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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Why is it hard?

Resilience

we want good uptime/availability with low supervision

Our very low-tech infrastructure

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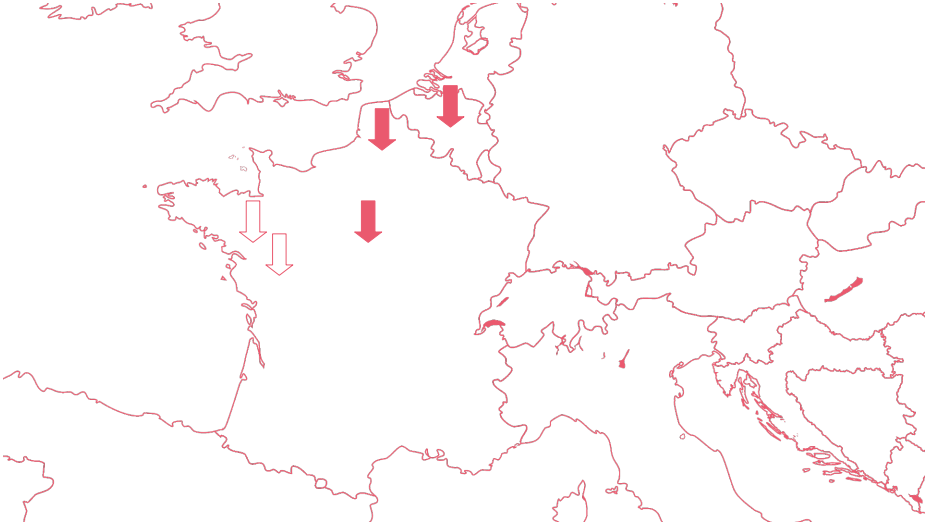
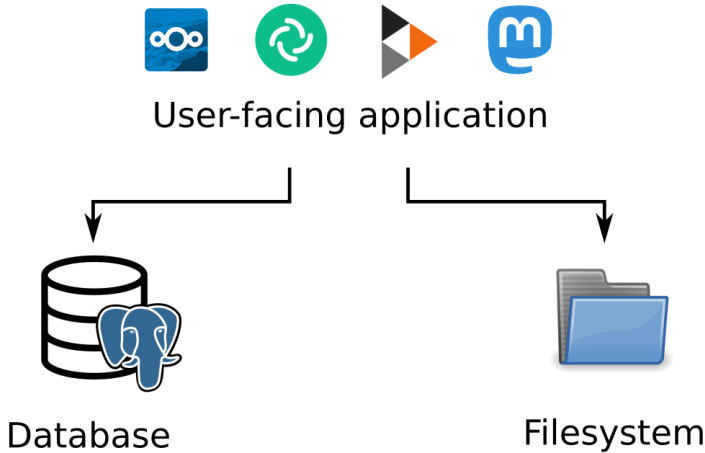
- **Geographical redundancy** (multi-site replication)

Our very low-tech infrastructure



How to make this happen



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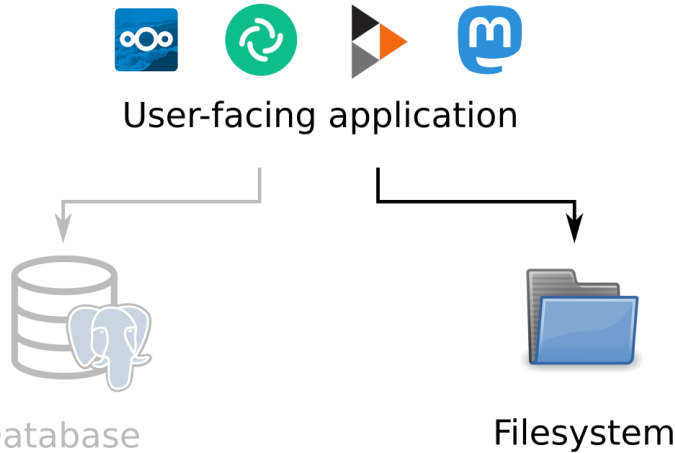

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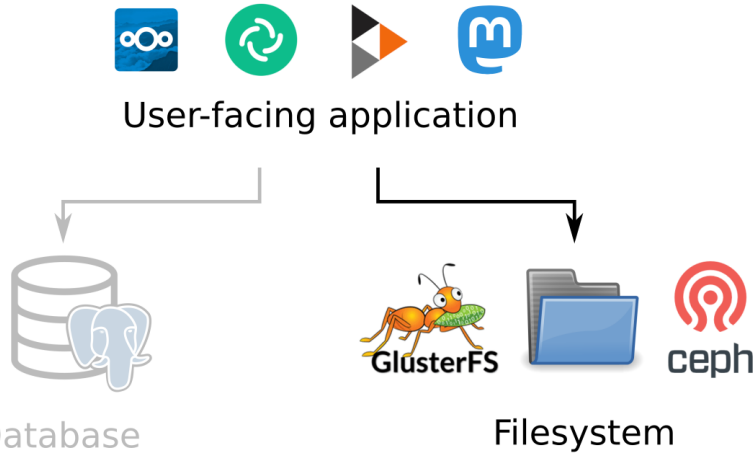

Distributed file systems are slow

File systems are complex, for example:

- Concurrent modification by several processes
- Folder hierarchies
- Other requirements of the POSIX spec (e.g. locks)

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!

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

Principle 1: based on CRDTs

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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  - **Sensitive to higher latency** between nodes

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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`
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`download/index.html`	`Content-Type: text/html; charset=utf-8`
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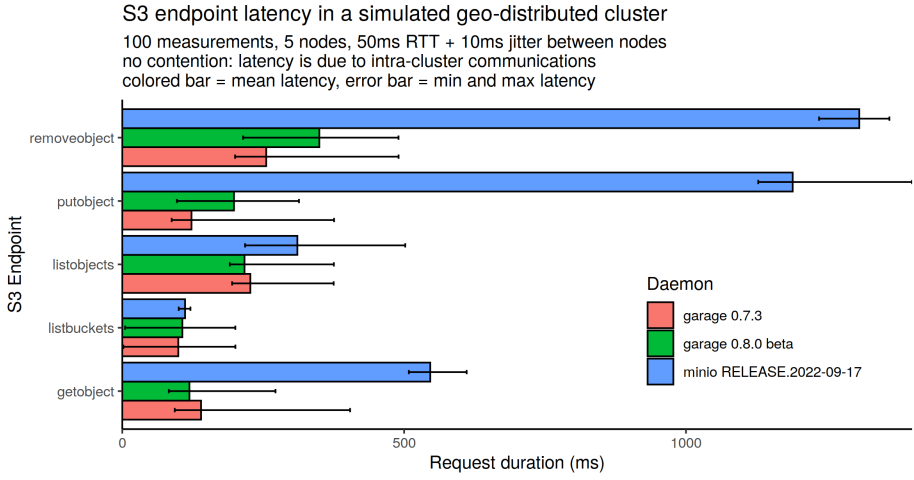
- Maps well to CRDT data types
- Read-after-write consistency with quorums

Performance gains in practice



Principle 2: geo-distributed data model

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

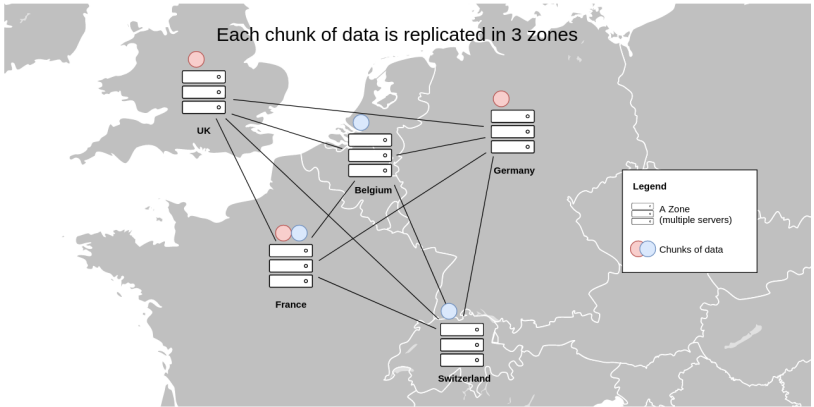
Partition key: bucket	Sort key: filename	Value
website	index.html	(file data)
website	img/logo.svg	(file data)
website	download/index.html	(file data)
backup	borg/index.2822	(file data)
backup	borg/data/2/2329	(file data)
backup	borg/data/2/2680	(file data)
private	qq3a2nbe1qjq0ebbvo6ocsp6co	(file data)

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
fdfaf7832d8359e0  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,scopio,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)

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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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Partition 255	Concombre (neptune)	df-ykl (bespin)	Abricot (scorpio)

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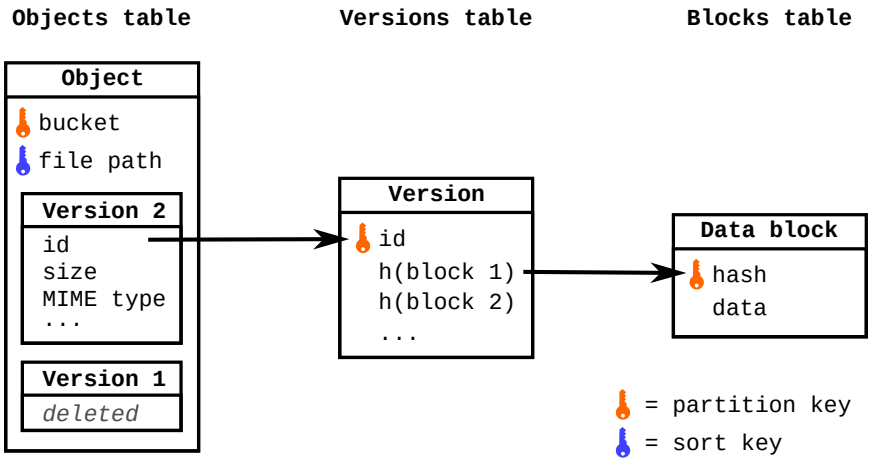
Oulamara, M., & Auvolat, A. (2023). *An algorithm for geo-distributed and redundant storage in Garage*. arXiv preprint arXiv:2302.13798.

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



Operating Garage clusters

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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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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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
```
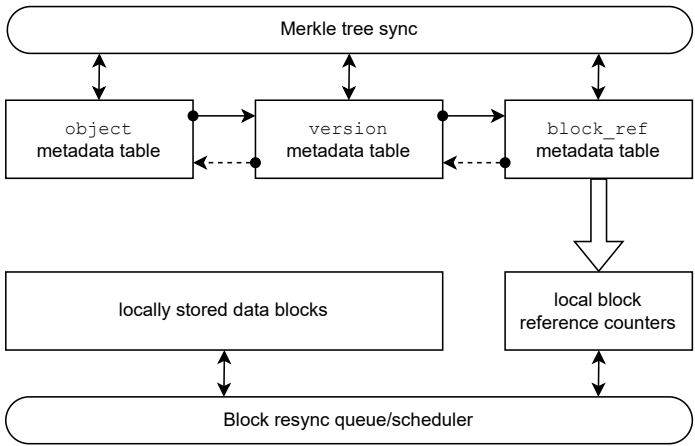

Background synchronization



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
```

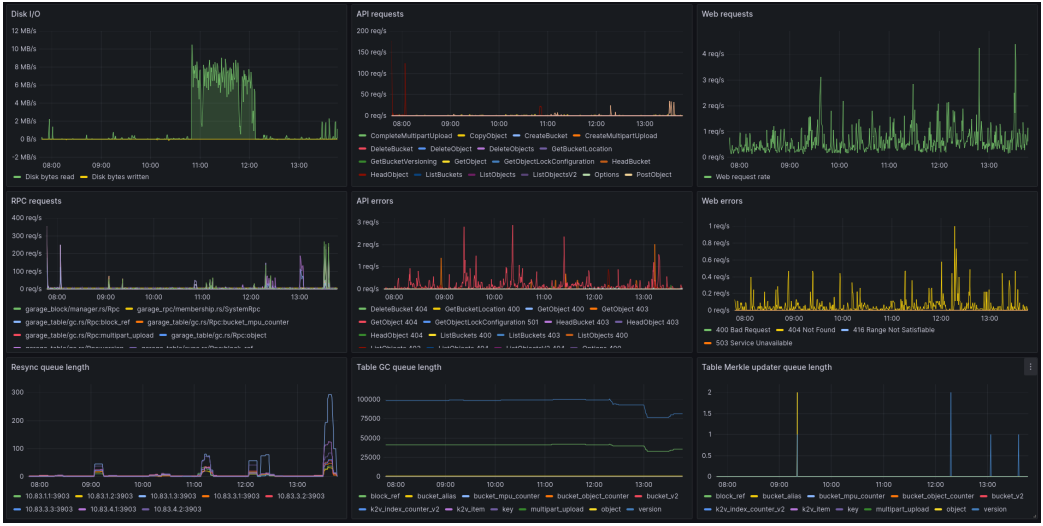
Digging deeper

```
$ garage worker list
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       -      -     -      -       -
```

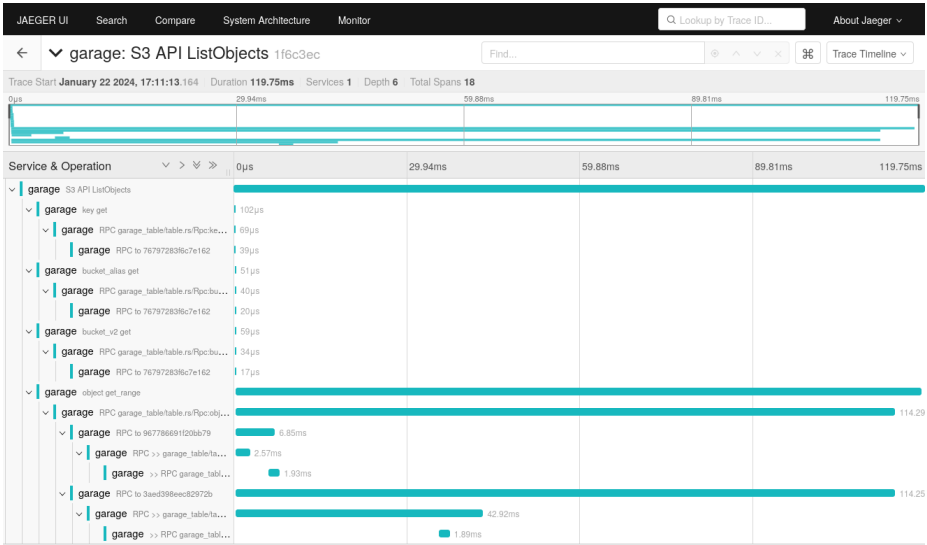
Digging deeper

```
$ 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
```

Monitoring with Prometheus + Grafana



Debugging with traces



Scaling Garage clusters

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 $\rightarrow$ 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

Our deployments: $<$ 10 TB. Some people have done more!

Where to find us

Garage

https://garagehq.deuxfleurs.fr/

mailto:garagehq@deuxfleurs.fr

#garage:deuxfleurs.fr on Matrix