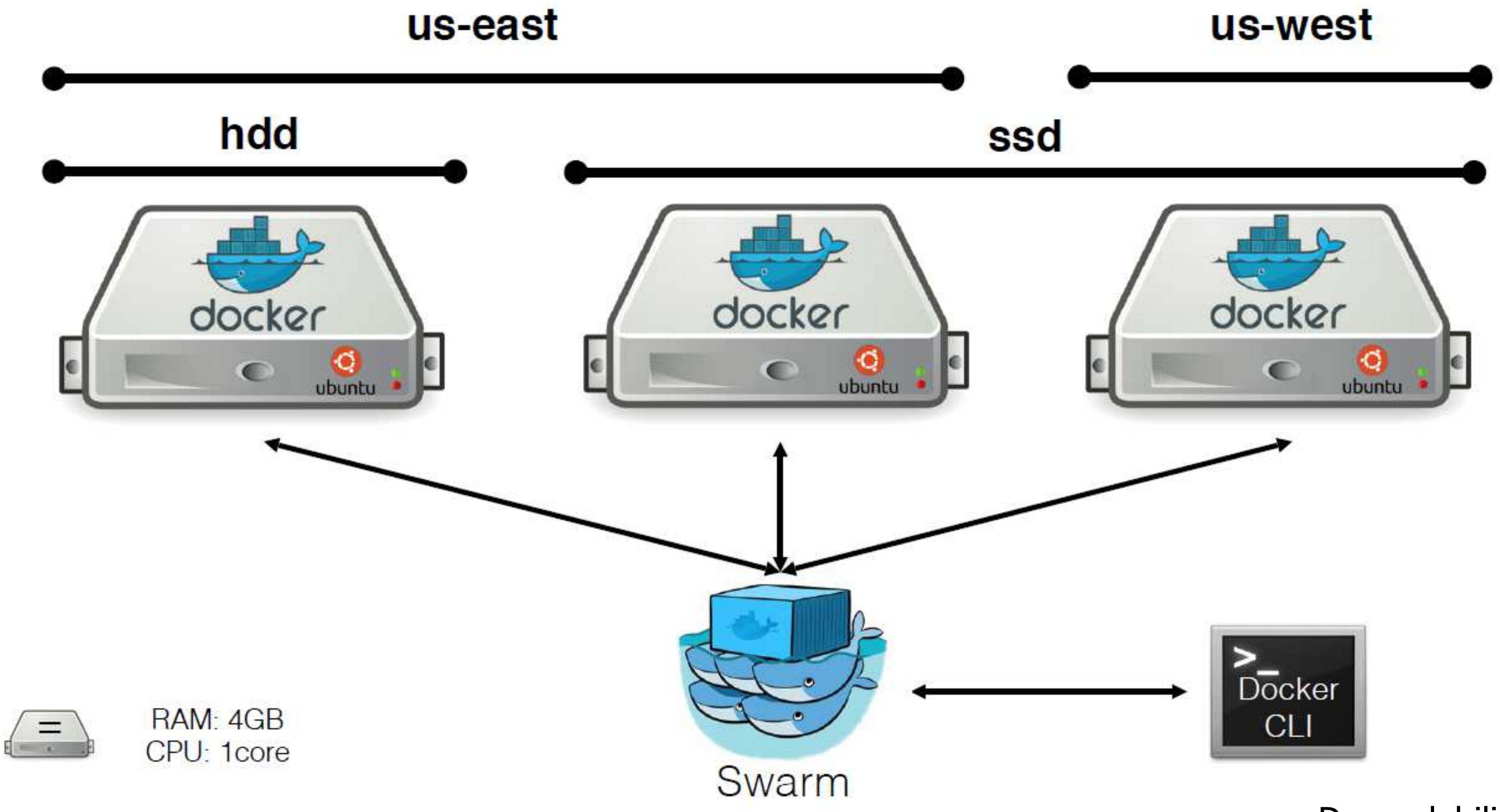
We use **lazy update**, when one copy can answer with a little (no) coordination with other copies in an **optimistic policy that can deliver the answer very fast …** as in the case of **Amazon S3** (Amazon **S**imple **S**torage **S**ervice)

Amazon memory & persistence support renounces to any strict consistency and provide both **consistent** and **eventually consistent** operations **ones**

- **Strong consistency has the eager update but slow answer**
- **Eventual consistency** (called final or tending to infinity) is a lazy update in the direction of **released consistency**: updates are commanded but not awaited for. So concurrent operations over other copies can see different values. On a long term, copy values are reconciliated and a consistent view is achieved.
- The **inconsistency window** may depend on many factors: communication delays, workload o f the system, copy replication degree … (**We are happy if it is as small as possible**)

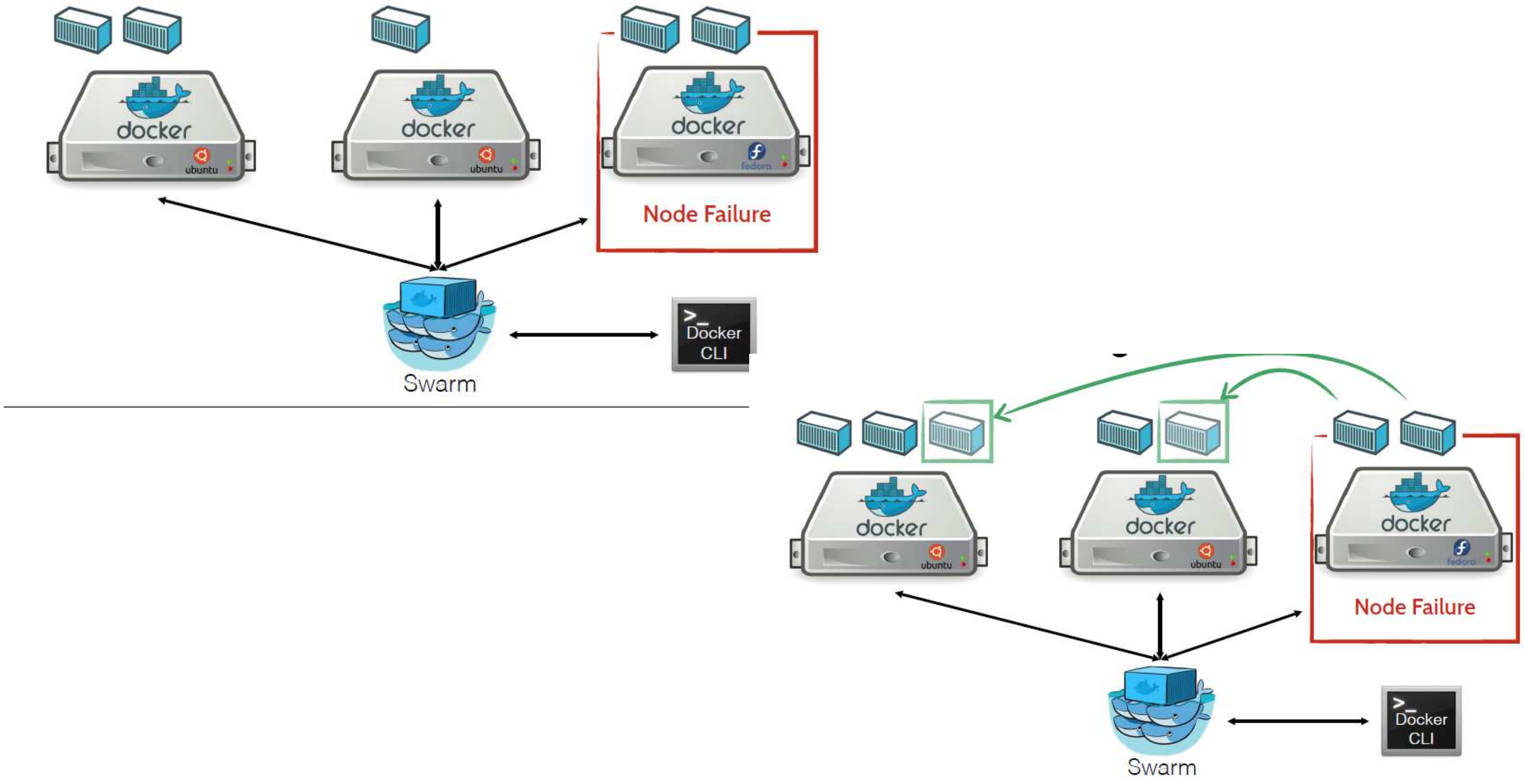
DOCKER SWARM

Docker Swarm proposes the feature of **loading a distributed system:** the example is with three nodes with a manager invoked via a central console for a portable dynamic loading



DOCKER SWARM

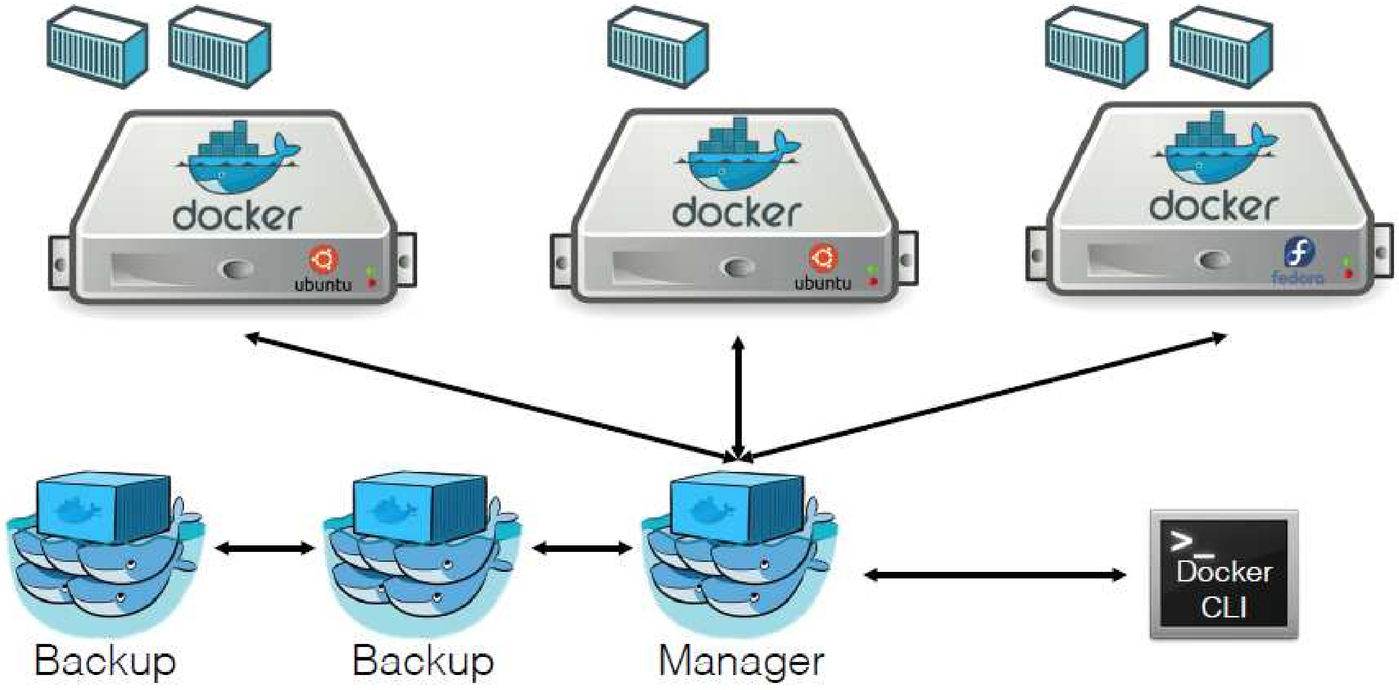
Docker Swarm can take automatically care of the case of failure of a node, and **can transfer some components to the new containers for a ‘degraded’ execution**



HA DOCKER SWARM

Docker Swarm can also allow **high availability** and can replicate also the manager for the distribution to overcome the single point of failure of the manager

In case of failure of any node, it **can still operate and without interruption**



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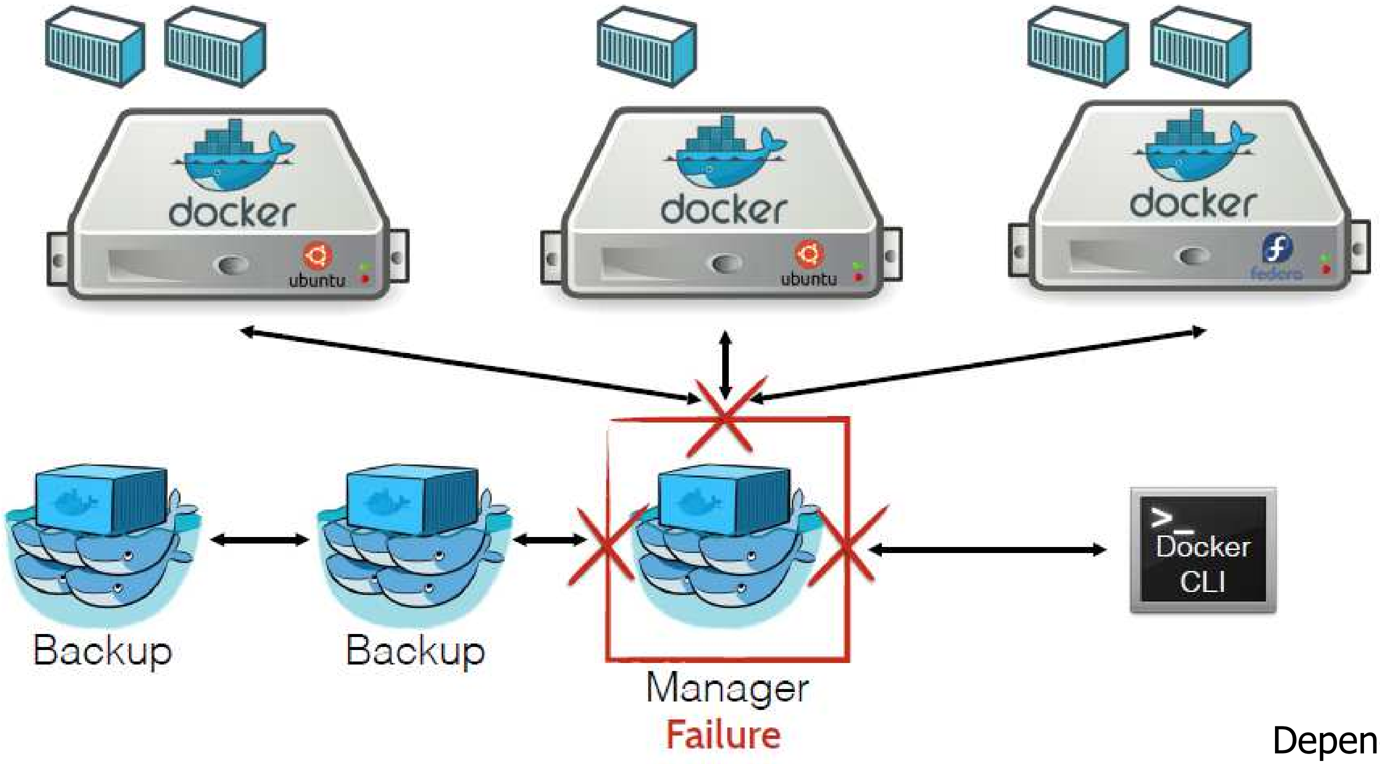

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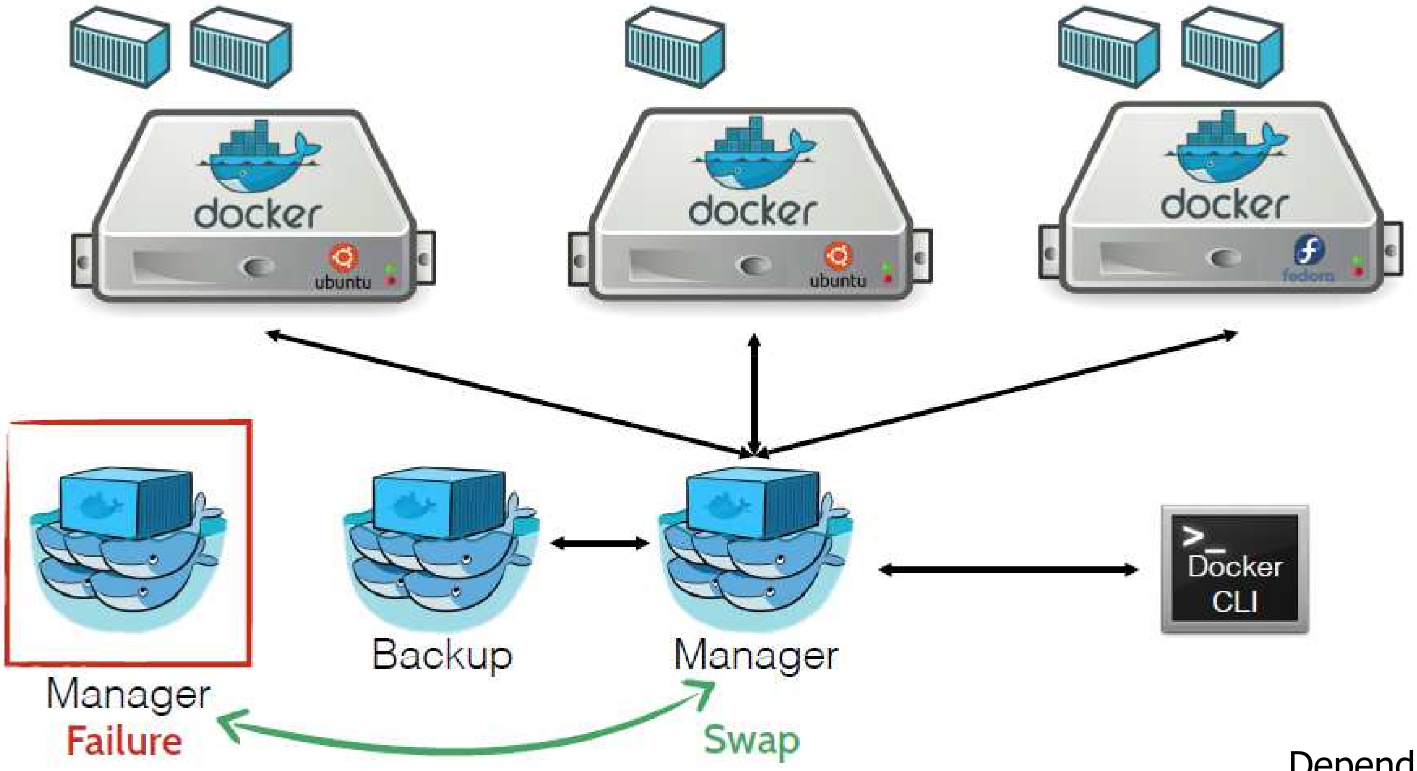
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