Alex Auvolat, Deuxfleurs Association

`https://garagehq.deuxfleurs.fr/`
Matrix channel: `#garage:deuxfleurs.fr`

Who I am

Alex Auvolat
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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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
- ...

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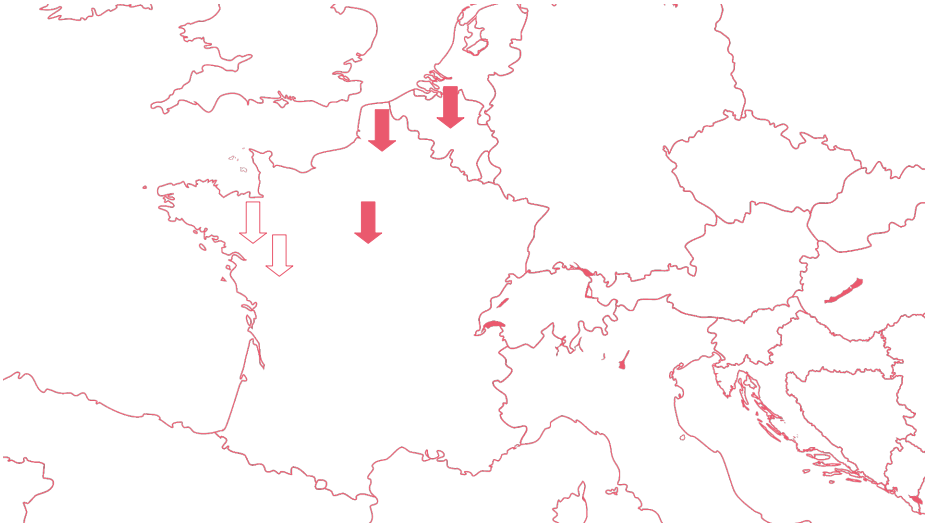
- Commodity Internet (e.g. FTTB, FTTH) and power grid

How to make a resilient system

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



Object storage: a crucial component

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

CRDTs / weak consistency instead of consensus

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

- **Software complexity**
- **Performance issues:**
  - The leader is a **bottleneck** for all requests
  - **Sensitive to higher latency** between nodes
  - **Takes time to reconverge** when disrupted (e.g. node going down)

→ Garage uses only CRDTs internally (conflict-free replicated data types)

The data model of object storage

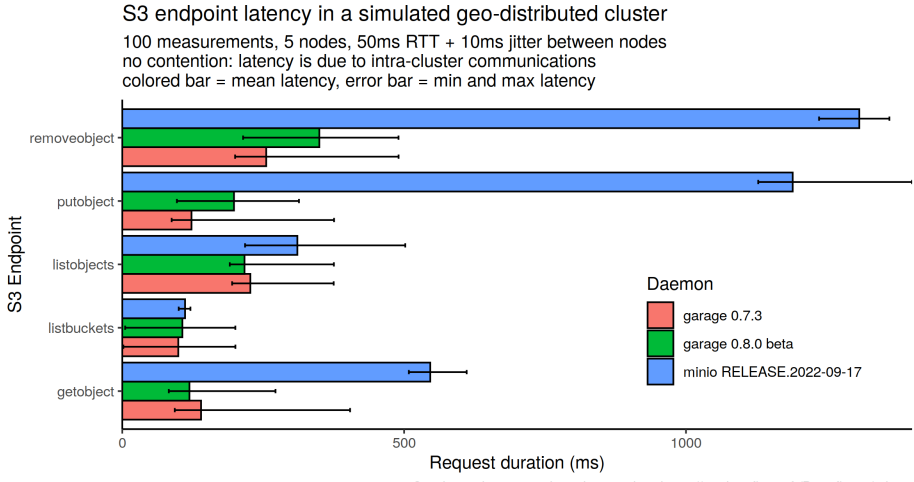
Object storage is basically a key-value store:

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>

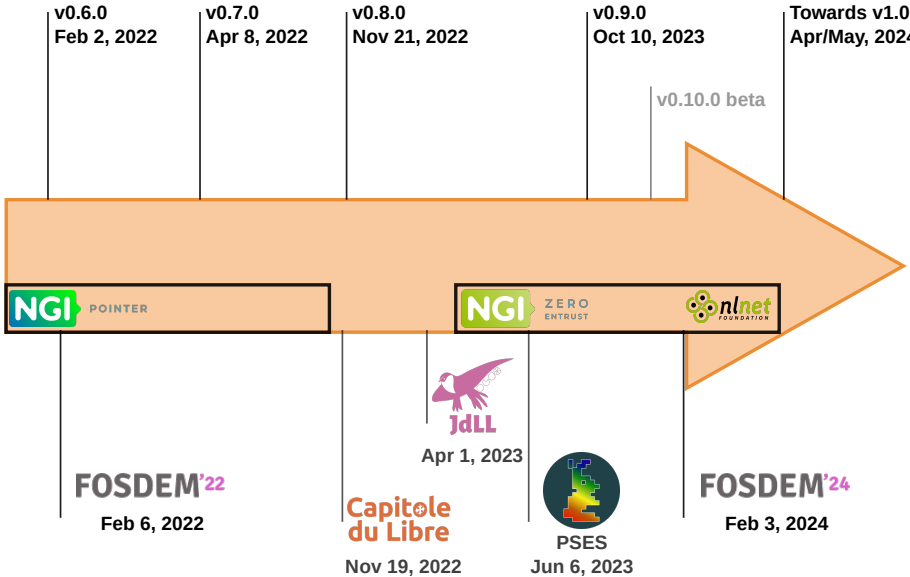
Simple interface, compatible with many existing applications

Maps well to CRDT data types

Performance gains in practice



Timeline

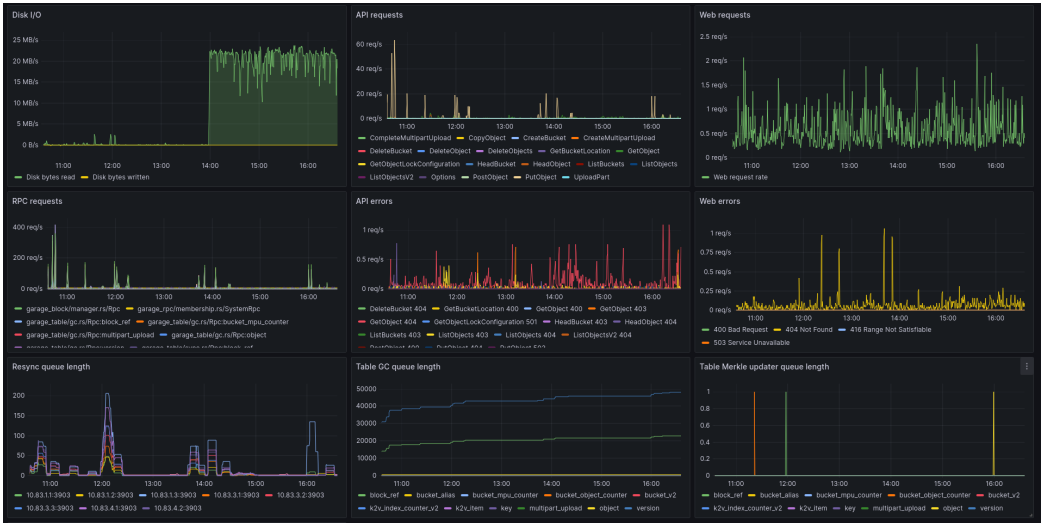

v0.6.0
Feb 2, 2022
v0.7.0
Apr 8, 2022
v0.8.0
Nov 21, 2022
v0.9.0
Oct 10, 2023
v0.10.0 beta
Towards v1.0 ?
Apr/May, 2024
NGI POINTER
NGI ZERO ENTRUST
nlnet FOUNDATION
JdLL
Apr 1, 2023
FOSDEM'22
Feb 6, 2022
Capitole du Libre
Nov 19, 2022
PSES
Jun 6, 2023
FOSDEM'24
Feb 3, 2024

April 2022 - Garage v0.7.0

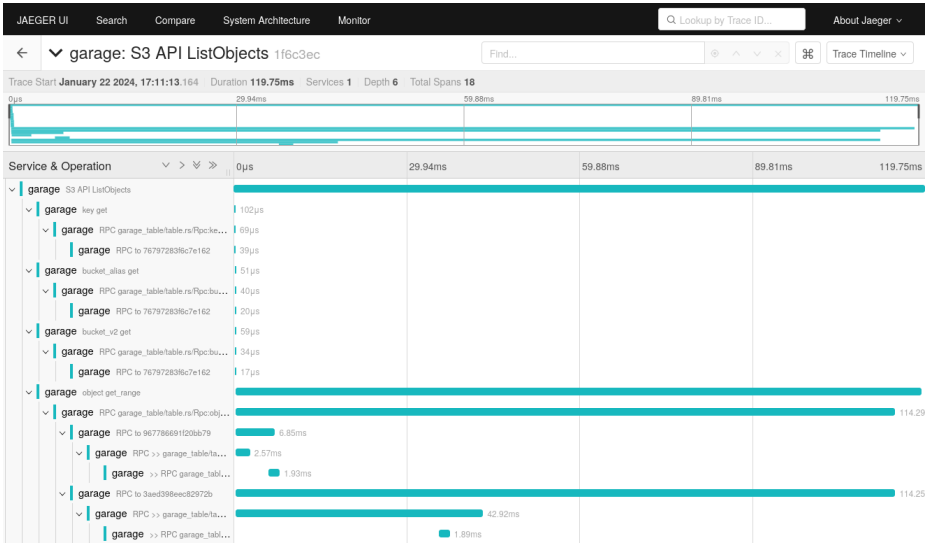
Focus on observability and ecosystem integration

- **Monitoring:** metrics and traces, using OpenTelemetry
- Alternative replication modes with 1 or 2 copies, modes with weaker consistency
- Kubernetes integration
- Admin API (v0.7.2)
- Experimental K2V API (v0.7.2)

Metrics (Prometheus + Grafana)



Traces (Jaeger)



November 2022 - Garage v0.8.0

Focus on performance

- **Alternative metadata DB engines** (LMDB, Sqlite)
- **Performance improvements:** block streaming, various optimizations...
- Bucket quotas (max size, max #objects)
- Quality of life improvements, observability, etc.

About metadata DB engines

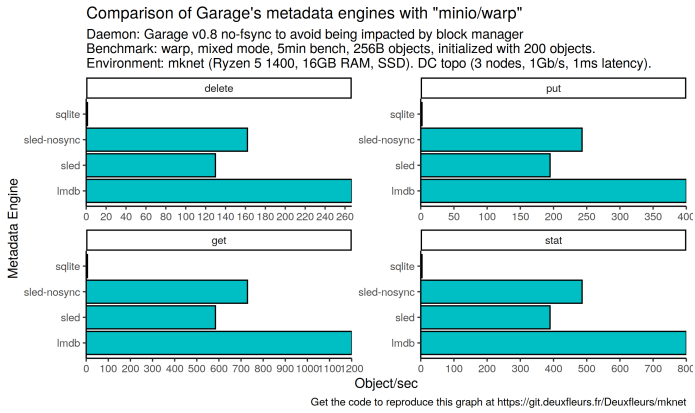
Issues with Sled:

- Huge files on disk
- Unpredictable performance, especially on HDD
- API limitations
- Not actively maintained

LMDB: very stable, good performance, reasonably small files on disk

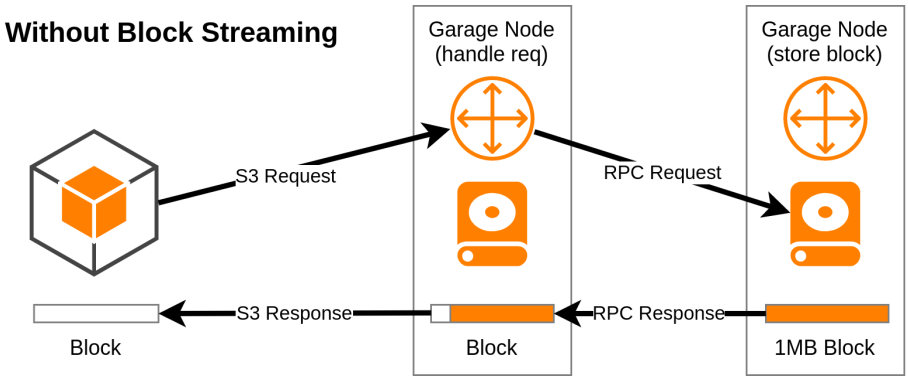
Sled will be removed in Garage v1.0

DB engine performance comparison



NB: Sqlite was slow due to synchronous journaling mode, now configurable

Block streaming



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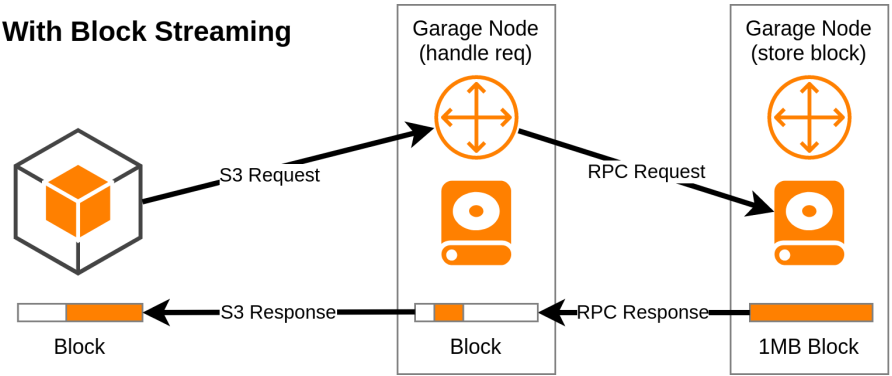
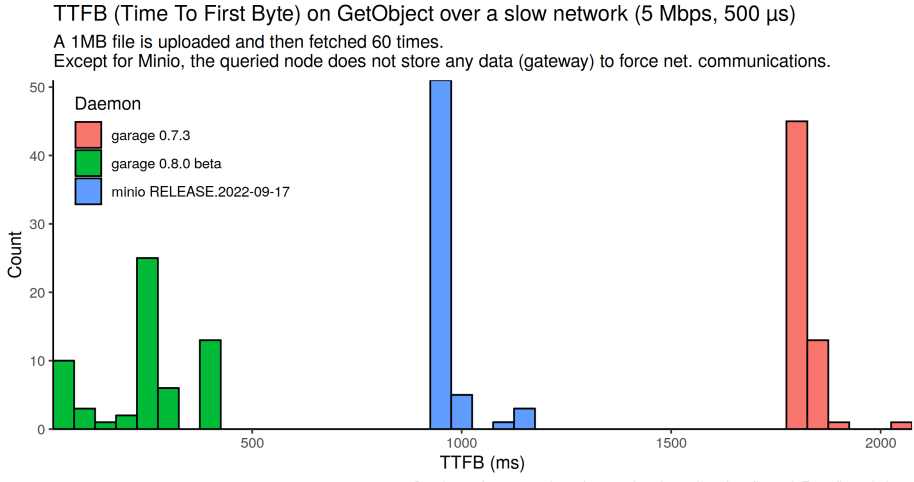
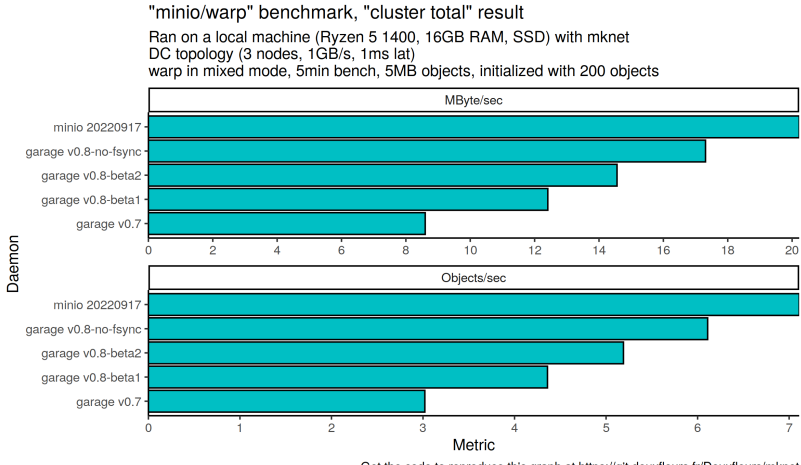


TTFB benchmark



Throughput benchmark



October 2023 - Garage v0.9.0

Focus on streamlining & usability

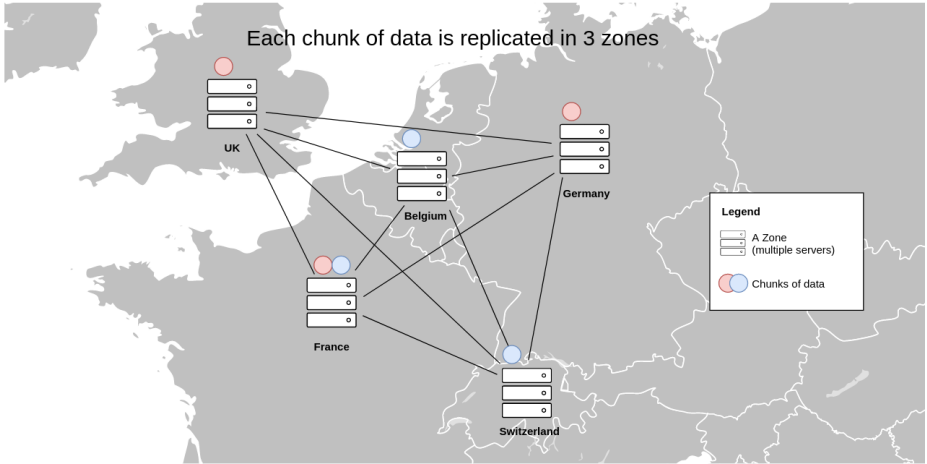
- Support multiple HDDs per node
- S3 compatibility:
  - support basic lifecycle configurations
  - allow for multipart upload part retries
- LMDB by default, deprecation of Sled
- New layout computation algorithm

Layout computation

```
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

Layout computation



Optimal layout computation

An algorithm for geo-distributed and redundant storage in Garage

Mendes Oulamara* and Alex Auvolat†

Deuxfleurs

Abstract

This paper presents an optimal algorithm to compute the assignment of data to storage nodes in the Garage geo-distributed storage system. We discuss the complexity of the different steps of the algorithm and metrics that can be displayed to the user.

1 Introduction

Garage[1] is an open-source distributed object storage service tailored for self-hosting. It was designed by the Deuxfleurs association[2] to enable small structures (associations, collectives, small companies) to share storage resources to reliably self-host their data, possibly with old and non-reliable machines. To achieve these reliability and availability goals, the data is broken into *partitions* and every partition is replicated over 3 different machines (that we call *nodes*). When the data is queried, it is fetched from one of the nodes. A *replication factor* of 3 ensures good guarantees regarding node failure[5]. But this parameter can be another (preferably larger and odd) number.

Moreover, if the nodes are spread over different *zones* (different houses, offices, cities. . .), we can require the data to be replicated over nodes belonging to different zones. This improves the storage robustness against zone failures (such as power outages). To do so, we define a *scattering factor*, that is no more than the replication factor, and we require that the replicas of any partition are spread over this number of zones at least.

In this work, we propose an assignment algorithm that, given the nodes specifications and the replication and scattering factors, computes an optimal assignment of partitions to nodes. We say that the assignment is optimal in the sense that it maximizes the size of the partitions, and hence the effective storage capacity of the system.

Moreover, when a former assignment exists, which is not optimal anymore due to node or zone changes, our algorithm computes a new optimal assignment that *minimizes* the amount of data to be transferred during the assignment update (the *transfer load*).

We call the set of nodes cooperating to store the data a *cluster*, and a description of the nodes, zones and the assignment of partitions to nodes a *cluster layout*

1.1 Notations

Let k be some fixed parameter value, typically 8, that we call the "partition bits". Every object to be stored in the system is split into data blocks of fixed size. We compute a hash $h(\mathbf{b})$ of every such block $\mathbf{b}$, and we define the k first bits of this hash to be the partition number $p(\mathbf{b})$ of the block. This label can take $P = 2^k$ different values, and hence there are P different partitions. We denote $\mathbf{P}$ the set of partition labels (i.e. $\mathbf{P} = [\![1, P]\!]$).

We are given a set $\mathbf{N}$ of N nodes and a set $\mathbf{Z}$ of Z zones. Every node n has a non-negative storage capacity $c_n \geq 0$ and belongs to a zone $z_n \in \mathbf{Z}$. We are also given a replication factor $\rho_{\mathbf{N}}$ and a scattering factor $\rho_{\mathbf{Z}}$ such that $1 \leq \rho_{\mathbf{Z}} \leq \rho_{\mathbf{N}}$ (typical values would be $\rho_N = \rho_Z = 3$).

Our goal is to compute an assignment $\alpha = (\alpha_p^1, \ldots, \alpha_p^{\rho_N})_{p \in \mathbf{P}}$ such that every partition p is associated to $\rho_{\mathbf{N}}$ distinct nodes $\alpha_p^1, \ldots, \alpha_p^{\rho_N} \in \mathbf{N}$ and these nodes belong to at least $\rho_{\mathbf{Z}}$ distinct zones. Among the possible assignments, we choose one that *maximizes* the effective storage capacity of the cluster. If the layout contained a previous assignment α', we *minimize* the amount of data to transfer during the layout update by making α as close as possible to α'. These maximization and minimization are described more formally in the following section.

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[1] https://garagehq.deuxfleurs.fr/

[2] https://deuxfleurs.fr/

What a "layout" is

A layout is a precomputed index table

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)

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

October 2023 - Garage v0.10.0 beta

Focus on consistency

- Fix consistency issues when reshuffling data

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

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2. **How to guarantee consistency?**

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

   $\rightarrow$ 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 (a.k.a. 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)
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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 independently, 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

Issues with consistent hashing

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  data quantities not well balanced between nodes
- Geographically aware adaptation, try 2:
  too many reshuffles when adding/removing nodes

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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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

From a theoretical point of view:

Consensus-based systems:

Require **additional assumptions** such as a fault detector or a strong RNG (FLP impossibility theorem)

Weakly consistent systems:

Can be implemented in **any asynchronous message passing distributed system** with node crashes

They represent **different classes of computational capability**

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:

Only CRDTs
(conflict-free replicated data types)

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

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

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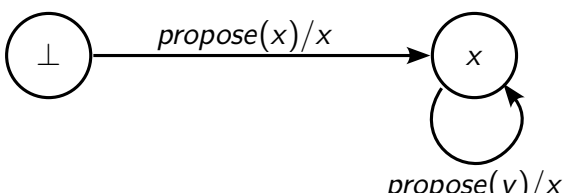
Implemented by this simple replicated state machine:



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

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  → the API is equivalent to consensus/total ordering of messages
  → the API cannot be implemented in a weakly consistent system

- **This API can be implemented using only weak primitives**
  (e.g. in the asynchronous message passing model with no further assumption)
  → the API is strictly weaker than consensus
  → we can implement it in Garage!

What can we implement without consensus?

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- **Read-after-write consistency** can be implemented using quorums on read and write operations

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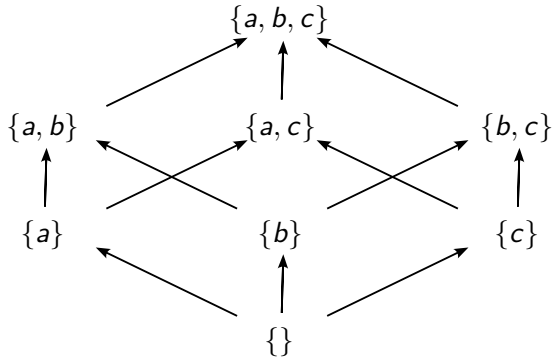
- **Read-after-write consistency** can be implemented using quorums on read and write operations
- **Monotonicity of reads** can be implemented with repair-on-read (makes reads more costly, not implemented in Garage)

CRDTs and quorums: read-after-write consistency



CRDTs and quorums: read-after-write consistency

$write(\{a\})$:

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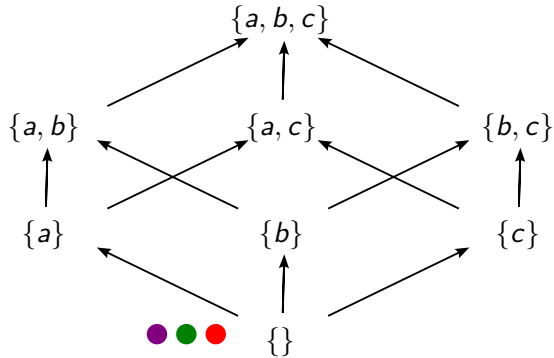

CRDTs and quorums: read-after-write consistency

$write(\{a\})$:

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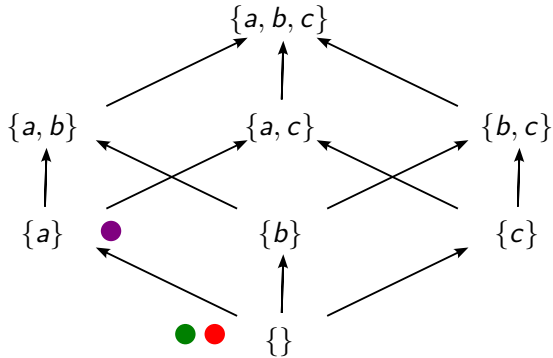

CRDTs and quorums: read-after-write consistency

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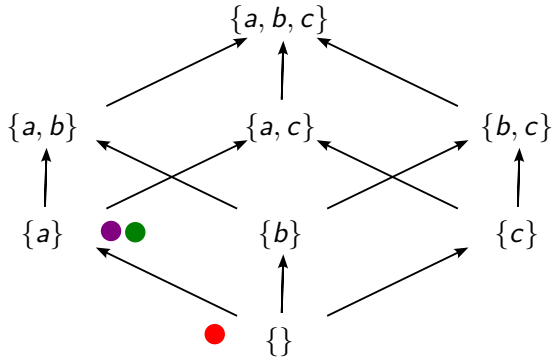
return OK



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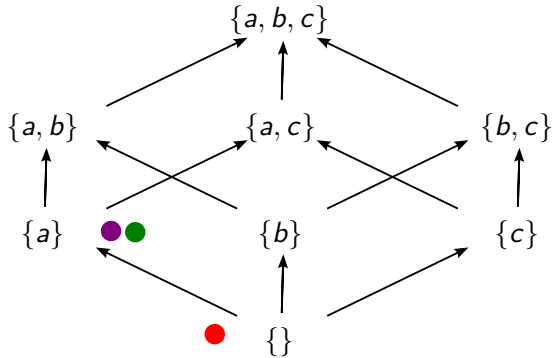

CRDTs and quorums: read-after-write consistency

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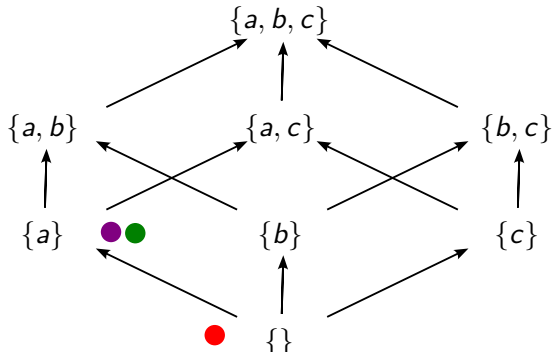
- $\rightarrow \{\}$



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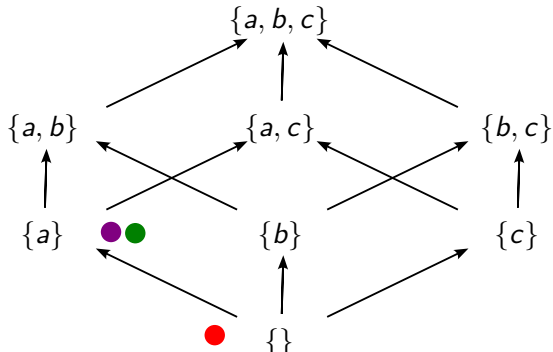
read():

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

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



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read():

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- $\rightarrow \{a\}$

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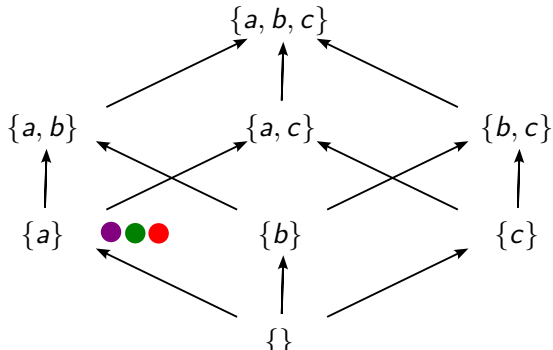


CRDTs and quorums: read-after-write consistency

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 ($x_i \sqsupseteq x$).

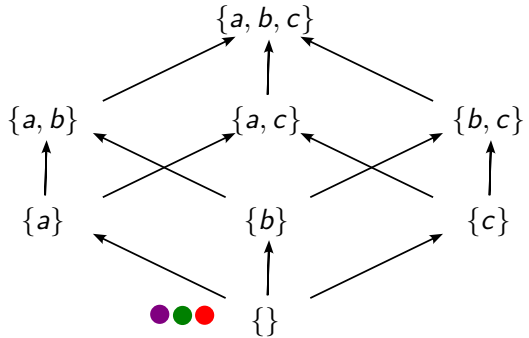
CRDTs and quorums: monotonic-reads consistency

$write(\{a\})$:

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

$write(\{b\})$:

- $\not\supseteq \{b\}$
- $\not\supseteq \{b\}$
- $\not\supseteq \{b\}$



CRDTs and quorums: monotonic-reads consistency

write($\{a\}$):

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

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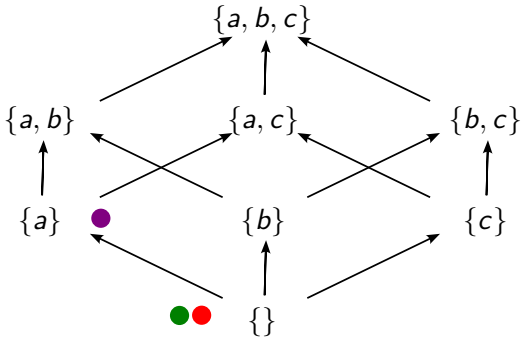
- $\not\sqsupseteq \{b\}$
- $\not\sqsupseteq \{b\}$



CRDTs and quorums: monotonic-reads consistency

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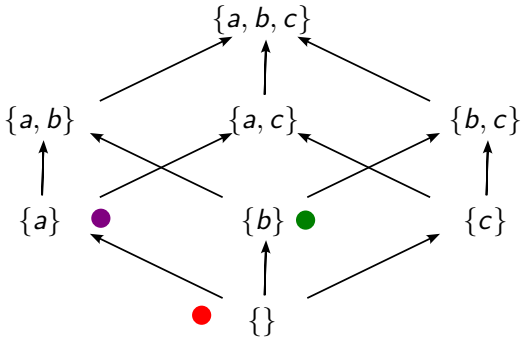

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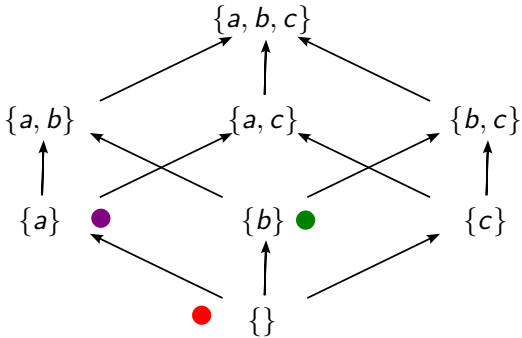

read():

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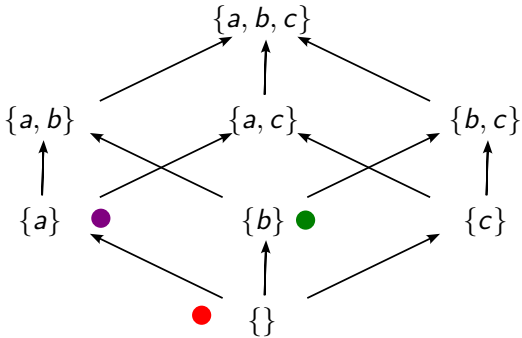

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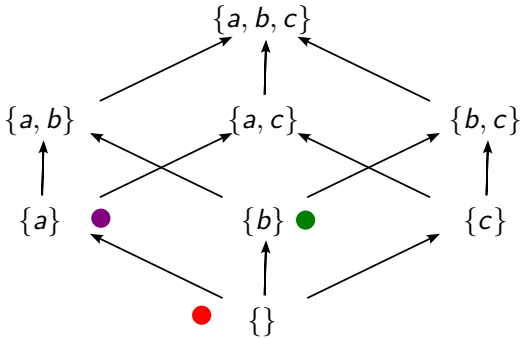

read():

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

return $\{a\}$

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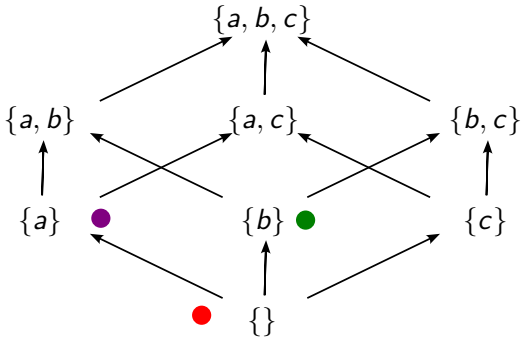

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- $\rightarrow \{\}$

return $\{a\}$

;

read():

CRDTs and quorums: monotonic-reads consistency

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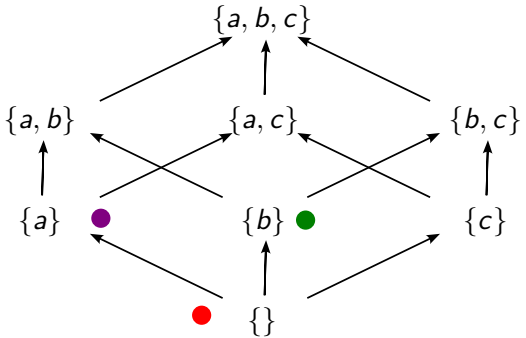

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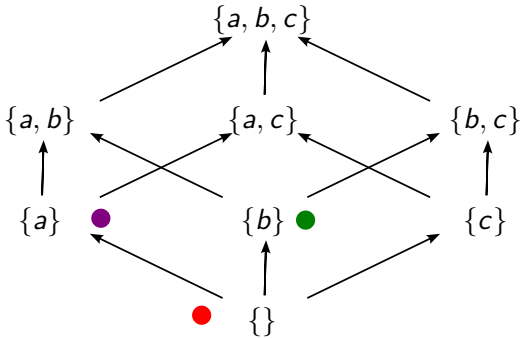

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;

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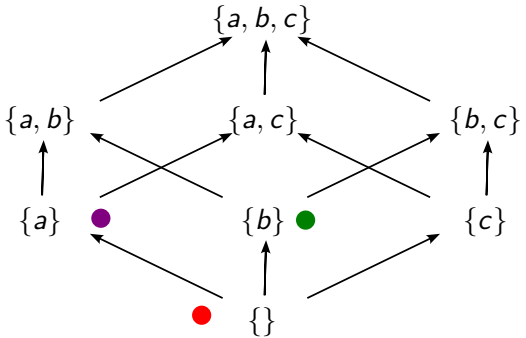

read():

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

return $\{a\}$

;

read():

- $\rightarrow \{\}$
- $\rightarrow \{b\}$

return $\{b\}$

??!

$\{a\} \not\sqsubseteq \{b\}$

CRDTs and quorums: monotonic-reads 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 *monotonic_read*(): (a.k.a. repair-on-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**.

A hard problem: layout changes

- We rely on quorums $k > n/2$ within each partition:

$$n = 3, \qquad k \geq 2$$

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$$\{n_A, n_B, n_C\} \rightarrow \{n_A, n_D, n_E\}$$

- During the rebalancing, D and E don't yet have the data,
  and B and C want to get rid of the data to free up space

  $\rightarrow$ quorums only within the new set of nodes don't work

  $\rightarrow$ how to coordinate? **currently, we don't...**

Operating big Garage clusters

Operating Garage

```
[root@celeri:~]# docker exec -ti 74a09 /garage status
==== HEALTHY NODES ====
ID                Hostname   Address                                      Tags                                          Zone     Capacity  DataAvail
a717e5b618267806  courgette  [2001:910:1204:1::32]:3901                   [courgette,neptune,france,alex]               neptune  5         393.3 GB (78.7%)
8cf284e7df17d0fd  celeri     [2001:910:1204:1::33]:3901                   [celeri,neptune,france,alex]                  neptune  20        1.6 TB (78.3%)
0a03ab7c082ad929  ananas     [2a01:e0a:e4:2dd0::42]:3901                  [ananas,scorpio,france,adrien]                scorpio  20        1.7 TB (83.6%)
fdfaf7832d8359e0  df-ymk     [2a02:a03f:6510:5102:6e4b:90ff:fe3b:e939]:3901  [df-ymk,bespin,belgium,max]                bespin   4         263.3 GB (52.7%)
5fcb3b6e39db3dcb  concombre  [2001:910:1204:1::31]:3901                   [concombre,neptune,france,alex]               neptune  5         393.4 GB (78.7%)
942dd71ea95f4904  df-ymf     [2a02:a03f:6510:5102:6e4b:90ff:fe3a:6174]:3901  [df-ymf,bespin,belgium,max]                bespin   4         264.5 GB (52.9%)
17ee03c6b81d9235  df-ykl     [2a02:a03f:6510:5102:6e4b:90ff:fe3b:e86c]:3901  [df-ykl,bespin,belgium,max]                bespin   4         280.2 GB (56.1%)
2032d0a37f249c4a  abricot    [2a01:e0a:e4:2dd0::41]:3901                   [abricot,scopio,france,adrien]                scorpio  20        1.7 TB (83.7%)
```

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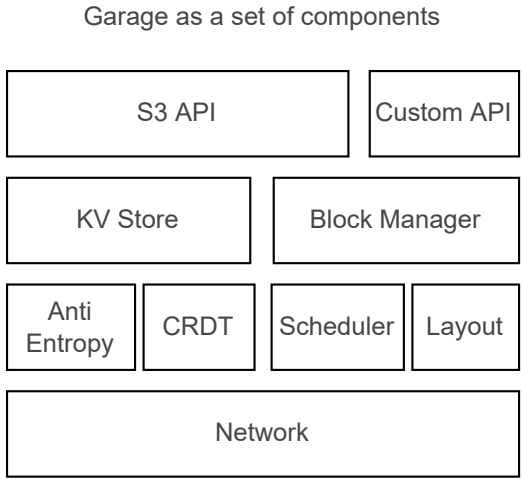
fdfaf7832d8359e0  df-ymk     [2a02:a03f:6510:5102:6e4b:90ff:fe3b:e939]:3901  [df-ymk,bespin,belgium,max]           bespin   4         263.3 GB (52.7%)
5fcb3b6e39db3dcb  concombre  [2001:910:1204:1::31]:3901              [concombre,neptune,france,alex]               neptune  5         393.4 GB (78.7%)
942dd71ea95f4904  df-ymf     [2a02:a03f:6510:5102:6e4b:90ff:fe3a:6174]:3901  [df-ymf,bespin,belgium,max]           bespin   4         264.5 GB (52.9%)
17ee03c6b81d9235  df-ykl     [2a02:a03f:6510:5102:6e4b:90ff:fe3b:e86c]:3901  [df-ykl,bespin,belgium,max]           bespin   4         280.2 GB (56.1%)
2032d0a37f249c4a  abricot    [2a01:e0a:e4:2dd0::41]:3901              [abricot,scopio,france,adrien]                scorpio  20        1.7 TB (83.7%)
```

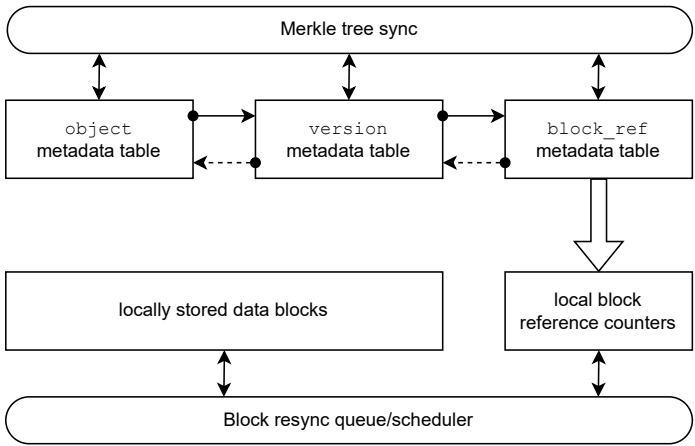
```
[lx@lindy:~]$ nomad exec -job garage-staging garage status
==== HEALTHY NODES ====
ID                Hostname  Address                                 Tags        Zone     Capacity  DataAvail
967786691f20bb79  caribou   [2001:910:1204:1::23]:3991              [caribou]   neptune  5         450.5 GB (91.8%)
ec5753c546756825  df-pw5    [2a02:a03f:6510:5102:223:24ff:feb0:e8a7]:3991  [df-pw5]    bespin   5         436.7 GB (90.6%)
3aed398eec82972b  origan    [2a01:e0a:5e4:1d0:223:24ff:feaf:fdec]:3991     [origan]    jupiter  5         461.9 GB (94.1%)
76797283f6c7e162  carcajou  [2001:910:1204:1::22]:3991              [carcajou]  neptune  2         165.4 GB (73.1%)

==== FAILED NODES ====
ID                Hostname  Address  Tags       Zone    Capacity  Last seen
8073f25ffb7d6944  ??        ??       [piranha]  corrin  gateway   never seen
```

Garage's architecture



Garage's architecture



Digging deeper

```
[root@celeri:~]# docker exec -ti 74a09 /garage stats

Garage version: v0.8.2 [features: k2v, sled, lmdb, sqlite, consul-discovery, kubernetes-discovery, metrics, telemetry-otlp, bundled-libs]
Rust compiler version: 1.63.0

Database engine: LMDB (using Heed crate)

Table stats:
  Table      Items    MklItems  MklTodo  GcTodo
  bucket_v2  124      150       0        0
  key        56       59        0        0
  object     607630   749155    0        0
  version    498551   553360    0        1285
  block_ref  1098024  1192560   0        470

Block manager stats:
  number of RC entries (~= number of blocks): 594820
  resync queue length: 3
  blocks with resync errors: 1

If values are missing above (marked as NC), consider adding the --detailed flag (this will be slow).

Storage nodes:
  ID                Hostname   Zone     Capacity  Part.  DataAvail                MetaAvail
  942dd71ea95f4904  df-ymf     bespin   4         86     264.5 GB/499.9 GB (52.9%)  264.5 GB/499.9 GB (52.9%)
  a717e5b618267806  courgette  neptune  5         42     393.3 GB/499.9 GB (78.7%)  372.8 GB/486.4 GB (76.7%)
  17ee03c6b81d9235  df-ykl     bespin   4         85     280.2 GB/499.9 GB (56.1%)  280.2 GB/499.9 GB (56.1%)
  5fcb3b6e39db3dcb  concombre  neptune  5         42     393.4 GB/499.9 GB (78.7%)  380.4 GB/486.4 GB (78.2%)
  fdfaf7832d8359e0  df-ymk     bespin   4         85     263.3 GB/499.9 GB (52.7%)  263.3 GB/499.9 GB (52.7%)
  0a03ab7c082ad929  ananas     scorpio  20        128    1.7 TB/2.0 TB (83.6%)      396.2 GB/477.9 GB (82.9%)
  8cf284e7df17d0fd  celeri     neptune  20        172    1.6 TB/2.0 TB (78.3%)      417.3 GB/486.4 GB (85.8%)
  2032d0a37f249c4a  abricot    scorpio  20        128    1.7 TB/2.0 TB (83.7%)      433.2 GB/482.7 GB (89.7%)

Estimated available storage space cluster-wide (might be lower in practice):
  data: 787.4 GB
  metadata: 621.1 GB
```

Digging deeper

```
[root@celeri:~]# docker exec -ti 74a09 /garage worker list
TID  State  Name                          Tranq  Done  Queue  Errors  Consec  Last
1    Idle   Block resync worker #1        1      -     3      -       -
2    Idle   Block resync worker #2        1      -     3      -       -
3    Idle   Block resync worker #3        -      -     -      -       -
4    Idle   Block resync worker #4        -      -     -      -       -
5    Idle   Block scrub worker            4      -     -      -       -
6    Idle   bucket_v2 Merkle              -      -     0      -       -
7    Idle   bucket_v2 sync                -      -     0      -       -
8    Idle   bucket_v2 GC                  -      -     0      -       -
9    Idle   bucket_v2 queue               -      -     0      -       -
10   Idle   bucket_alias Merkle           -      -     0      -       -
11   Idle   bucket_alias sync             -      -     0      -       -
12   Idle   bucket_alias GC               -      -     0      -       -
13   Idle   bucket_alias queue            -      -     0      -       -
14   Idle   key Merkle                    -      -     0      -       -
15   Idle   key sync                      -      -     0      -       -
16   Idle   key GC                        -      -     0      -       -
17   Idle   key queue                     -      -     0      -       -
18   Idle   object Merkle                 -      -     0      -       -
19   Idle   object sync                   -      -     0      -       -
20   Idle   object GC                     -      -     0      -       -
21   Idle   object queue                  -      -     0      -       -
22   Idle   bucket_object_counter Merkle  -      -     0      -       -
23   Idle   bucket_object_counter sync    -      -     0      -       -
24   Idle   bucket_object_counter GC      -      -     0      -       -
25   Idle   bucket_object_counter queue   -      -     0      4       0       3 days ago
26   Idle   version Merkle                -      -     0      -       -
27   Idle   version sync                  -      -     0      -       -
28   Idle   version GC                    -      -     1285   -       -
29   Idle   version queue                 -      -     0      -       -
30   Idle   block_ref Merkle              -      -     0      -       -
31   Idle   block_ref sync                -      -     0      -       -
32   Idle   block_ref GC                  -      -     470    -       -
33   Idle   block_ref queue               -      -     0      -       -
```

Digging deeper

```
[root@celeri:~]# docker exec -ti 74a09 /garage worker get
8cf284e7df17d0fd  resync-tranquility          1
8cf284e7df17d0fd  resync-worker-count         2
8cf284e7df17d0fd  scrub-corruptions_detected  0
8cf284e7df17d0fd  scrub-last-completed        2023-09-09T19:10:37.167Z
8cf284e7df17d0fd  scrub-next-run              2023-10-07T05:51:49.167Z
8cf284e7df17d0fd  scrub-tranquility           4

[root@celeri:~]# docker exec -ti 74a09 /garage worker get -a resync-tranquility
0a03ab7c082ad929  resync-tranquility  1
17ee03c6b81d9235  resync-tranquility  1
2032d0a37f249c4a  resync-tranquility  1
5fcb3b6e39db3dcb  resync-tranquility  1
8cf284e7df17d0fd  resync-tranquility  1
942dd71ea95f4904  resync-tranquility  1
a717e5b618267806  resync-tranquility  1
fdfaf7832d8359e0  resync-tranquility  1
```

Potential limitations and bottlenecks

- Global:
  - Max. ∼100 nodes per cluster (excluding gateways)
- Metadata:
  - One big bucket = bottleneck, object list on 3 nodes only
- Block manager:
  - Lots of small files on disk
  - Processing the resync queue can be slow
  - Multi-HDD support not yet released (soon!)

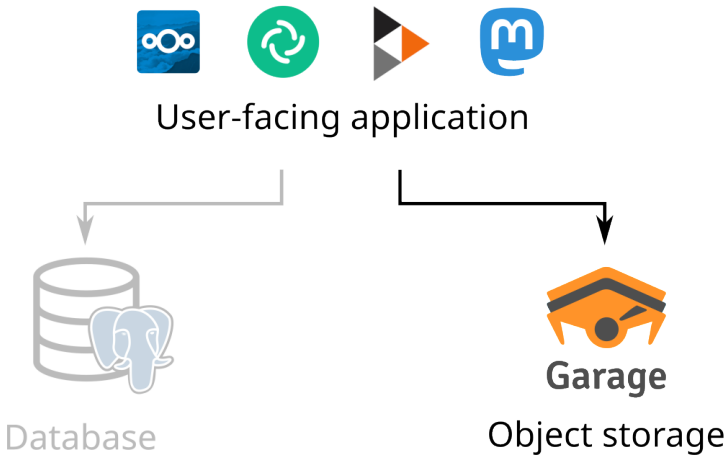
Deployment advice for very large clusters

- Metadata storage:
  - ZFS mirror (x2) on fast NVMe
  - Use LMDB storage engine
- Data block storage:
  - Wait for v0.9 with multi-HDD support
  - XFS on individual drives
  - Increase block size (1MB $\rightarrow$ 10MB, requires more RAM and good networking)
  - Tune `resync-tranquility` and `resync-worker-count` dynamically
- Other :
  - Split data over several buckets
  - Use less than 100 storage nodes
  - Use gateway nodes

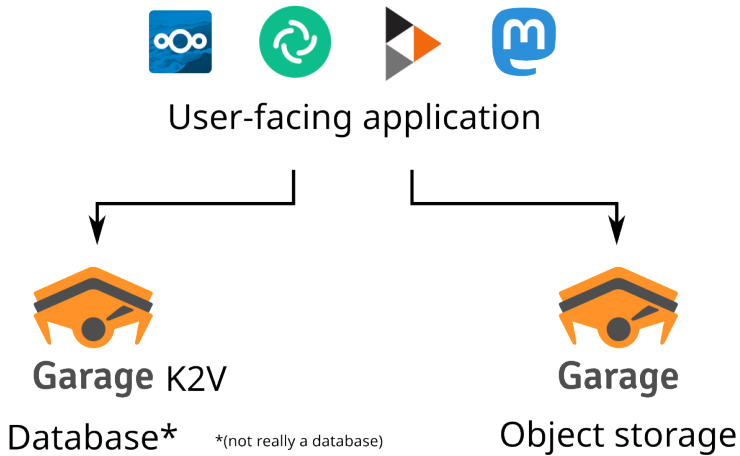
Current deployments: $<$ 10 TB, we don't have much experience with more

Going further than the S3 API

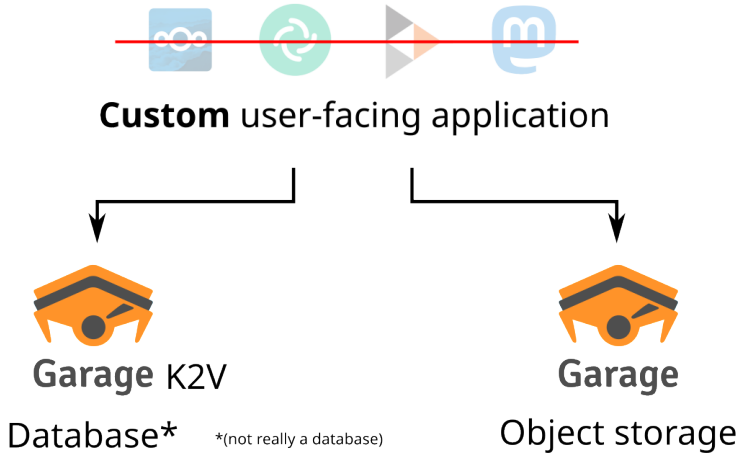
Using Garage for everything



Using Garage for everything



Using Garage for everything



K2V Design

- A new, custom, minimal API
  - Single-item operations
  - Operations on ranges and batches of items
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- Exposes the partitoning mechanism of Garage
  K2V = partition key / sort key / value (like Dynamo)

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- A new, custom, minimal API
  - Single-item operations
  - Operations on ranges and batches of items
  - Polling operations to help implement a PubSub pattern
- Exposes the partitoning mechanism of Garage
  K2V = partition key / sort key / value (like Dynamo)
- Weakly consistent, CRDT-friendly
  $\rightarrow$ no support for transactions (not ACID)

K2V Design

- A new, custom, minimal API
  - Single-item operations
  - Operations on ranges and batches of items
  - Polling operations to help implement a PubSub pattern
- Exposes the partitoning mechanism of Garage
  K2V = partition key / sort key / value (like Dynamo)
- Weakly consistent, CRDT-friendly
  $\rightarrow$ no support for transactions (not ACID)
- Cryptography-friendly: values are binary blobs

Handling concurrent values

How to handle concurrency? Example:

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2. Client B also reads the initial value x_0 of that key
3. Client A modifies x_0, and writes a new value x_1
4. Client B also modifies x_0, and writes a new value x'_1, without having a chance to first read x_1

   $\rightarrow$ what should the final state be?

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- Values are opaque binary blobs, **K2V cannot resolve conflicts** by itself (e.g. by implementing a CRDT)
- Solution: **we keep both!**
  $\rightarrow$ the value of the key is now $\{x_1, x_1'\}$
  $\rightarrow$ the client application can decide how to resolve conflicts on the next read

Keeping track of causality

How does K2V know that x_1 and x_1' are concurrent?

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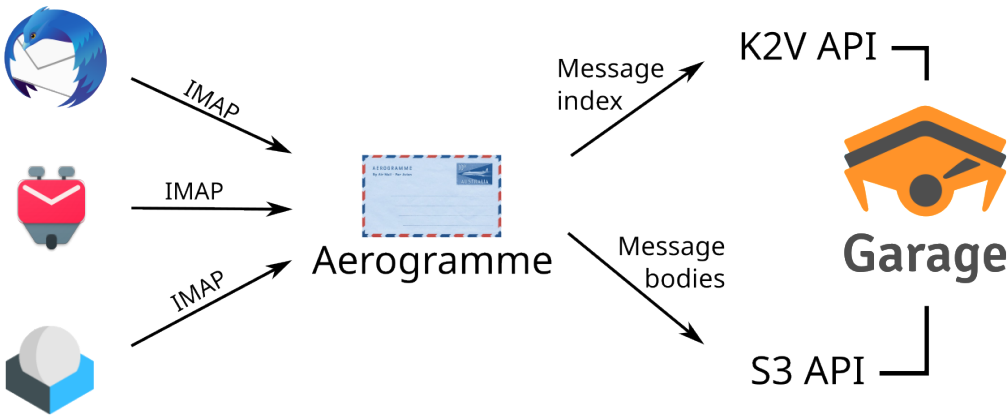
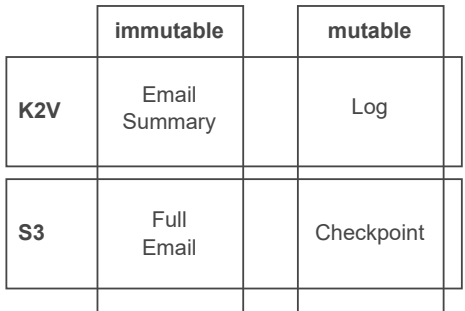
- Internally, the causality token is **a vector clock**

Application: an e-mail storage server



Aerogramme data model



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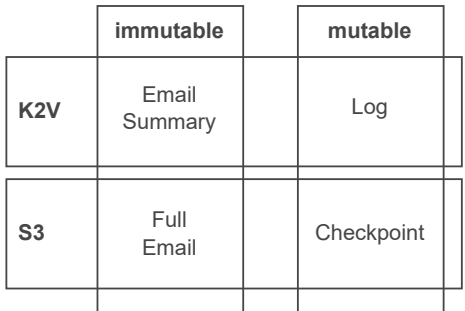
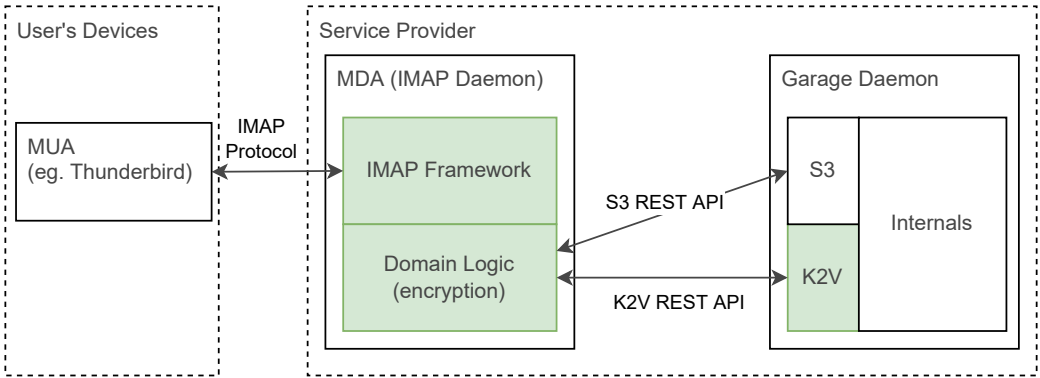


Aerogramme encrypts all stored values for privacy
(Garage server administrators can't read your mail)

Different deployment scenarios



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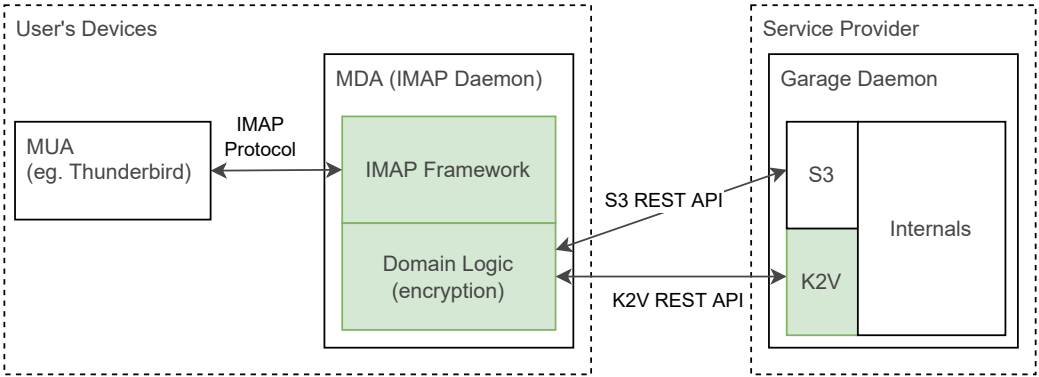

A new model for building resilient software

How to build an application using only Garage as a data store:

1. 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)
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2. Store big blobs (files) using the S3 API
3. Let Garage manage sharding, replication, failover, etc.

Conclusion

Perspectives

- Fix the consistency issue when rebalancing
- Write about Garage's architecture and properties,
  and about our proposed architecture for (E2EE) apps over K2V+S3
- Continue developing Garage; finish Aerogramme; build new applications...
- Anything else?

Where to find us

Garage

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