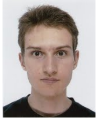
Deuxfleurs Association

`https://garagehq.deuxfleurs.fr/`

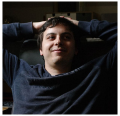
Matrix channel: `#garage:deuxfleurs.fr`

Who we are



Alex Auvolat
PhD; co-founder of Deuxfleurs

Quentin Dufour
PhD; co-founder of Deuxfleurs



Deuxfleurs
A non-profit self-hosting collective,
member of the CHATONS network

Our objective at Deuxfleurs

**Promote self-hosting and small-scale hosting
as an alternative to large cloud providers**

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Why is it hard?

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Promote self-hosting and small-scale hosting
as an alternative to large cloud providers

Why is it hard?

Resilience

(we want good uptime/availability with low supervision)

How to make a stable system

Enterprise-grade systems typically employ:

- RAID
- Redundant power grid + UPS
- Redundant Internet connections
- Low-latency links
- ...

→ it's costly and only worth it at DC scale

How to make a resilient system

Instead, we use:

- Commodity hardware (e.g. old desktop PCs)

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- Commodity Internet (e.g. FTTB, FTTH) and power grid

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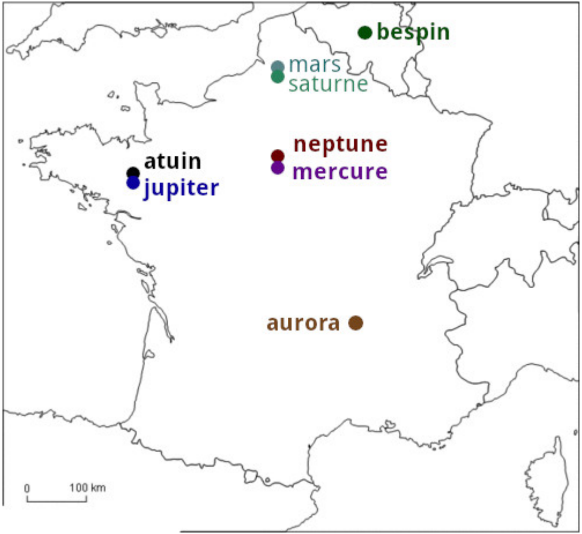
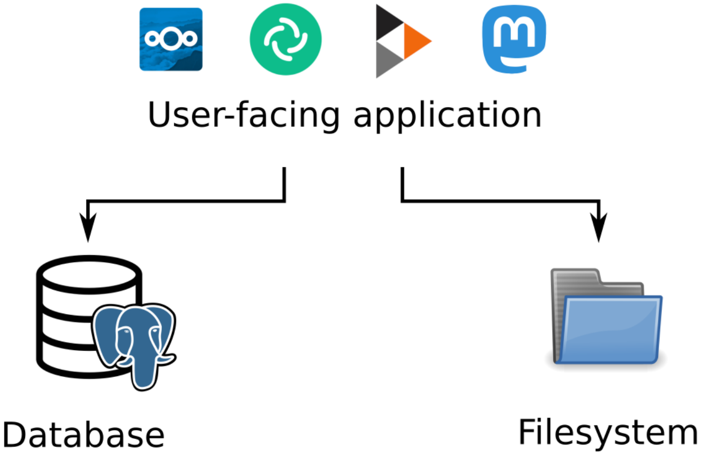
Instead, we use:

- Commodity hardware (e.g. old desktop PCs)
- Commodity Internet (e.g. FTTB, FTTH) and power grid
- **Geographical redundancy** (multi-site replication)

How to make a resilient system



How to make this happen



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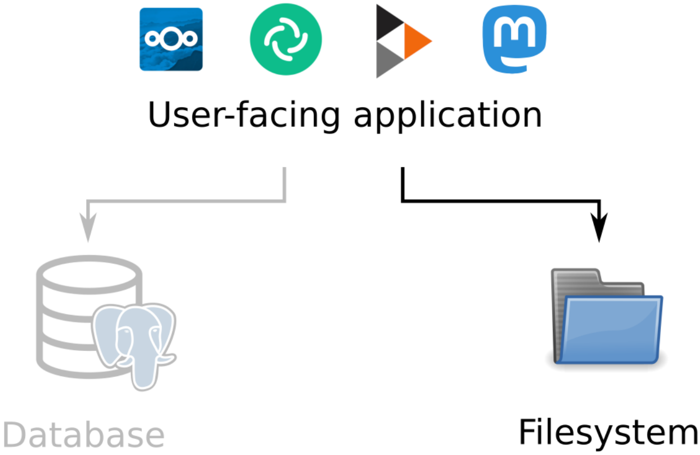

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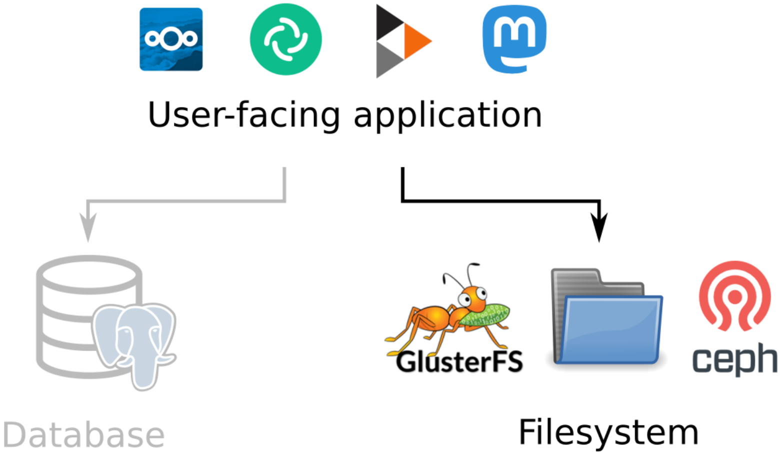


Distributed file systems are slow

File systems are complex, for example:

- Concurrent modification by several processes
- Folder hierarchies
- Other requirements of the POSIX spec

Coordination in a distributed system is costly

Costs explode with commodity hardware / Internet connections
(we experienced this!)

A simpler solution: object storage

Only two operations:

- Put an object at a key
- Retrieve an object from its key

(and a few others)

Sufficient for many applications!

A simpler solution: object storage

S3: a de-facto standard, many compatible applications

MinIO is self-hostable but not suited for geo-distributed deployments

Garage is a self-hosted drop-in replacement for the Amazon S3 object store

The data model of object storage

Object storage is basically a key-value store:

Key: file path + name	**Value: file data + metadata**

`index.html`	`Content-Type: text/html; charset=utf-8`
	`Content-Length: 24929`
	`<binary blob>`

`img/logo.svg`	`Content-Type: text/svg+xml`
	`Content-Length: 13429`
	`<binary blob>`

`download/index.html`	`Content-Type: text/html; charset=utf-8`
	`Content-Length: 26563`
	`<binary blob>`

Two big problems

1. **How to place data on different nodes?**

   Constraints: heterogeneous hardware
   Objective: n copies of everything, maximize usable capacity, maximize resilience

   $\rightarrow$ the Dynamo model + optimization algorithms

Two big problems

1. **How to place data on different nodes?**

   Constraints: heterogeneous hardware
   Objective: n copies of everything, maximize usable capacity, maximize resilience

   → the Dynamo model + optimization algorithms

2. **How to guarantee consistency?**

   Constraints: slow network (geographical distance), node unavailability/crashes
   Objective: maximize availability, read-after-write guarantee

   → CRDTs, monotonicity, read and write quorums

Problem 1: placing data

Key-value stores, upgraded: the Dynamo model

Two keys:

- Partition key: used to divide data into partitions (shards)
- Sort key: used to identify items inside a partition

Partition key: bucket	**Sort key: filename**	**Value**
`website`	`index.html`	(file data)
`website`	`img/logo.svg`	(file data)
`website`	`download/index.html`	(file data)
`backup`	`borg/index.2822`	(file data)
`backup`	`borg/data/2/2329`	(file data)
`backup`	`borg/data/2/2680`	(file data)
`private`	`qq3a2nbe1qjq0ebbvo6ocsp6co`	(file data)

Key-value stores, upgraded: the Dynamo model

- Data with different partition keys is stored independantly, on a different set of nodes

  → no easy way to list all partition keys
  → no cross-shard transactions

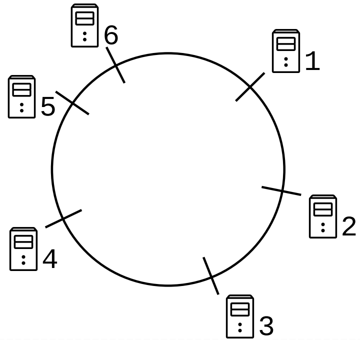
- Placing data: hash the partition key, select nodes accordingly

  → distributed hash table (DHT)

- For a given value of the partition key, items can be listed using their sort keys

How to spread files over different cluster nodes?

Consistent hashing (Dynamo):



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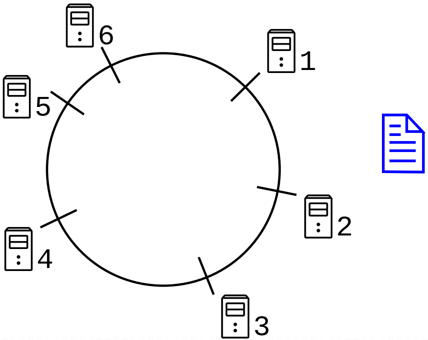

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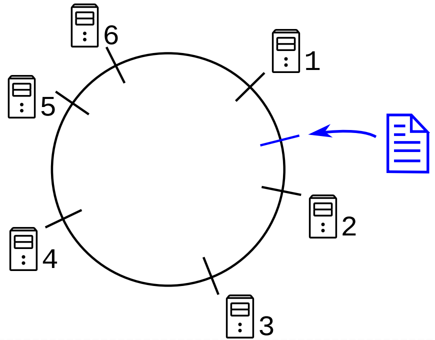

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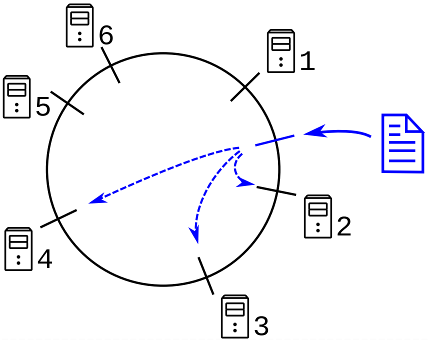
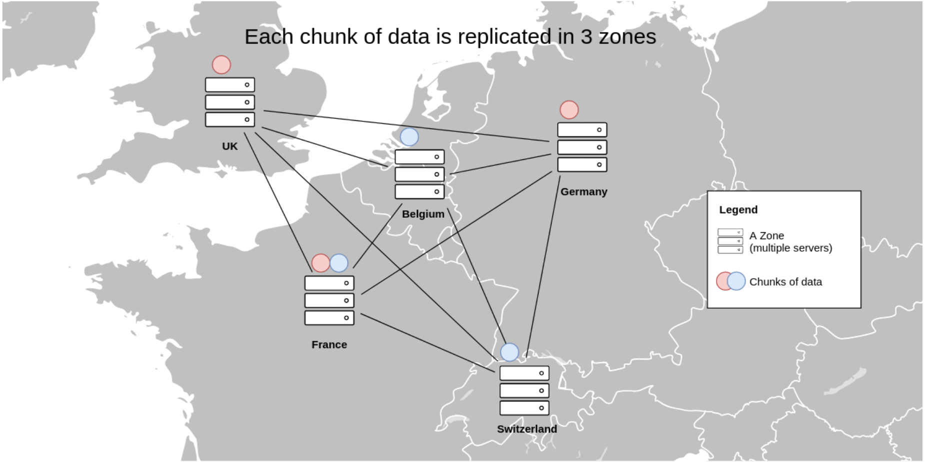


Constraint: location-awareness

```
alex@io:~$ docker exec -ti garage /garage status
==== HEALTHY NODES ====
ID                Hostname   Address                          Tags                    Zone     Capacity
7d50f042280fea98  io         [2a01:e0a:5e4:1d0::57]:3901     [io,jupiter]            jupiter  20
d9b5959e58a3ab8c  drosera    [2a01:e0a:260:b5b0::4]:3901     [drosera,atuin]         atuin    20
966dfc7ed8049744  datura     [2a01:e0a:260:b5b0::2]:3901     [datura,atuin]          atuin    10
8cf284e7df17d0fd  celeri     [2a06:a004:3025:1::33]:3901     [celeri,neptune]        neptune  5
156d0f7a88b1e328  digitale   [2a01:e0a:260:b5b0::3]:3901     [digitale,atuin]        atuin    10
5fcb3b6e39db3dcb  concombre  [2a06:a004:3025:1::31]:3901     [concombre,neptune]     neptune  5
a717e5b618267806  courgette  [2a06:a004:3025:1::32]:3901     [courgette,neptune]     neptune  5
alex@io:~$
```

Garage replicates data on different zones when possible

Constraint: location-awareness



Issues with consistent hashing

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- Consistent hashing doesn't dispatch data based on geographical location of nodes
- Geographically aware adaptation, try 1:
  data quantities not well balanced between nodes
- Geographically aware adaptation, try 2:
  too many reshuffles when adding/removing nodes

How to spread files over different cluster nodes?

Garage's method: build an index table

Realization: we can actually precompute an optimal solution

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Garage's method: build an index table

Realization: we can actually precompute an optimal solution

Partition	**Node 1**	**Node 2**	**Node 3**
Partition 0	Io (jupiter)	Drosera (atuin)	Courgette (neptune)
Partition 1	Datura (atuin)	Courgette (neptune)	Io (jupiter)
Partition 2	Io(jupiter)	Celeri (neptune)	Drosera (atuin)
⋮	⋮	⋮	⋮
Partition 255	Concombre (neptune)	Io (jupiter)	Drosera (atuin)

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Garage's method: build an index table

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⋮	⋮	⋮	⋮
Partition 255	Concombre (neptune)	Io (jupiter)	Drosera (atuin)

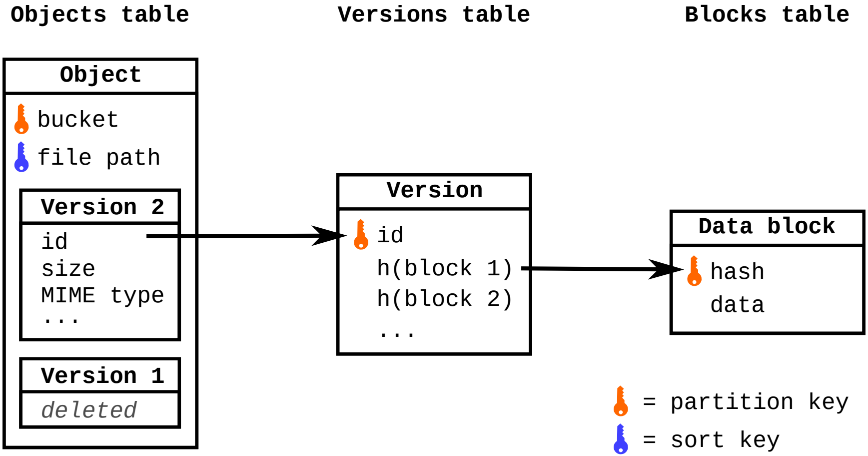
The index table is built centrally using an optimal algorithm,
then propagated to all nodes

The relationship between *partition* and *partition key*

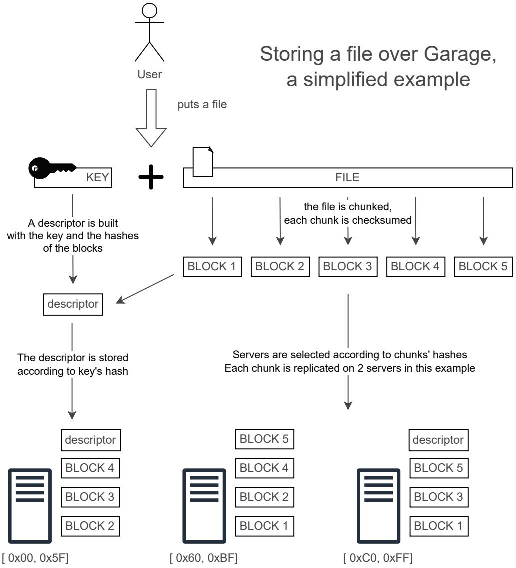
Partition key	Partition	Sort key	Value
`website`	Partition 12	`index.html`	(file data)
`website`	Partition 12	`img/logo.svg`	(file data)
`website`	Partition 12	`download/index.html`	(file data)
`backup`	Partition 42	`borg/index.2822`	(file data)
`backup`	Partition 42	`borg/data/2/2329`	(file data)
`backup`	Partition 42	`borg/data/2/2680`	(file data)
`private`	Partition 42	`qq3a2nbe1qjq0ebbvo6ocsp6co`	(file data)

To read or write an item: hash partition key
→ determine partition number (first 8 bits)
→ find associated nodes

Garage's internal data structures



Storing and retrieving files



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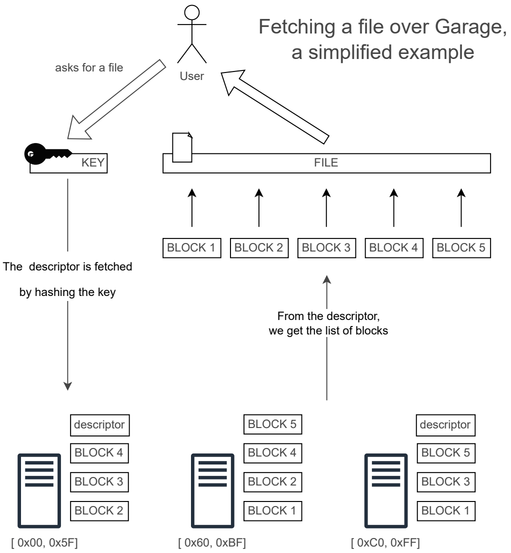

Problem 2: ensuring consistency

Consensus vs weak consistency

Consensus-based systems:

- **Leader-based:** a leader is elected to coordinate all reads and writes
- **Linearizability** of all operations (strongest consistency guarantee)
- Any sequential specification can be implemented as a **replicated state machine**
- **Costly**, the leader is a bottleneck; leader elections on failure take time

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- **Costly**, the leader is a bottleneck; leader elections on failure take time

Weakly consistent systems:

- **Nodes are equivalent**, any node can originate a read or write operation
- **Read-after-write consistency** with quorums, eventual consistency without
- **Operations have to commute**, i.e. we can only implement CRDTs
- **Fast**, no single bottleneck; works the same with offline nodes

Consensus vs weak consistency

The same objects cannot be implemented in both models.

Consensus-based systems:

Any sequential specification

Easier to program for: just write your program as if it were sequential on a single machine

Weakly consistent systems:

CRDTs only
(conflict-free replicated data types)

Part of the complexity is **reported to the consumer of the API**

Consensus vs weak consistency

From a theoretical point of view:

Consensus-based systems:

Require **additionnal assumptions** such as a fault detector or a strong RNG

Weakly consistent systems:

Can be implemented in **any asynchronous message passing distributed system**

They represent **different classes of computational capability**

Understanding the power of consensus

Consensus: an API with a single operation, $propose(x)$

1. nodes all call $propose(x)$ with their proposed value;
2. nodes all receive the same value as a return value, which is one of the proposed values

Understanding the power of consensus

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Equivalent to a distributed algorithm that gives a total order on all requests

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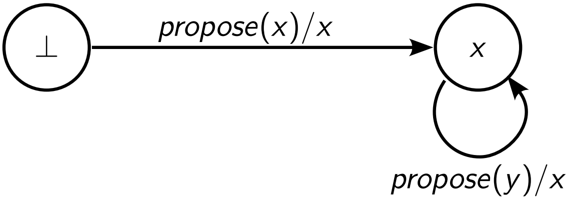
Equivalent to a distributed algorithm that gives a total order on all requests

Implemented by this simple replicated state machine:



Can my object be implemented without consensus?

Given the specification of an API:

- **Using this API, we can implement the consensus object** (the *propose* function)
  $\rightarrow$ the API is equivalent to consensus/total ordering of messages
  $\rightarrow$ the API cannot be implemented in a weakly consistent system
- **This API can be implemented using only weak primitives**
  (e.g. a bunch of atomic registers)
  $\rightarrow$ the API is strictly weaker than consensus
  $\rightarrow$ we can implement it in Garage!

Why avoid consensus?

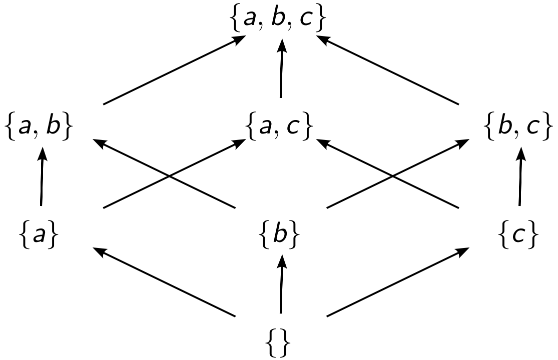
Consensus can be implemented reasonably well in practice, so why avoid it?

- **Software complexity:** RAFT and PAXOS are complex beasts; harder to prove, harder to reason about
- **Performance issues:**
  - The leader is a **bottleneck** for all requests
  - Particularly **sensitive to higher latency** between nodes

What can we implement without consensus?

- Any **conflict-free replicated data type** (CRDT)
- Non-transactional key-value stores such as S3 are equivalent to a simple CRDT: a **last-writer-wins registry**
- **Read-after-write consistency** can be implemented using quorums on read and write operations
- **Monotonicity of reads** can be implemented with repair-on-read (makes reads more costly, not implemented in Garage)

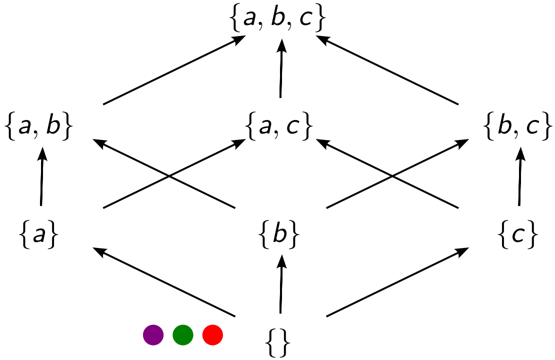
Understanding CRDTs and quorums



Understanding CRDTs and quorums

$write(\{a\})$:

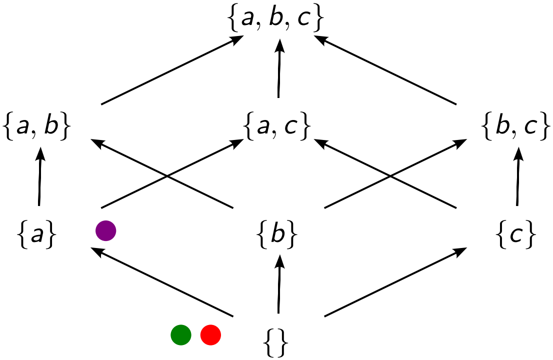
- $\not\supseteq \{a\}$
- $\not\supseteq \{a\}$
- $\not\supseteq \{a\}$



Understanding CRDTs and quorums

$write(\{a\})$:

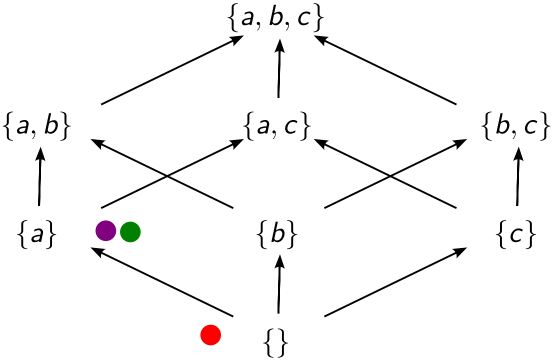
- $\sqsupseteq \{a\} \rightarrow$ OK
- $\not\sqsupseteq \{a\}$
- $\not\sqsupseteq \{a\}$



Understanding CRDTs and quorums

write($\{a\}$):

● $\sqsupseteq \{a\} \rightarrow$ OK
● $\sqsupseteq \{a\} \rightarrow$ OK
● $\not\sqsupseteq \{a\}$
return OK



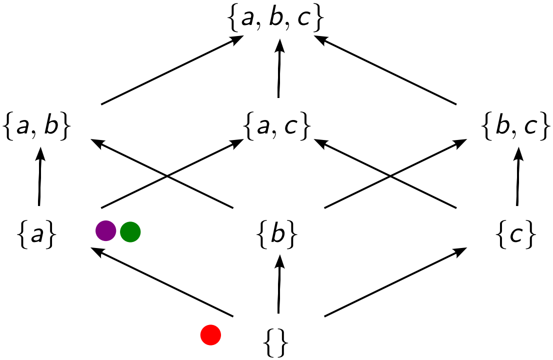
Understanding CRDTs and quorums

write($\{a\}$):

- ● $\sqsupseteq \{a\} \rightarrow$ OK
- ● $\sqsupseteq \{a\} \rightarrow$ OK
- ● $\not\sqsupseteq \{a\}$

return OK

read():



Understanding CRDTs and quorums

write$(\{a\})$:

$\sqsupseteq \{a\} \rightarrow$ OK

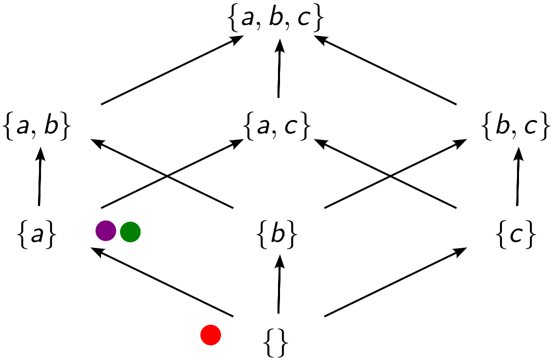
$\sqsupseteq \{a\} \rightarrow$ OK

$\not\sqsupseteq \{a\}$

return OK

read$()$:

$\rightarrow \{\}$



Understanding CRDTs and quorums

write($\{a\}$):

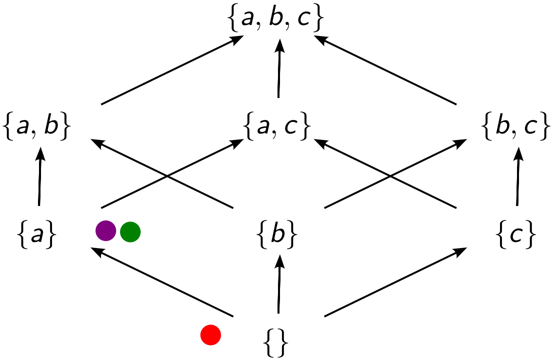
- $\sqsupseteq \{a\} \rightarrow$ OK
- $\sqsupseteq \{a\} \rightarrow$ OK
- $\not\sqsupseteq \{a\}$

return OK

read():

- $\rightarrow \{\}$
- $\rightarrow \{a\}$

return $\{\} \sqcup \{a\} = \{a\}$



Understanding CRDTs and quorums

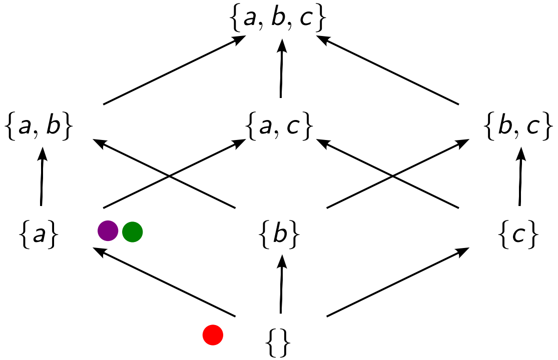
write($\{a\}$):

- $\sqsupseteq \{a\} \to$ OK
- $\sqsupseteq \{a\} \to$ OK
- $\not\sqsupseteq \{a\}$

return OK

write($\{b\}$):

- $\not\sqsupseteq \{b\}$
- $\not\sqsupseteq \{b\}$
- $\not\sqsupseteq \{b\}$



Understanding CRDTs and quorums

$write(\{a\})$:

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return OK

$write(\{b\})$:

- $\not\sqsupseteq \{b\}$
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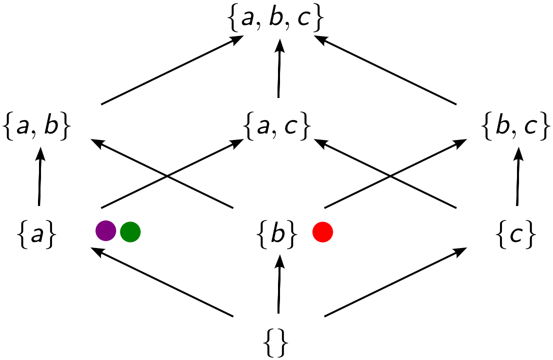

Understanding CRDTs and quorums

$write(\{a\})$:

- $\sqsupseteq \{a\} \rightarrow$ OK
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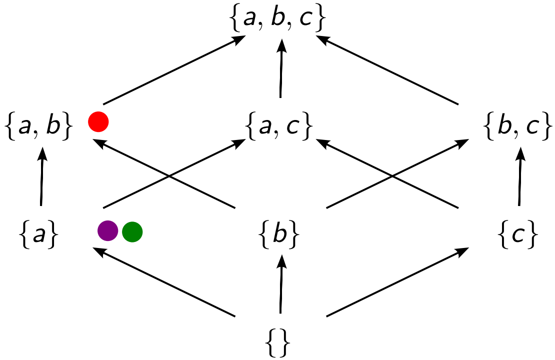
- $\sqsupseteq \{a\}$

return OK

$write(\{b\})$:

- $\not\sqsupseteq \{b\}$
- $\not\sqsupseteq \{b\}$
- $\sqsupseteq \{b\} \rightarrow$ OK



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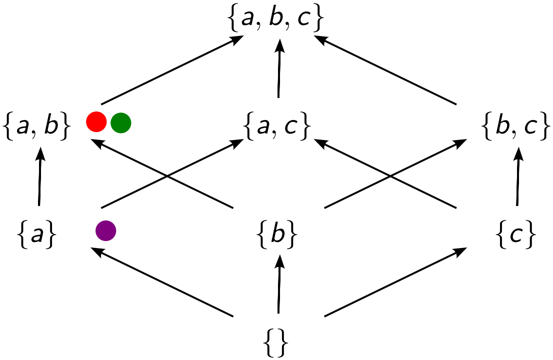
return OK



Understanding CRDTs and quorums

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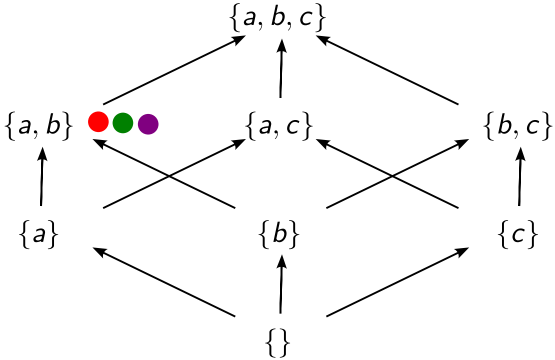
- $\sqsupseteq \{b\} \rightarrow$ OK

return OK



Read-after-write consistency:

Property: If node A did an operation $write(x)$ and received an OK response,
and node B starts an operation $read()$ after A received OK,
then B will read a value $x' \sqsupseteq x$.

Algorithm $write(x)$**:**

1. Broadcast $write(x)$ to all nodes
2. Wait for $k > n/2$ nodes to reply OK
3. Return OK

Algorithm $read()$**:**

1. Broadcast $read()$ to all nodes
2. Wait for $k > n/2$ nodes to reply with values $x_1, \ldots, x_k$
3. Return $x_1 \sqcup \ldots \sqcup x_k$

Why does it work? There is at least one node at the intersection between the two sets of nodes that replied to each request, that "saw" x before the $read()$ started ($x_i \sqsupseteq x$).

Monotonical read consistency:

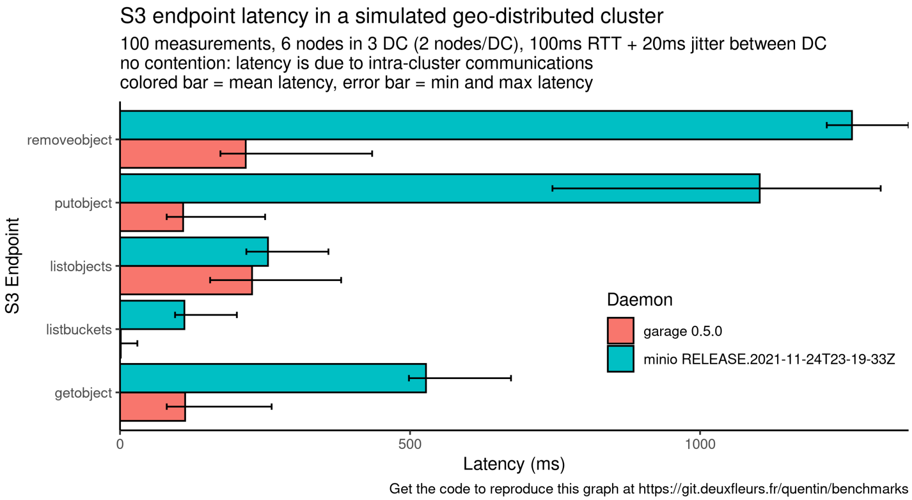
Property: If node A did an operation *read*() and received x as a response,
and node B starts an operation *read*() after A received x,
then B will read a value $x' \sqsupseteq x$.

Algorithm *read*()**:**

1. Broadcast *read*() to all nodes
2. Wait for $k > n/2$ nodes to reply with values $x_1, \ldots, x_k$
3. If $x_i \neq x_j$ for some nodes i and j,
   then call $write(x_1 \sqcup \ldots \sqcup x_k)$ and wait for OK from $k' > n/2$ nodes
4. Return $x_1 \sqcup \ldots \sqcup x_k$

This makes reads slower in some cases, and is **not implemented in Garage**.

Performance gains in practice

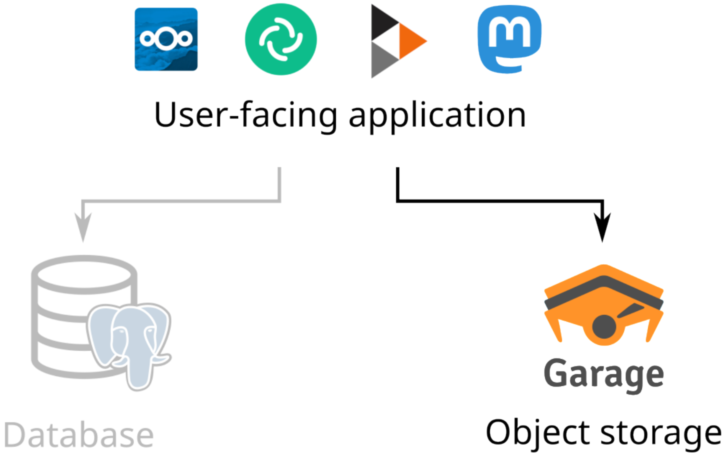


The hard parts we don't address (yet!)

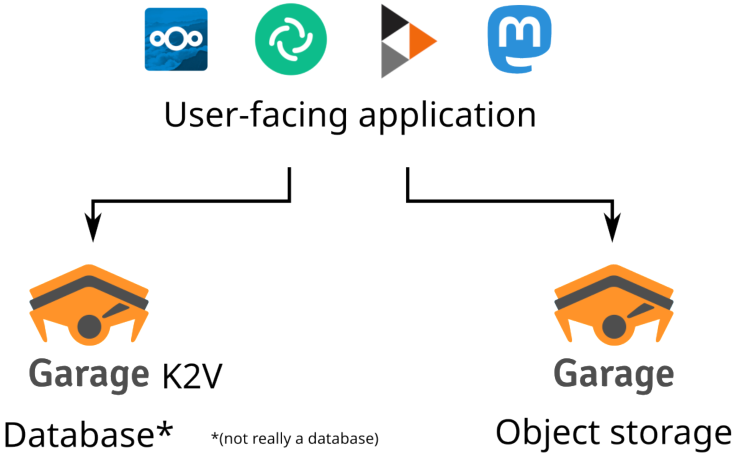
- Maintain consistency changes when nodes assigned to a partition change:
- TODO

Going further than the S3 API

Further plans for Garage



Further plans for Garage



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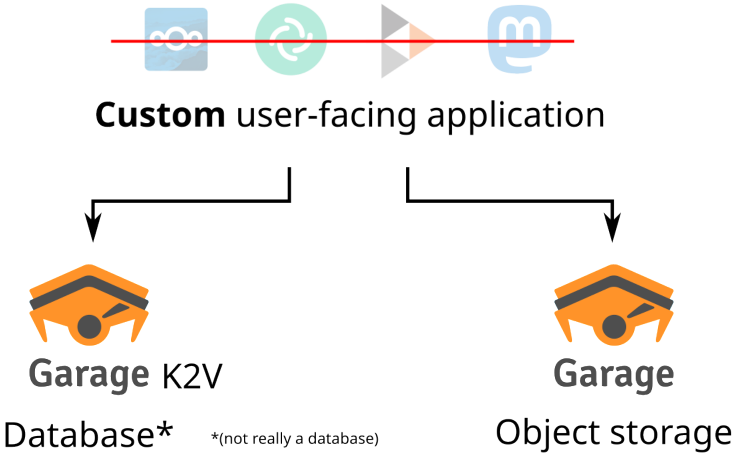

K2V Design

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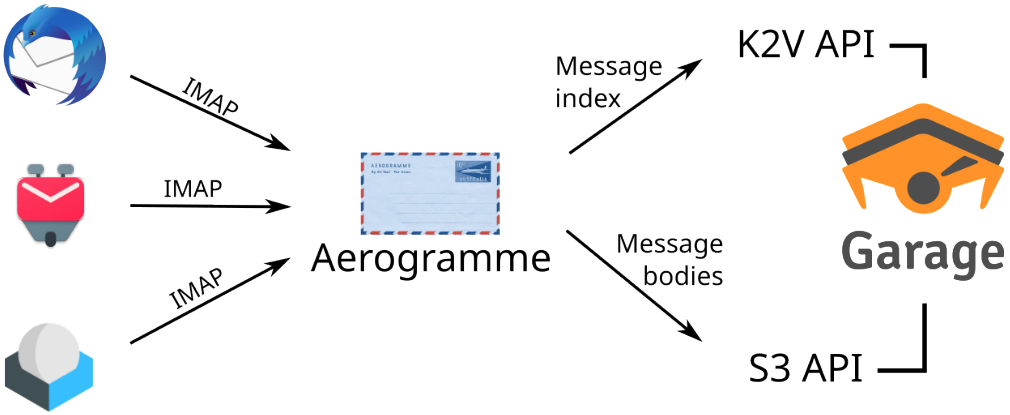
- Cryptography-friendly: values are binary blobs

Application: an e-mail storage server



A new model for building resilient software

- Design a data model suited to K2V
  (see Cassandra docs on porting SQL data models to Cassandra)
  - Use CRDTs or other eventually consistent data types (see e.g. Bayou)
  - Store opaque binary blobs to provide End-to-End Encryption
- Store big blobs (files) in S3
- Let Garage manage sharding, replication, failover, etc.

Research perspectives

- Write about Garage's global architecture *(paper in progress)*
- Measure and improve Garage's performances
- Discuss the optimal layout algorithm, provide proofs
- Write about our proposed architecture for (E2EE) apps over K2V+S3

Where to find us

Garage

`https://garagehq.deuxfleurs.fr/`

`mailto:garagehq@deuxfleurs.fr`

`#garage:deuxfleurs.fr` on Matrix

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Free as in Freedom