



## Garage, an S3 backend as reliable as possible

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<mailto:garagehq@deuxfleurs.fr>  
#garage:deuxfleurs.fr on Matrix

# Meet Garage

# A non-profit initiative



## Part of a degrowth initiative

Garage has been created at Deuxfleurs where we experiment running Internet services without datacenter on commodity and refurbished hardware.



## Developed by a community

Some recent contributors: Arthur C, Charles H, dongdigua, Etienne L, Jonah A, Julien K, Lapineige, MagicRR, Milas B, Niklas M, RockWolf, Schwitzd, trinity-1686a, Xavier S, babykart, Baptiste J, eddster2309, James O'C, Joker9944, Maximilien R, Renjaya RZ, Yureka...



## Owned by nobody, locked under AGPL AGPL

# Getting support for Garage



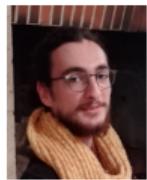
**Alex Auvolat**

PhD; co-founder of Deuxfleurs  
Garage maintainer, Freelance



**Quentin Dufour**

PhD; co-founder of Deuxfleurs  
Garage contributor, Freelance



**Armaël Guéneau**

PhD; member of Deuxfleurs  
Garage contributor, Freelance

## Our initial goal

Being a self-sovereign community to be free of our degrowth choice.  
We need reliability without relying on hardware.

# Building a resilient system with cheap stuff

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

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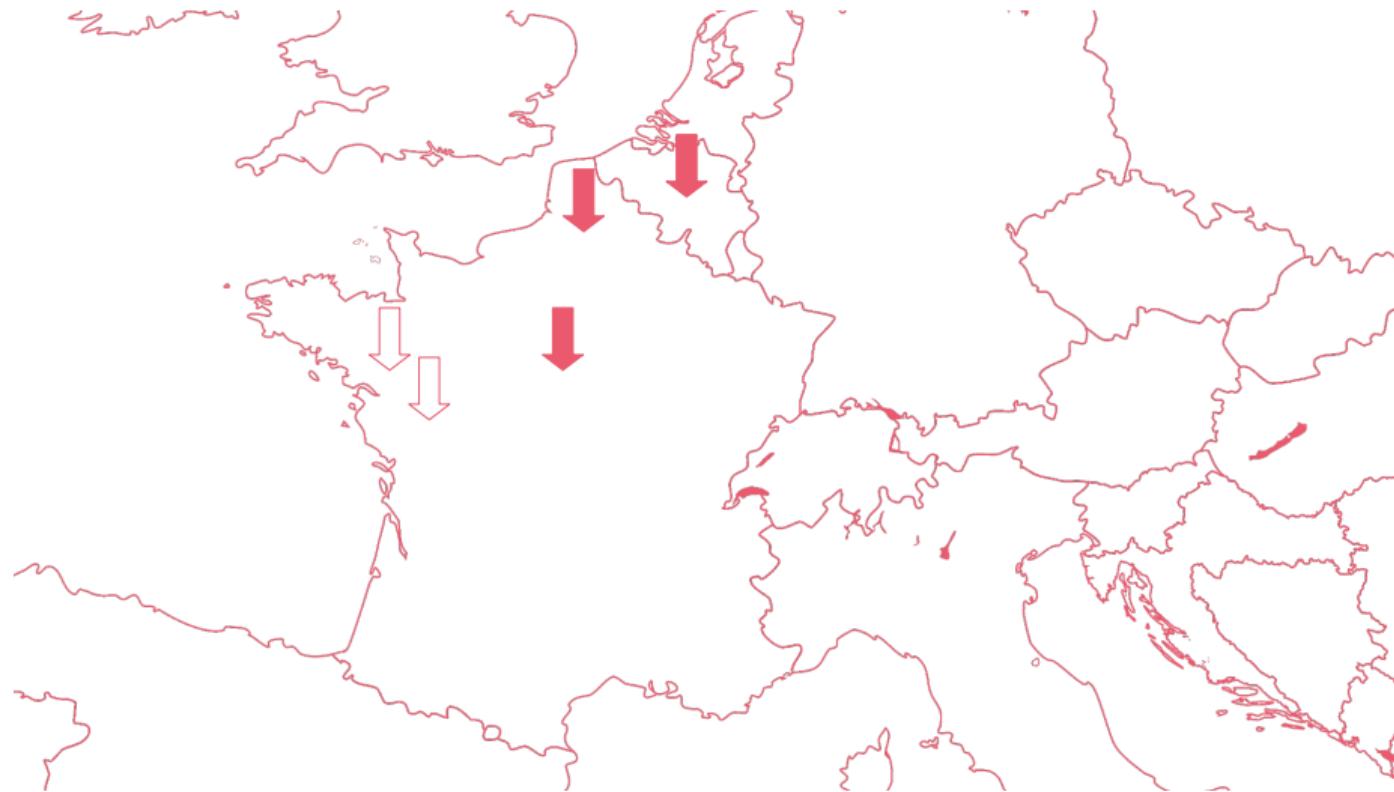
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# Building a resilient system with cheap stuff

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(can die at any time)
- ▶ Regular Internet (e.g. FTTB, FTTH) and power grid connections  
(can be unavailable randomly)
- ▶ **Geographical redundancy** (multi-site replication)

# Building a resilient system with cheap stuff



# Object storage: a crucial component



Amazon S3

S3: a de-facto standard, many compatible applications

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Garage

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

Internally, Garage uses only CRDTs (conflict-free replicated data types)

Why not Raft, Paxos, ...? Issues of consensus algorithms:

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- ▶ **Software complexity**

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- ▶ **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)

# 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>

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

- ▶ Maps well to CRDT data types

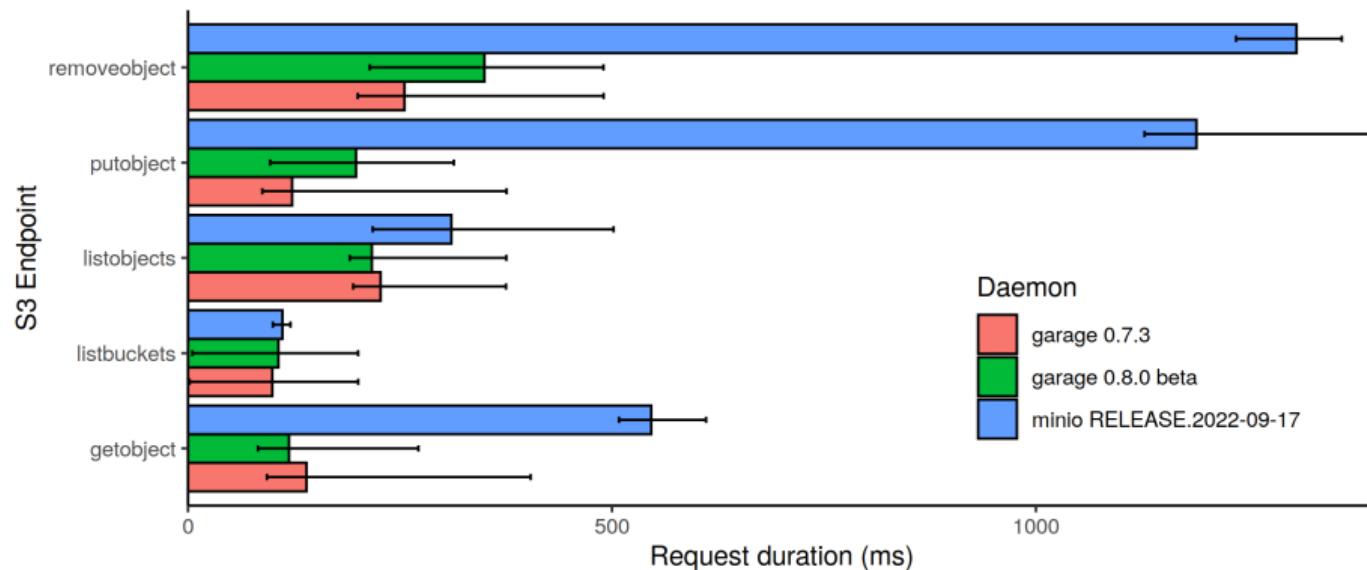
# Performance gains in practice

S3 endpoint latency in a simulated geo-distributed cluster

100 measurements, 5 nodes, 50ms RTT + 10ms jitter between nodes

no contention: latency is due to intra-cluster communications

colored bar = mean latency, error bar = min and max latency



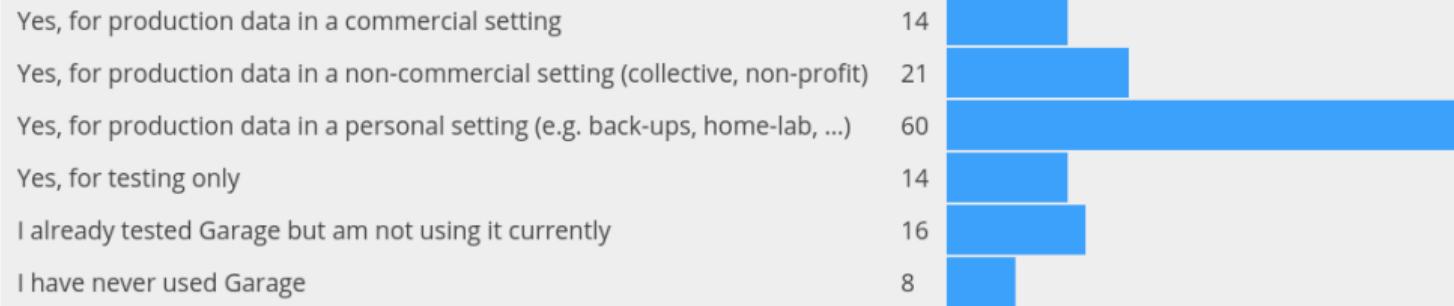
Get the code to reproduce this graph at <https://git.deuxfleurs.fr/Deuxfleurs/mknet>

## Production clusters

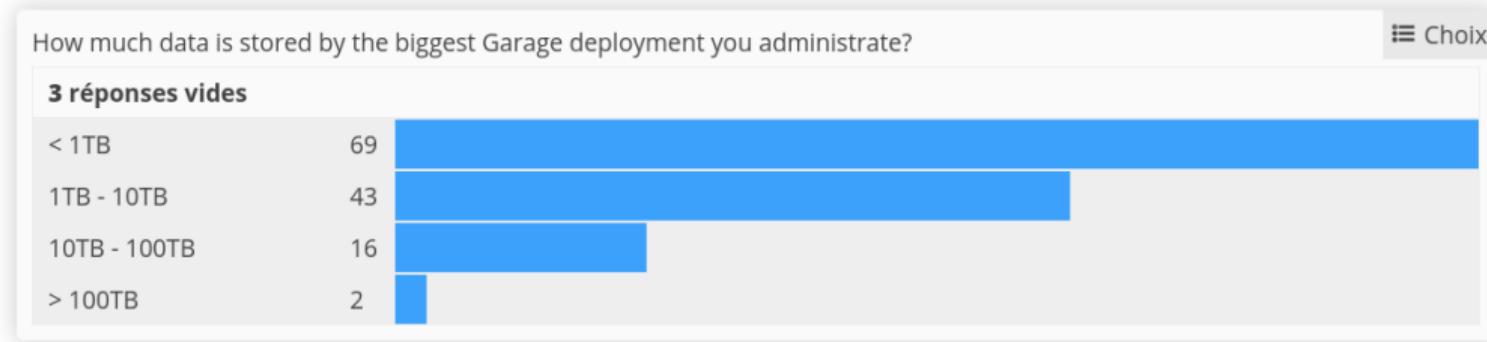
# Deployment kinds

Are you currently an administrator of a Garage deployment?

Choix



# How big they are?



*"Petabyte storage setup for a video site. Nginx as CDN in-front using garage-s3-website feature. Each storage node has 64TB storage with raid10, no replication within garage. 25gbit nic. haproxy to loadbalance across 5 nodes. mostly reads with very few writes."*

*"We currently manage 7 Garage nodes, 28TB total storage, 6M blocks for 3M objects and 4TB of object data. We have been running Garage in production for 2.5 years."*

# Operating Garage

```
$ garage status
==== HEALTHY NODES ====
ID          Hostname  Address                                     Tags      Zone    Capacity  DataAvail
ec5753c546756825  df-pw5    [2a02:a03f:6510:5102:223:24ff:feb0:e8a7]:3991  [df-pw5]   bespin   500.0 GB  429.1 GB (89.0%)
76797283f6c7e162  carcajou  [2001:470:ca43::22]:3991                  [carcajou] neptune  200.0 GB  166.3 GB (73.5%)
8073f25ffb7d6944  piranha   [2a01:cb05:911e:ec00:223:24ff:feb0:ea82]:3991  [piranha] corrin   500.0 GB  457.3 GB (94.0%)
3aed398eec82972b  origan    [2a01:e0a:5e4:1d0:223:24ff:feaf:fdec]:3991  [origan]  jupiter  500.0 GB  457.1 GB (93.1%)
967786691f20bb79  caribou   [2001:470:ca43::23]:3991                  [caribou] neptune  500.0 GB  453.1 GB (92.3%)
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# Operating Garage

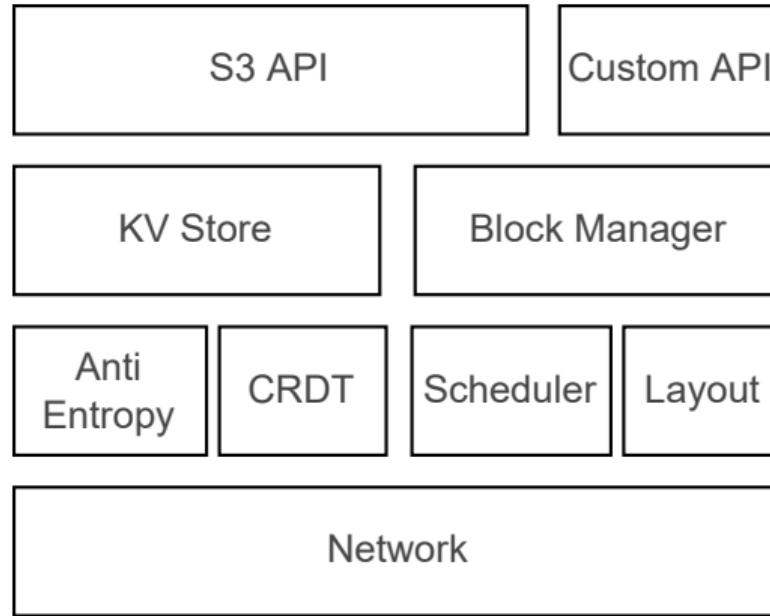
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3aed398eec82972b  origan    [2a01:e0a:5e4:1d0:223:24ff:feaf:fdec]:3991  [origan]  jupiter  500.0 GB  457.1 GB (93.1%)
967786691f20bb79  caribou   [2001:470:ca43::23]:3991                      [caribou]  neptune  500.0 GB  453.1 GB (92.3%)

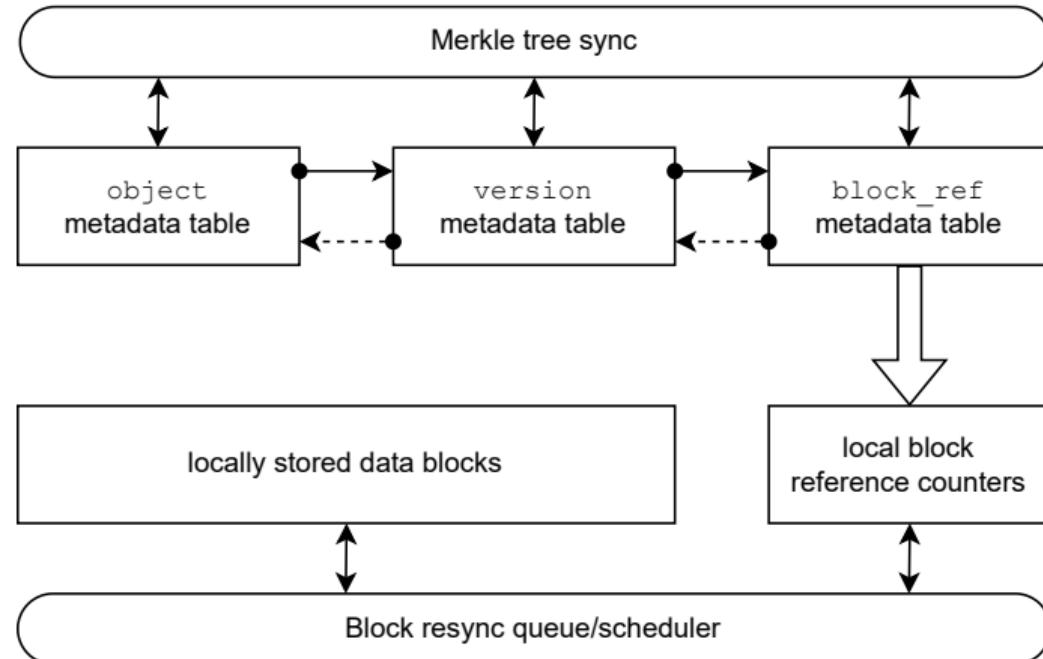
==== FAILED NODES ====
ID          Hostname  Address                                     Tags      Zone    Capacity  Last seen
ec5753c546756825  df-pw5    [2a02:a03f:6510:5102:223:24ff:feb0:e8a7]:3991  [df-pw5]   bespin   500.0 GB  5 minutes ago
```

# Garage's architecture

Garage as a set of components



# Garage's architecture



# Digging deeper

```
$ garage stats

Garage version: 20240116133343 [features: k2v, sled, lmdb, sqlite, consul-discovery, kubernetes-discovery, metrics, telemetry-otlp, bundled-libs]
Rust compiler version: 1.68.0

Database engine: LMDB (using Heed crate)

Table stats:
  Table    Items   MklItems  MklTodo  GcTodo
bucket_v2     19        20        0        0
key           12        14        0        0
object        67391     80964      0        0
version       33909     42045      0        0
block_ref     334735    370927      0        0

Block manager stats:
  number of RC entries (≈ number of blocks): 42376
  resync queue length: 0
  blocks with resync errors: 0

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
ec5753c546756825  df-pw5  bespin  500.0 GB  175  429.1 GB/482.1 GB (89.0%)  429.1 GB/482.1 GB (89.0%)
76797283f6c7e162  carcajou neptune 200.0 GB   70   166.3 GB/226.2 GB (73.5%)  166.3 GB/226.2 GB (73.5%)
8073f25ffb7d6944  piranha  corrin  500.0 GB  173  457.3 GB/486.4 GB (94.0%)  457.3 GB/486.4 GB (94.0%)
3aed398eec82972b  origan   jupiter 500.0 GB  175  457.1 GB/490.7 GB (93.1%)  457.1 GB/490.7 GB (93.1%)
967786691f20bb79  caribou  neptune 500.0 GB  175  453.1 GB/490.8 GB (92.3%)  453.1 GB/490.8 GB (92.3%)

Estimated available storage space cluster-wide (might be lower in practice):
  data: 608.3 GB
  metadata: 608.3 GB
```

# Digging deeper

TID	State	Name	Tranq	Done	Queue	Errors	Consec	Last
1	Idle	Block resync worker #1	0	-	0	-	-	
2	Idle	Block resync worker #2	0	-	0	-	-	
3	Idle	Block resync worker #3	0	-	0	-	-	
4	Idle	Block resync worker #4	0	-	0	-	-	
5	Idle	Block resync worker #5	-	-	-	-	-	
6	Idle	Block resync worker #6	-	-	-	-	-	
7	Idle	Block resync worker #7	-	-	-	-	-	
8	Idle	Block resync worker #8	-	-	-	-	-	
9	Idle	Block scrub worker	4	-	-	-	-	
10	Idle	bucket v2 Merkle	-	-	0	-	-	
11	Idle	bucket_v2 sync	-	-	0	1	0	17 hours ago
12	Idle	bucket_v2 GC	-	-	0	-	-	
13	Idle	bucket_v2 queue	-	-	0	-	-	
14	Idle	bucket alias Merkle	-	-	0	-	-	
15	Idle	bucket alias sync	-	-	0	1	0	17 hours ago
16	Idle	bucket_alias GC	-	-	0	-	-	
17	Idle	bucket_alias queue	-	-	0	-	-	
18	Idle	key Merkle	-	-	0	-	-	
19	Idle	key sync	-	-	0	1	0	17 hours ago
20	Idle	key GC	-	-	0	-	-	
21	Idle	key queue	-	-	0	-	-	
22	Idle	object Merkle	-	-	0	-	-	
23	Idle	object sync	-	-	0	4	0	17 hours ago
24	Idle	object GC	-	-	0	-	-	
25	Idle	object queue	-	-	0	-	-	
26	Idle	bucket_object_counter Merkle	-	-	0	-	-	
27	Idle	bucket_object_counter sync	-	-	0	4	0	17 hours ago
28	Idle	bucket_object_counter GC	-	-	0	-	-	
29	Idle	bucket object counter queue	-	-	0	-	-	
30	Idle	multipart upload Merkle	-	-	0	-	-	
31	Idle	multipart upload sync	-	-	0	5	0	17 hours ago
32	Idle	multipart_upload GC	-	-	0	-	-	
33	Idle	multipart_upload queue	-	-	0	-	-	
34	Idle	bucket_mpu_counter Merkle	-	-	0	-	-	
35	Idle	bucket_mpu_counter sync	-	-	0	-	-	
36	Idle	bucket_mpu_counter GC	-	-	0	-	-	
37	Idle	bucket_mpu_counter queue	-	-	0	-	-	
38	Idle	version Merkle	-	-	0	-	-	
39	Idle	version sync	-	-	0	50	0	17 hours ago
40	Idle	version GC	-	-	0	-	-	
41	Idle	version queue	-	-	0	-	-	
42	Idle	block_ref Merkle	-	-	0	-	-	
43	Idle	block_ref sync	-	-	0	45	0	17 hours ago
44	Idle	block_ref GC	-	-	0	-	-	
45	Idle	block_ref queue	-	-	0	-	-	
46	Idle	object lifecycle worker	-	-	-	-	-	

# Digging deeper

```
$ garage worker get
8073f25ffb7d6944 lifecycle-last-completed 2024-01-23
8073f25ffb7d6944 resync-tranquility 1
8073f25ffb7d6944 resync-worker-count 4
8073f25ffb7d6944 scrub-corruptions_detected 0
8073f25ffb7d6944 scrub-last-completed 2023-12-27T13:49:33.234Z
8073f25ffb7d6944 scrub-next-run 2024-01-31T03:23:02.234Z
8073f25ffb7d6944 scrub-tranquility 4

$ garage worker get -a resync-tranquility
3aed398eec82972b resync-tranquility 1
76797283f6c7e162 resync-tranquility 1
8073f25ffb7d6944 resync-tranquility 1
967786691f20bb79 resync-tranquility 1
ec5753c546756825 resync-tranquility 1
```

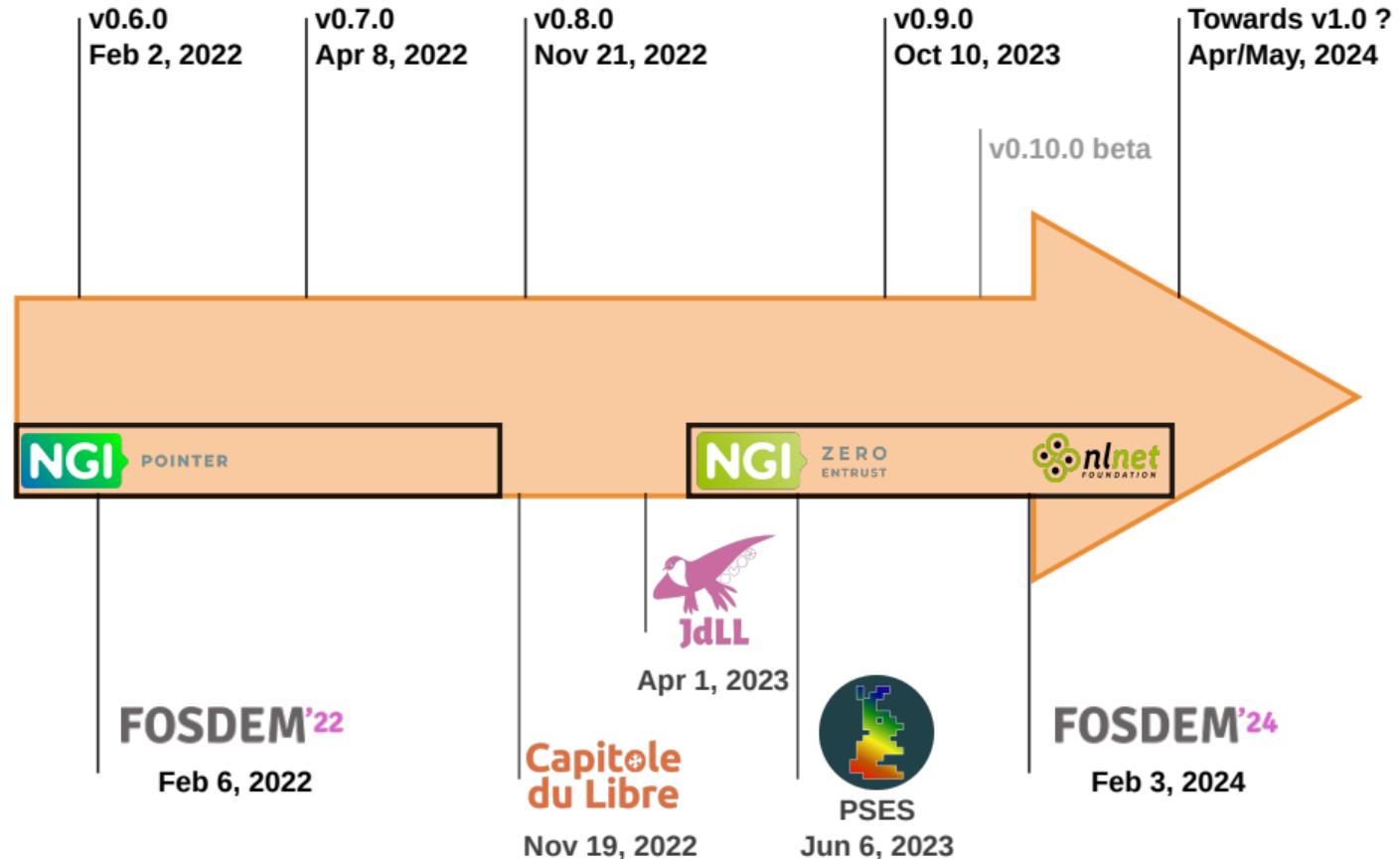
# Potential limitations and bottlenecks

- ▶ 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

# Deployment advice for very large clusters

- ▶ Metadata storage:
  - ▶ ZFS mirror (x2) on fast NVMe
  - ▶ Use LMDB storage engine
- ▶ Data block storage:
  - ▶ Use Garage's native multi-HDD support
  - ▶ XFS on individual drives
  - ▶ Increase block size (1MB → 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

## Recent developments

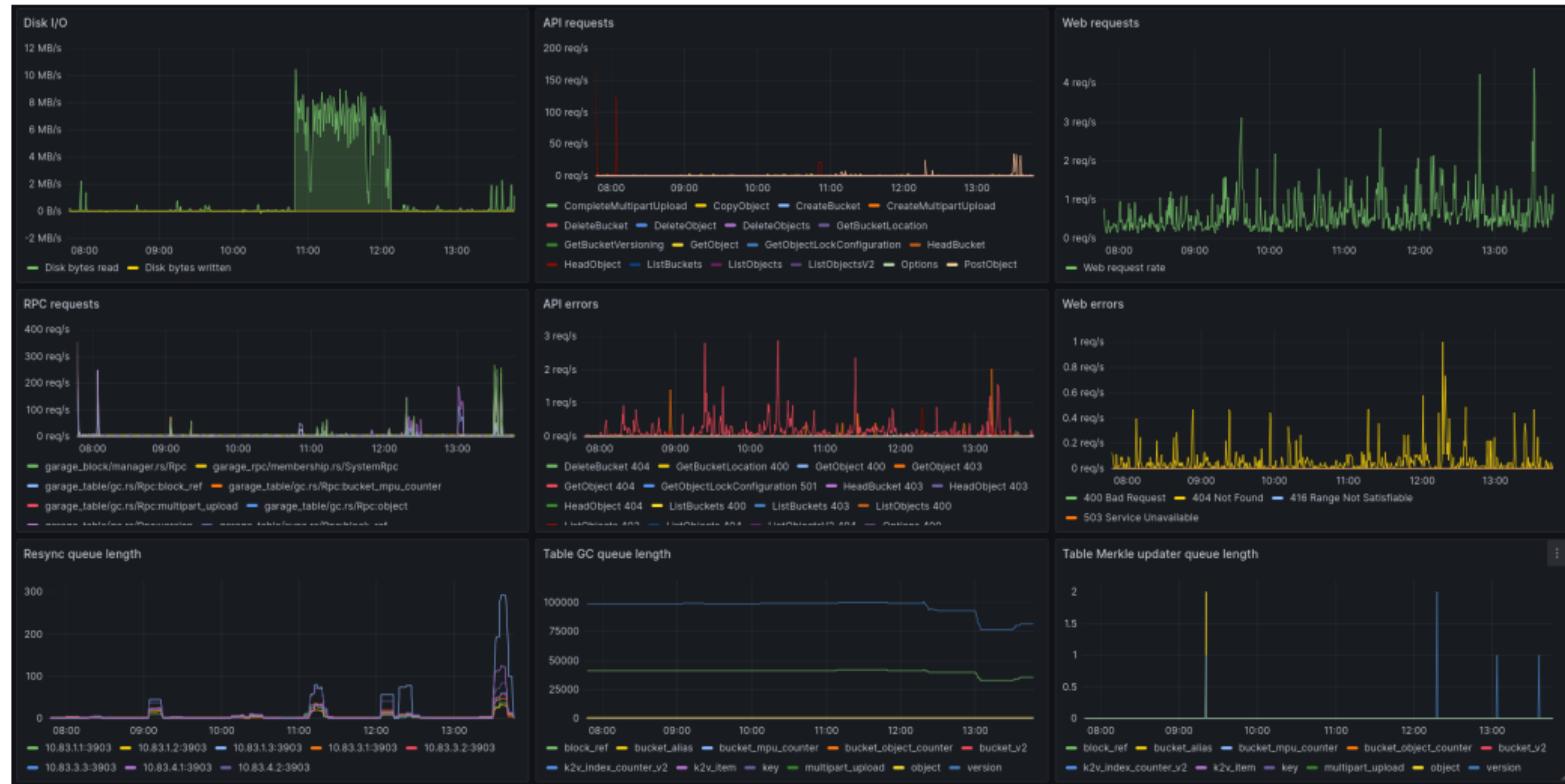


# April 2022 - Garage v0.7.0

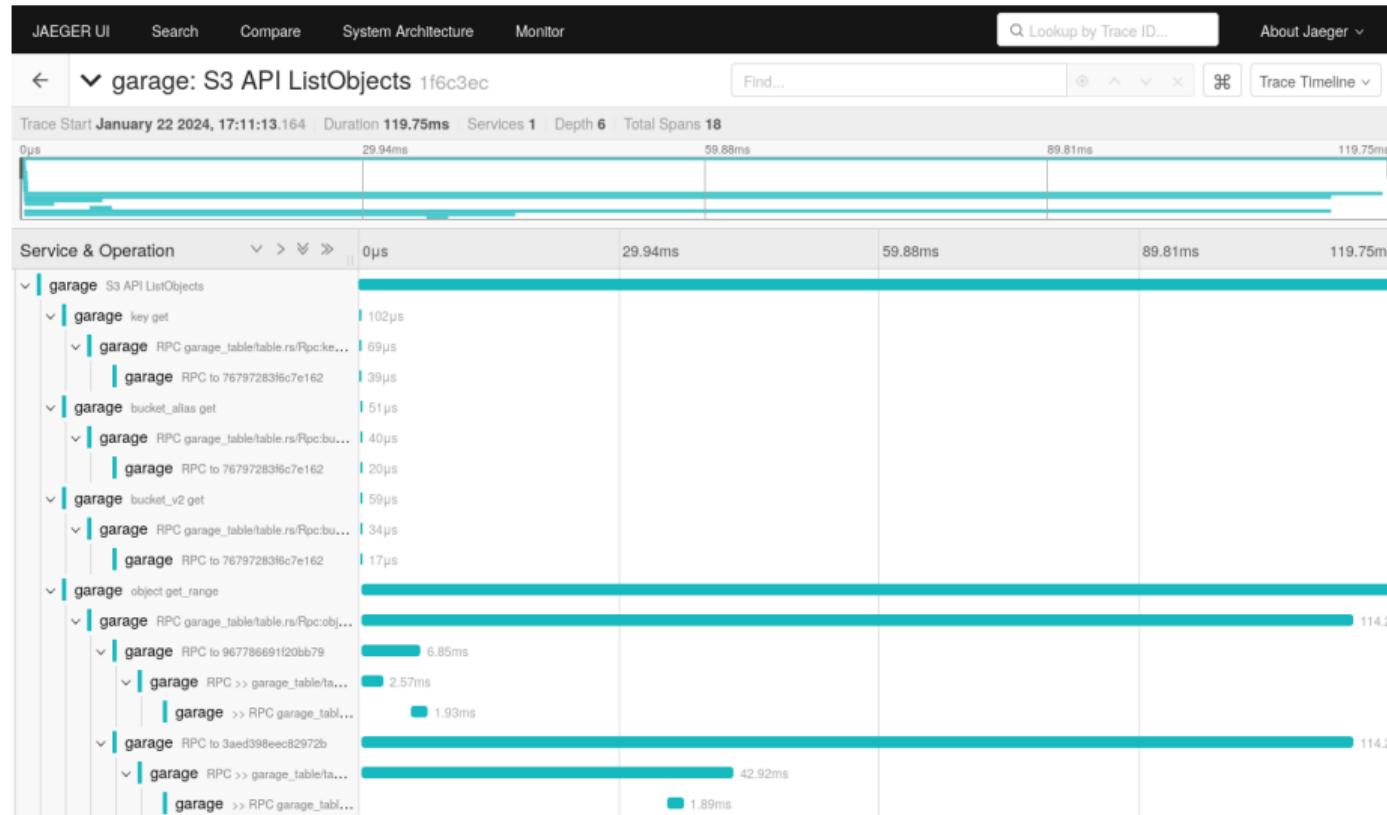
Focus on observability and ecosystem integration

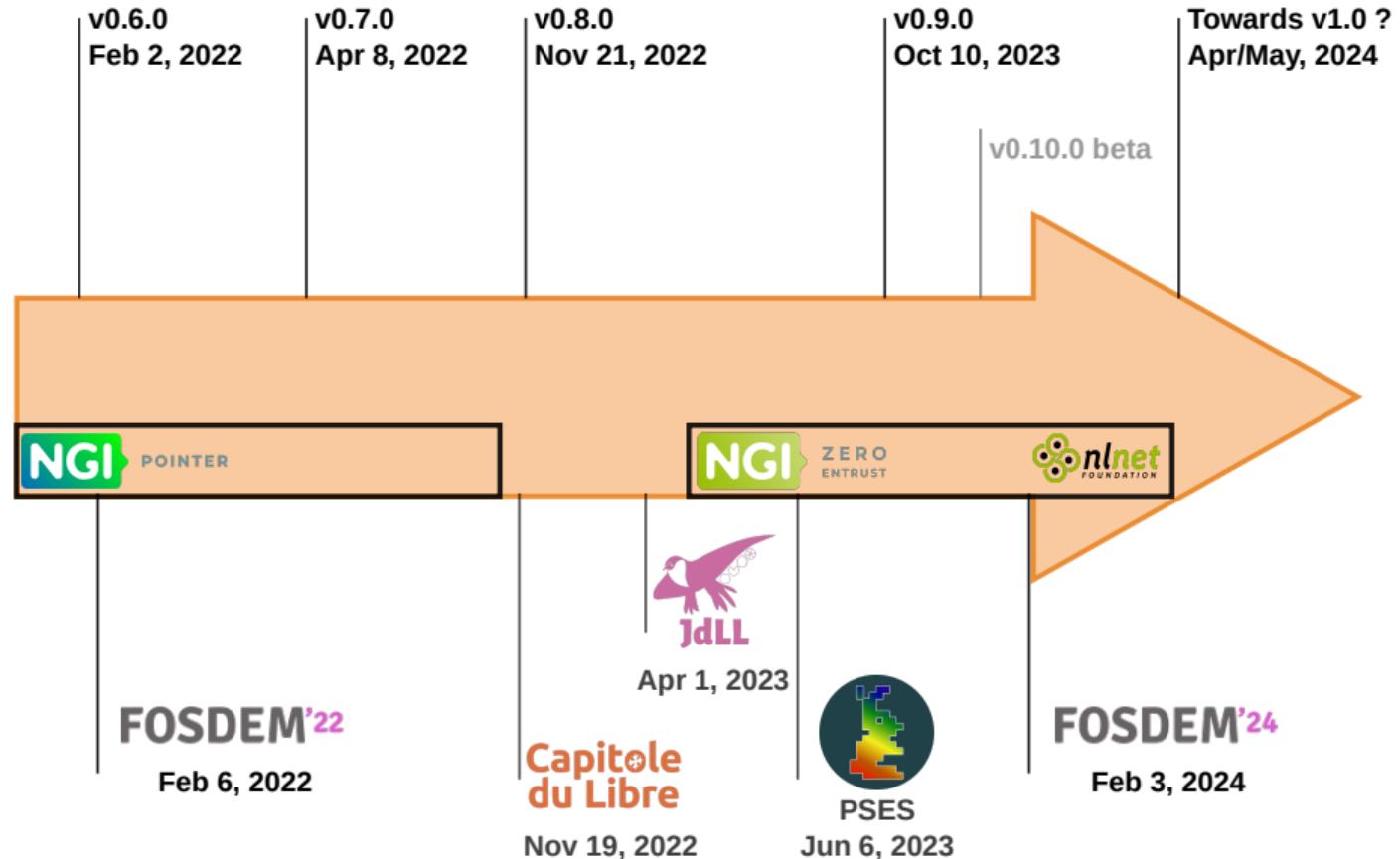
- ▶ **Monitoring:** metrics and traces, using OpenTelemetry
- ▶ Replication modes with 1 or 2 copies / weaker consistency
- ▶ Kubernetes integration for node discovery
- ▶ Admin API (v0.7.2)

# 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, file size is reasonable

**Sqlite** also available as a second choice

Sled will be removed in Garage v1.0

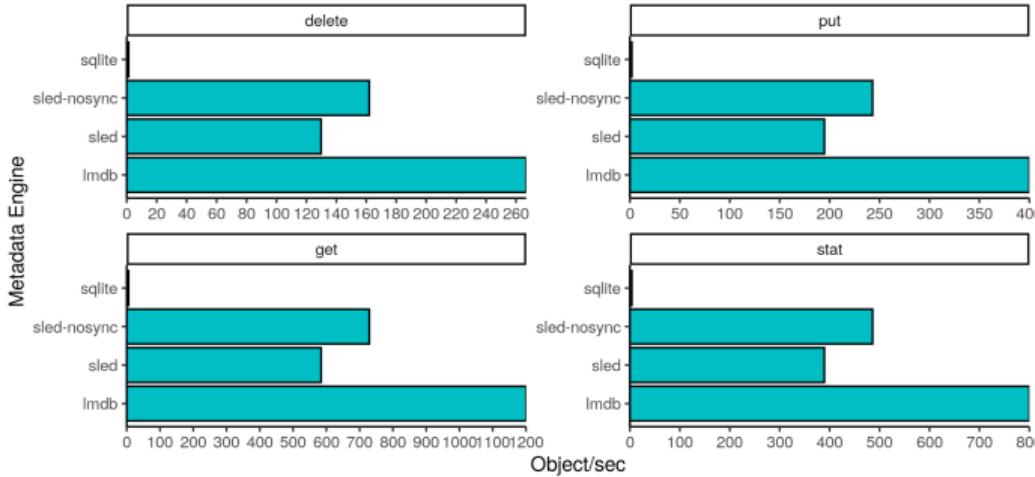
# DB engine performance comparison

## Comparison of Garage's metadata engines with "minio/warp"

Daemon: Garage v0.8 no-fsync to avoid being impacted by block manager

Benchmark: warp, mixed mode, 5min bench, 256B objects, initialized with 200 objects.

Environment: mknet (Ryzen 5 1400, 16GB RAM, SSD). DC topo (3 nodes, 1Gb/s, 1ms latency).

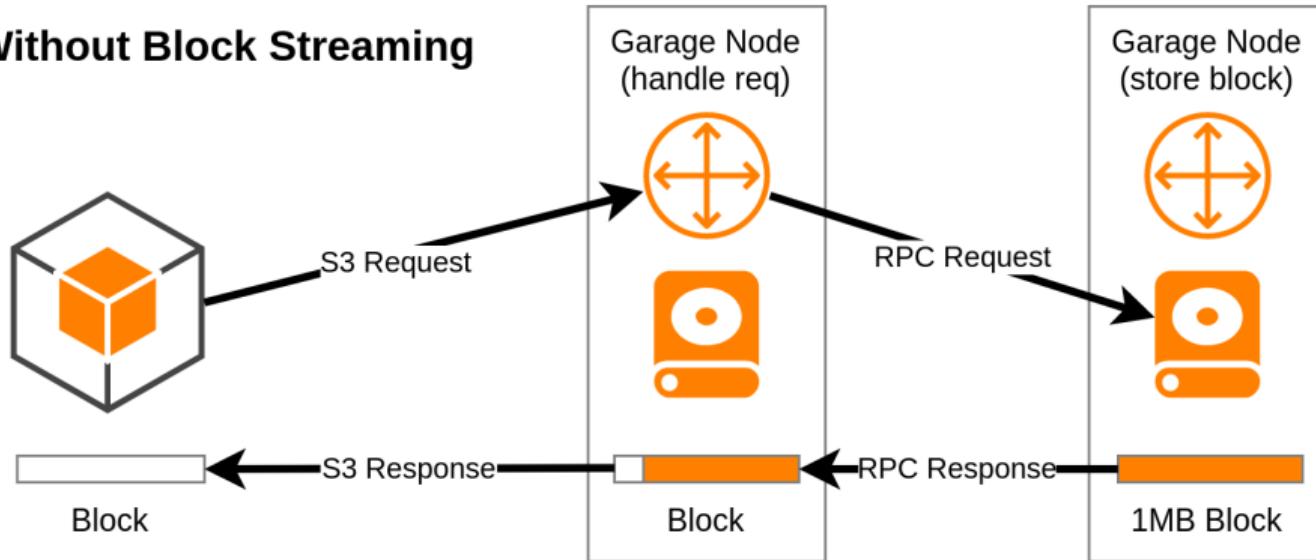


Get the code to reproduce this graph at <https://git.deuxfleurs.fr/Deuxfleurs/mknet>

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

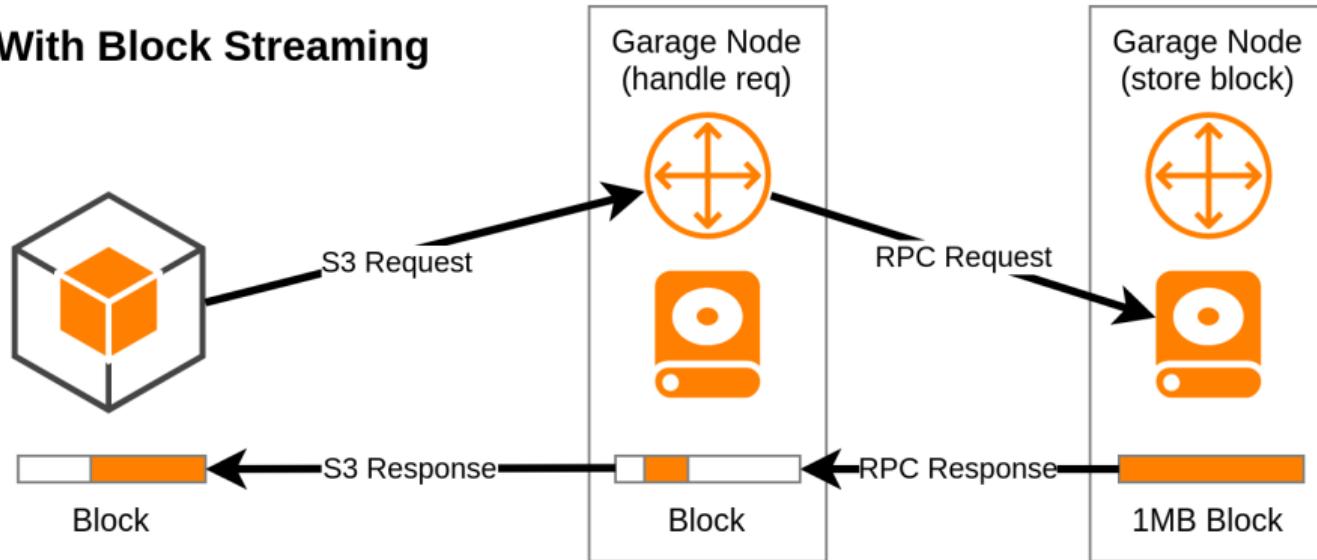
# Block streaming

## Without Block Streaming



# Block streaming

## With Block Streaming

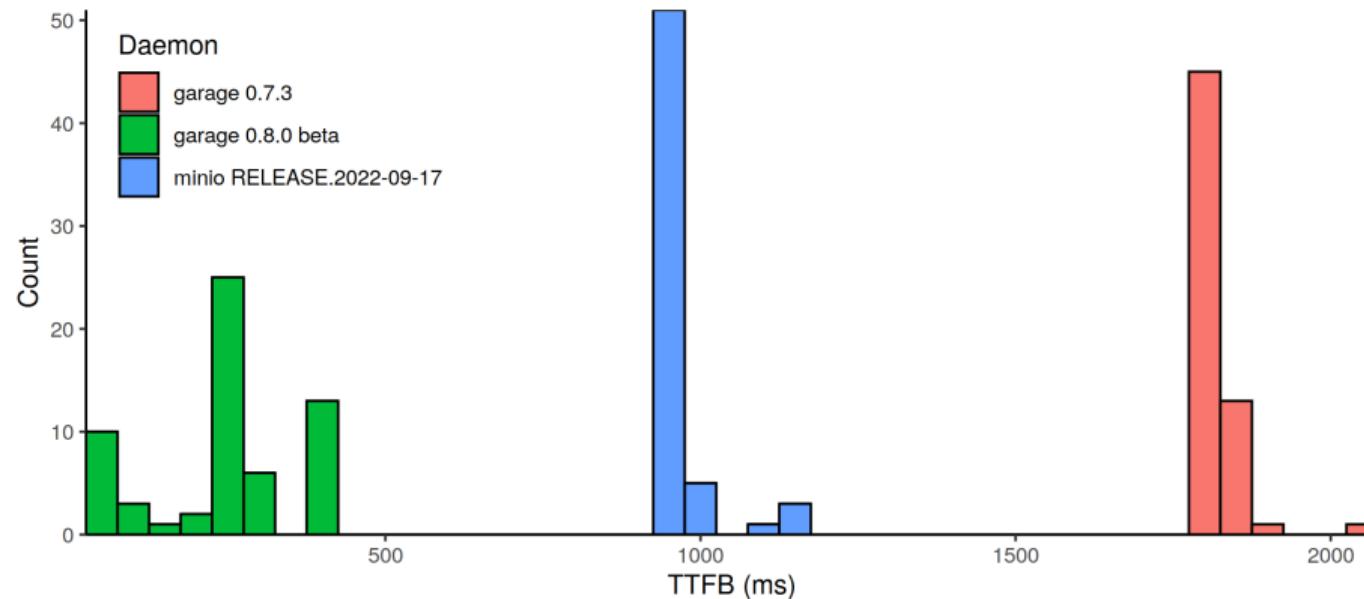


# TTFB benchmark

TTFB (Time To First Byte) on GetObject over a slow network (5 Mbps, 500  $\mu$ s)

A 1MB file is uploaded and then fetched 60 times.

Except for Minio, the queried node does not store any data (gateway) to force net. communications.



Get the code to reproduce this graph at <https://git.deuxfleurs.fr/Deuxfleurs/mknet>

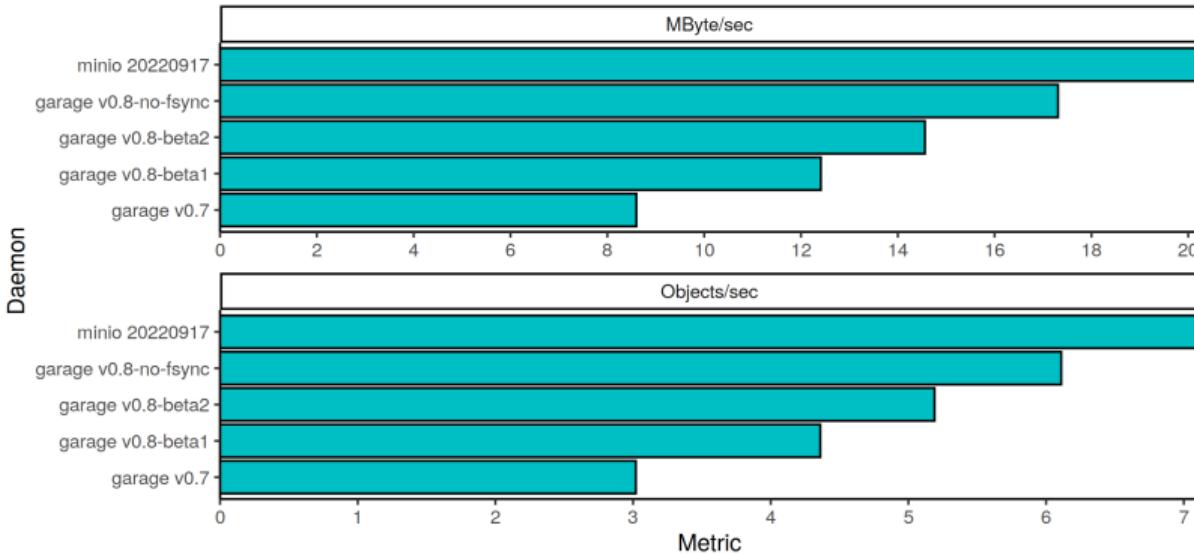
# Throughput benchmark

"minio/warp" benchmark, "cluster total" result

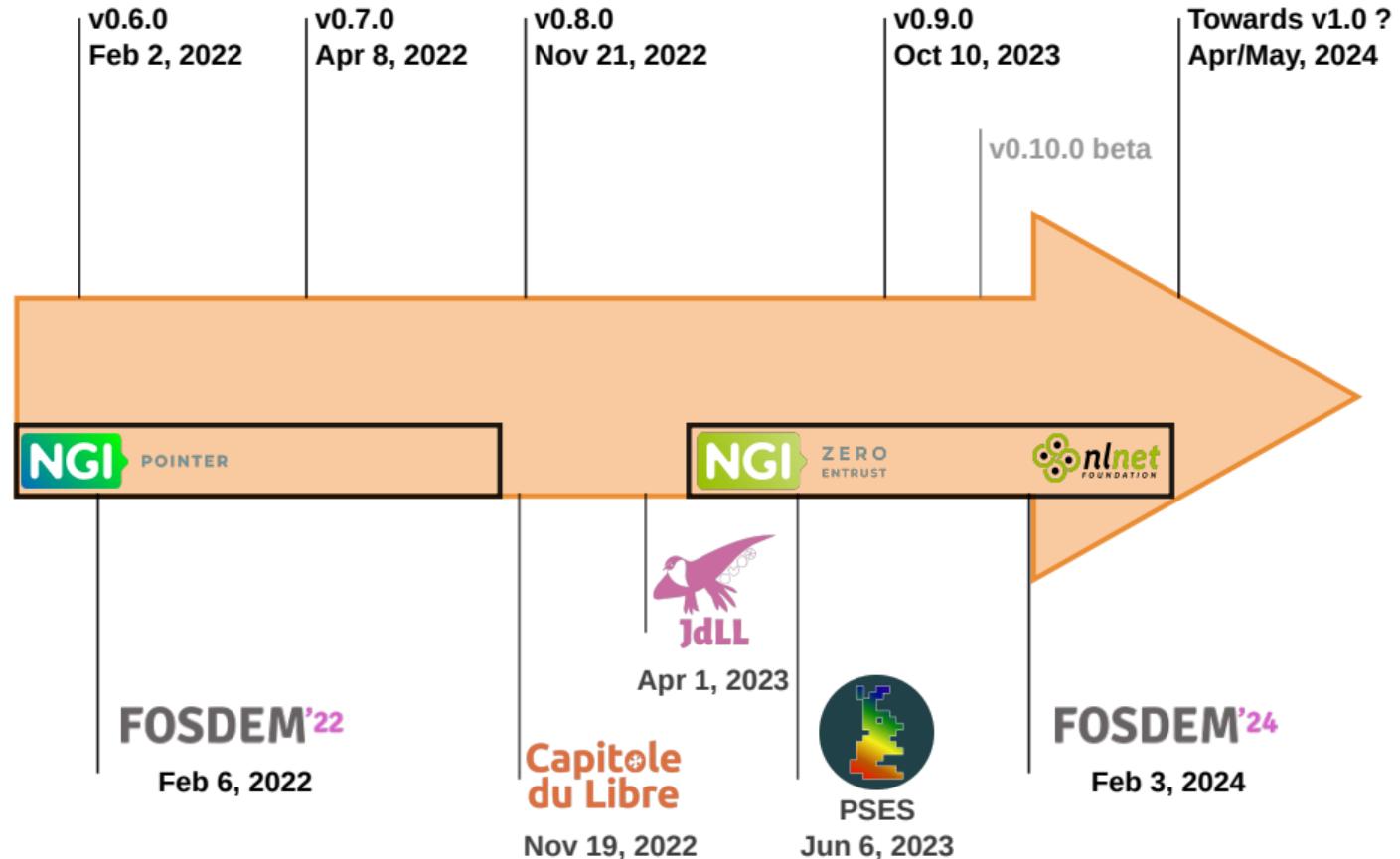
Ran on a local machine (Ryzen 5 1400, 16GB RAM, SSD) with mknet

DC topology (3 nodes, 1GB/s, 1ms lat)

warp in mixed mode, 5min bench, 5MB objects, initialized with 200 objects



Get the code to reproduce this graph at <https://git.deuxfleurs.fr/Deuxfleurs/mknet>



# 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

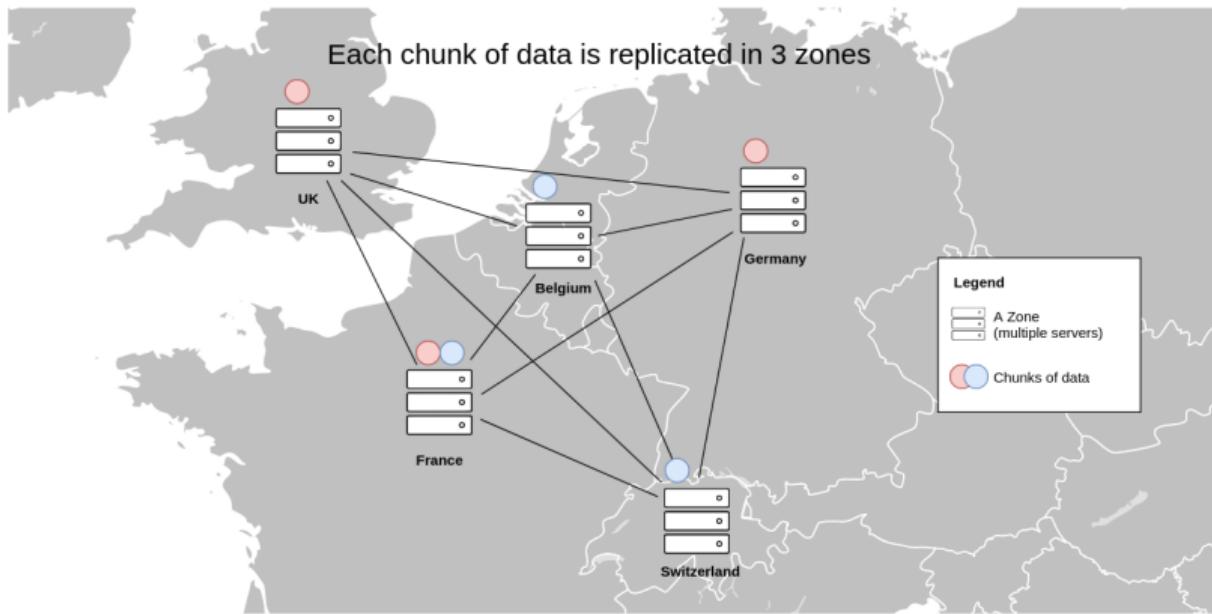
```
[root@celeri:/home/lx]# docker exec -ti e338 /garage status
```

```
==== HEALTHY NODES ====
```

ID	Hostname	Address	Tags	Zone	Capacity
5fcb3b6e39db3dcb	concombre	[2001:470:ca43::31]:3901	[concombre,neptune,france,alex]	neptune	500.0 GB
942dd71ea95f4904	df-ymf	[2a02:a03f:6510:5102:6e4b:90ff:fe3a:6174]:3901	[df-ymf,bespin,belgium,max]	bespin	500.0 GB
fdfaff7832d8359e0	df-ymk	[2a02:a03f:6510:5102:6e4b:90ff:fe3b:e939]:3901	[df-ymk,bespin,belgium,max]	bespin	500.0 GB
0a03ab7c082ad929	ananas	[2a01:e0a:e4:2dd0::42]:3901	[ananas,scorpio,france,adrien]	scorpio	2.0 TB
a717e5b618267806	courgette	[2001:470:ca43::32]:3901	[courgette,neptune,france,alex]	neptune	500.0 GB
2032d0a37f249c4a	abricot	[2a01:e0a:e4:2dd0::41]:3901	[abricot,scorpio,france,adrien]	scorpio	2.0 TB
8cf284e7df17d0fd	celeri	[2001:470:ca43::33]:3901	[celeri,neptune,france,alex]	neptune	2.0 TB
17ee03c6b81d9235	df-ykl	[2a02:a03f:6510:5102:6e4b:90ff:fe3b:e86c]:3901	[df-ykl,bespin,belgium,max]	bespin	500.0 GB

Garage stores replicas on different zones when possible

# Layout computation



Garage stores replicas on different zones when possible

## What a "layout" is

A layout is a precomputed index table:

Partition	Node 1	Node 2	Node 3
Partition 0	df-ymk (bespin)	Abricot (scorpio)	Courgette (neptune)
Partition 1	Ananas (scorpio)	Courgette (neptune)	df-ykl (bespin)
Partition 2	df-ymf (bespin)	Celeri (neptune)	Abricot (scorpio)
:	:	:	:
Partition 255	Concombre (neptune)	df-ykl (bespin)	Abricot (scorpio)

## What a "layout" is

A layout is a precomputed index table:

Partition	Node 1	Node 2	Node 3
Partition 0	df-ymk (bespin)	Abricot (scorpio)	Courgette (neptune)
Partition 1	Ananas (scorpio)	Courgette (neptune)	df-ykl (bespin)
Partition 2	df-ymf (bespin)	Celeri (neptune)	Abricot (scorpio)
:	:	:	:
Partition 255	Concombre (neptune)	df-ykl (bespin)	Abricot (scorpio)

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

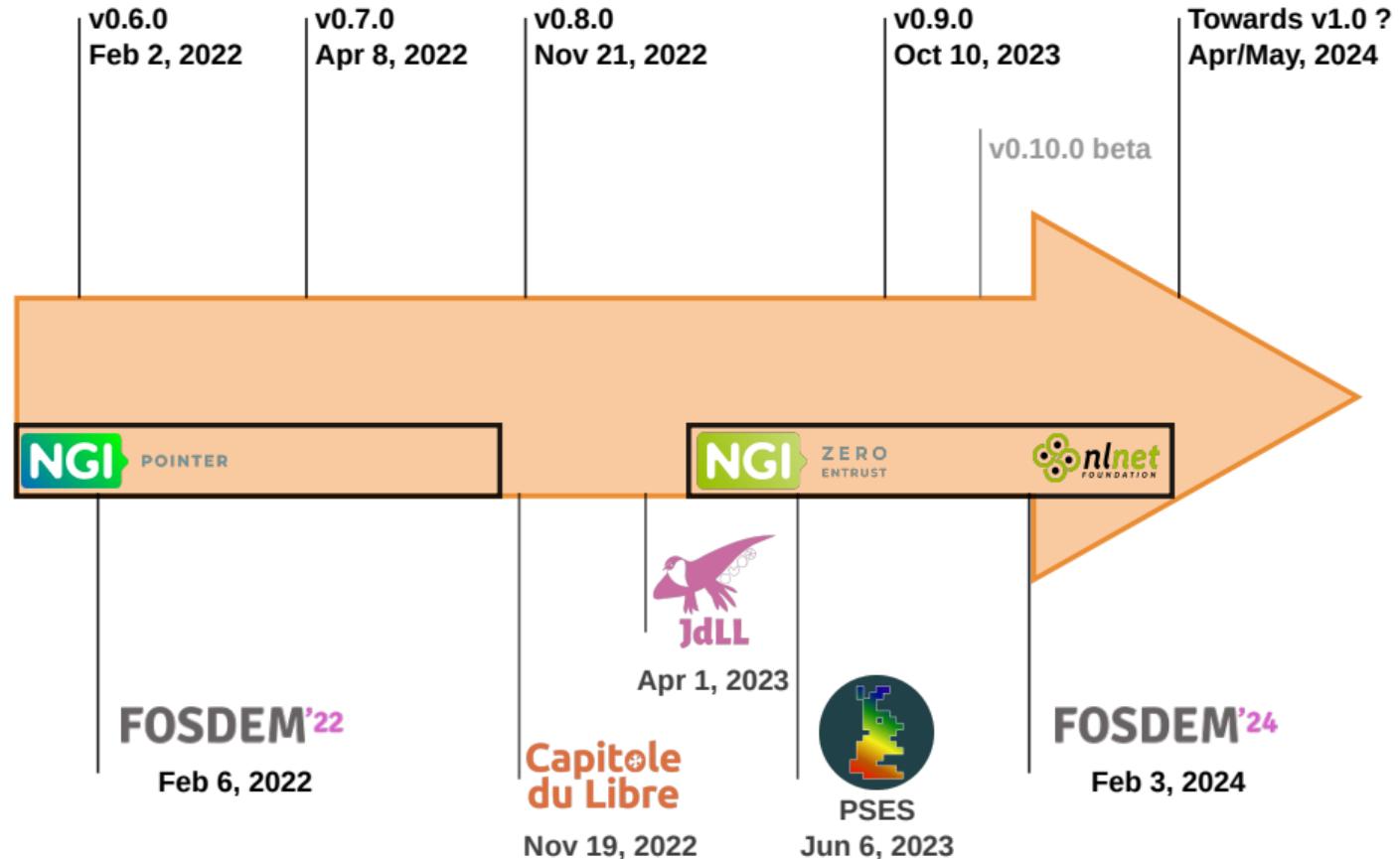
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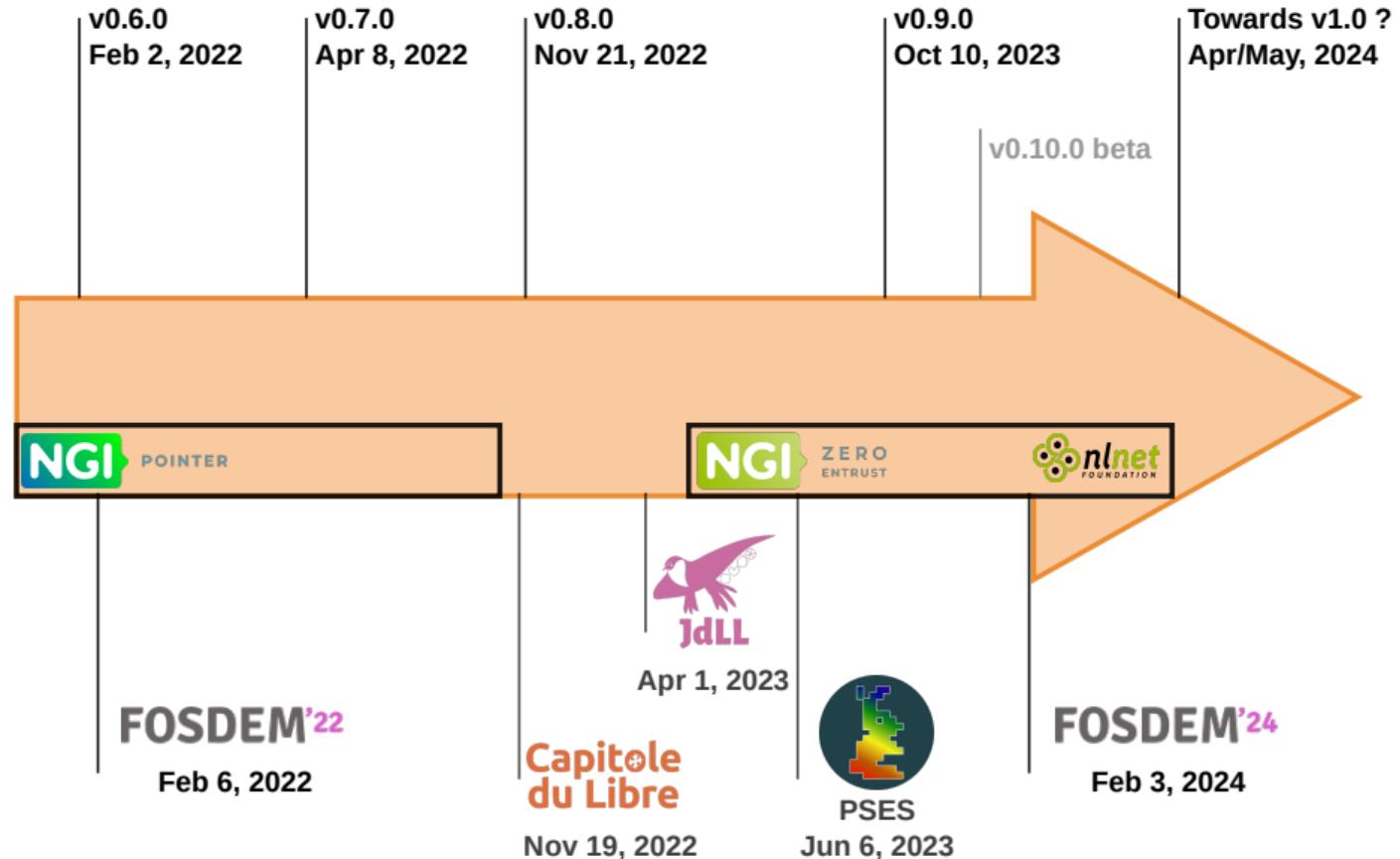
Oulamara, M., & Auvolat, A. (2023). *An algorithm for geo-distributed and redundant storage in Garage*. arXiv preprint arXiv:2302.13798.



# April 2024 - Garage v1.0.0

Focus on consistency, security & stability

- ▶ Fix consistency issues when reshuffling data (Jepsen testing)
- ▶ **Security audit** by Radically Open Security
- ▶ Misc. S3 features (SSE-C, checksums, ...) and compatibility fixes



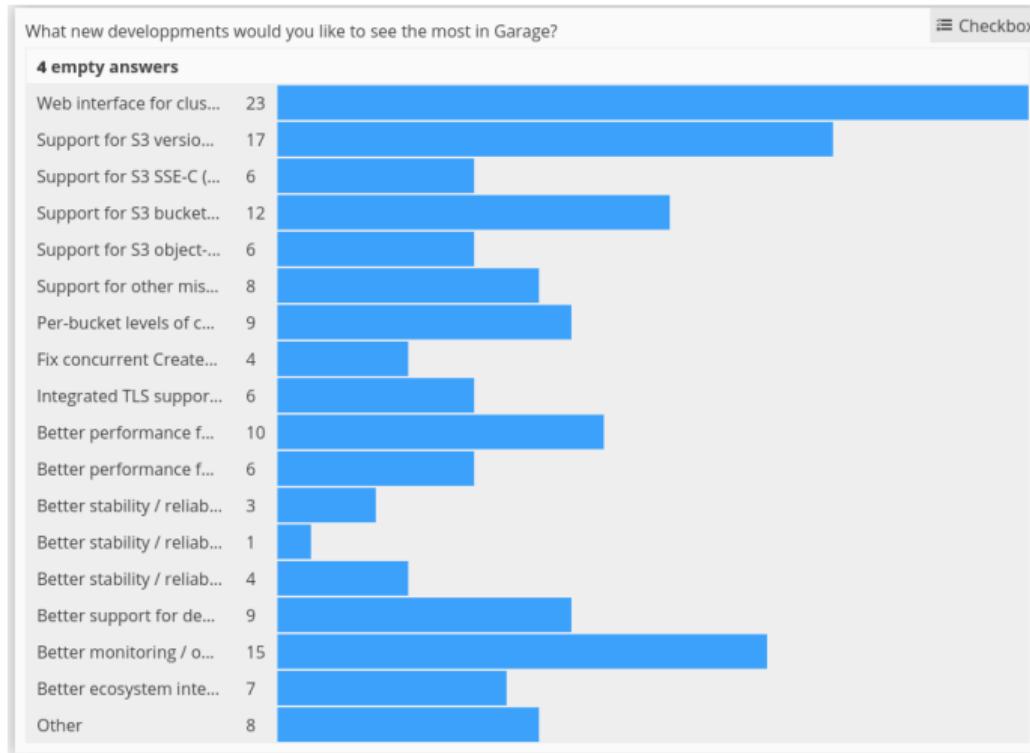
# Garage v2.0.0

Focus on

Currently funding...

...

# Our backlog



## Where to find us



# Garage

<https://garagehq.deuxfleurs.fr/>

<mailto:garagehq@deuxfleurs.fr>

#garage:deuxfleurs.fr on Matrix

