# Distributed object storage is centralised

## A quest for autonomy in the modern hosting ecology

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# A very casual motivation

I want to host **resilient web services** with **acceptable performance** on commodity hardware behind **household networks**.

## Keywords

- Decentralised networks
- Edge computing
- Distributed storage
- Privacy

# Context

**Resilience**: Ability to recover quickly from failures and changes.

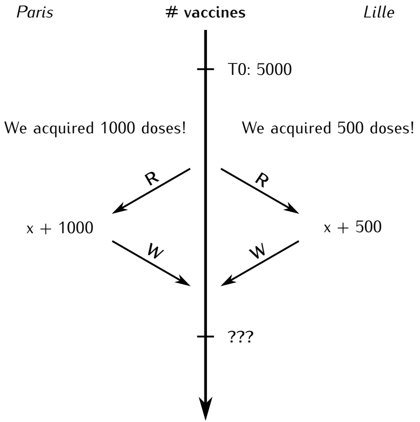
Only achievable through distribution of the hosted applications across several physical locations.

**Application = computations on data**

- **Computation**: Stateless; easy to distribute & orchestrate.
- **Data**: Stateful; hard to distribute & full of trade-offs.

# Concurrent writes example

How to lose vaccines



# The problem

Can we design an available data store tailored for adverse network conditions?

# The CAP theorem



## Eric Brewer's theorem

"A shared-state system can have **at most two** of the following properties at any given time:

- **C**onsistency
- **A**vailability
- **P**artition tolerance"

Under network partitions, a distributed data store has to sacrifice either availability or consistency.

- **Consistency-first**: Abort incoming queries;
- **Availability-first**: Return possibly stale data.

# Consistency-first: the ACID model



**Transaction**: unit of work within an ACID data store.

- **Atomicity**: Transactions either complete entirely or fail. No transaction ever seen as in-progress.
- **Consistency**: Transactions always generate a valid state. The database maintains its invariants across transactions.
- **Isolation**: Concurrent transactions are seen as sequential. Transactions are serializable, or sequentially consistent.
- **Durability**: Committed transactions are never forgotten.

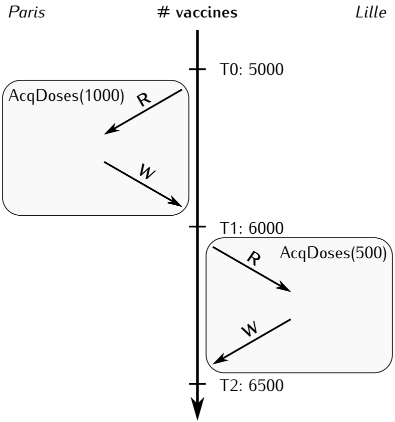
Reads are fast, writes are slow.

Example: relational databases.

# Concurrent writes in ACID



```
transaction AcqDoses(y):
  x <- SELECT #vaccines;
  UPDATE #vaccines = (x + y);
```




Supports compound operations.

# Availability-first: the BASE model



Some apps prefer availability, e.g. Amazon products' reviews.

The BASE model trades Consistency & Isolation for Availability.

- **Basic Availability**: The data store thrives to be available.
- **Soft-state**: Replicas can disagree on the valid state.
- **Eventual consistency**: In the absence of write queries, the data store will eventually converge to a single valid state.

Writes are fast, reads are slow.

Examples: key-value & object stores.

# Concurrent writes in BASE

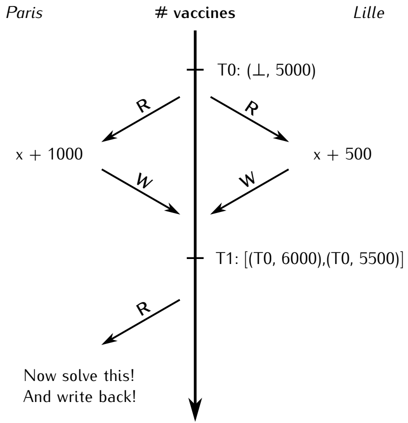


**Object**

- Unique key
- Arbitrary value
- Metadata

Conflict resolution = client's job!

No compound operations.



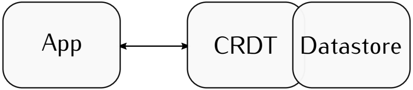
# Strong Eventual Consistency w/ CRDTs



M. Shapiro et al. “Conflict-Free Replicated Data Types”. In: *Stabilization, Safety, and Security of Distributed Systems*. Berlin, Heidelberg, 2011

## Strong Eventual Consistency (SEC)

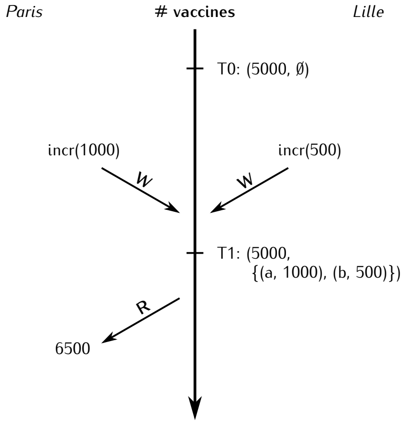
- CRDTs specify distributed operations
- Conflicts will be solved according to specification
- Proven & bound eventual convergence



# Concurrent writes with CRDTs



```
CRDT Counter(x0):
  history = {}
  op. incr(y):
    history ∪= {(UUID(), y)}
  op. decr(y):
    history ∪= {(UUID(), −y)}
  op. read():
    x = x0
    for (_, y) in history:
        x += y
    return x
```




Operations commute?
$\implies$ screw total order!

# A complex CRDT: the DAG



payload set $V$, $A$ -- *sets of pairs* { (element $e$, unique-tag $w$), ... }
  initial $\varnothing, \varnothing$ -- *$V$: vertices; $A$: arcs*
query *lookup* (vertex $v$) : boolean b
  let $b = (\exists w : (v, w) \in V)$
query *lookup* (arc $(v', v'')$) : boolean b
  let $b = (lookup(v') \wedge lookup(v'') \wedge (\exists w : ((v', v''), w) \in A)$
update *addVertex* (vertex $v$)
  prepare $(v)$ : $w$
    let $w = unique()$ -- *$unique()$ returns a unique value*
  effect $(v, w)$
    $V := V \cup \{(v, w)\}$ -- *$v$ + unique tag*
update *removeVertex* (vertex $v$)
  prepare $(v)$ : $R$
    pre $lookup(v)$ -- *precondition*
    pre $\nexists v' : lookup((v, v'))$ -- *$v$ is not the head of an existing arc*
    let $R = \{(v, w) | \exists w : (v, w) \in V\}$ -- *Collect all unique pairs in $V$ containing $v$*
  effect $(R)$
    $V := V \setminus R$
update *addArc* (vertex $v'$, vertex $v''$)
  prepare $(v', v'')$ : $w$
    pre $lookup(v')$ -- *head node must exist*
    let $w = unique()$ -- *$unique()$ returns a unique value*
  effect $(v', v'', w)$
    $A := A \cup \{((v', v''), w)\}$ -- *$(v', v'')$ + unique tag*
update *removeArc* (vertex $v'$, vertex $v''$)
  prepare $(v', v'')$ : $R$
    pre $lookup((v', v''))$ -- *$arc(v', v'')$ exists*
    let $R = \{((v', v''), w) | \exists w : ((v', v''), w) \in A\}$
  effect $(R)$ -- *Collect all unique pairs in $A$ containing arc $(v', v'')$*
    $A := A \setminus R$

# A complex CRDT: the DAG



Just to say I swept a lot under the rug.

For details, go read:
M. Shapiro et al. "Conflict-Free Replicated Data Types". In: *Stabilization, Safety, and Security of Distributed Systems.* Berlin, Heidelberg, 2011

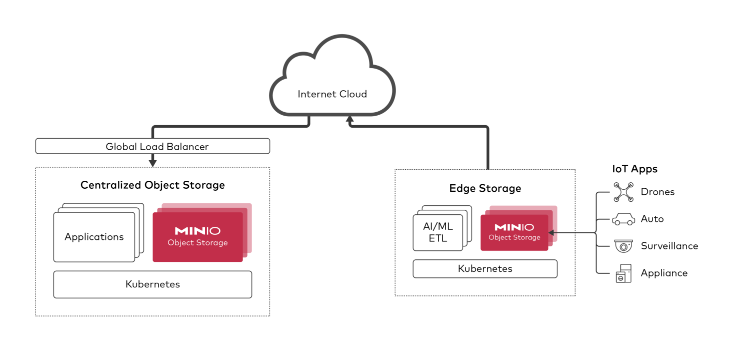
For an implementation, check **AntidoteDB**.

# State of the practice

Path dependency to the “cloud”

## The BASE model is fashionable because

“*High-performance* object storage for *AI analytics* with PBs of *IoT data streams* at the *edge*, using *5G*.”




- Always backed by cloud: high performance network links.
- Edge nodes always seen as clients or data sources, not peers.

# Why?

- **Privacy**: no prying eyes besides your ISP
- **Control** of your infrastructure
- **Ecology**: reuse old hardware

*Tim Berners-Lee* (1994)

"Now, if someone tries to monopolize the Web, for example pushes proprietary variations on network protocols, then that would make me unhappy."

- Make Tim Berners-Lee happy

# What?

A data store for commodity hardware on heterogenous household connections.

## Targetting user-facing services

- Static sites
- E-mails
- Instant communication
- Collaboration

Nothing fancy like sensors data streams, AI or IoT.

# What?

## Requirements

- **No single point of failure** / flat hierarchy:
  Any node can die for extended periods of time.
- **Multi-site**: cluster spans regions/countries.
- **Acceptable performance**.
- **Lightweight**: targets legacy hardware.
- **Conceptually simple**: built for low-tech organisations.
  Adding/maintaining cluster nodes should be easy.

## Non-goals

- **Super badass performance**.
- NAT **traversal** etc.: we require full-mesh connectivity.

# How?

- Theoretically possible with object storage & CRDTs.
- Household uplinks are getting decent (optical fibers).

# Research Questions

- Decent performance despite bad inter-node connectivity.
- Tailoring workloads as a function of nodes' capabilities:
  - Make use of low-end nodes (e.g. Raspberry Pis),
  - Avoid impeding global performance because of low-end nodes.
- Building CRDTs for target use-cases:
  - Software engineering: DSL or native code?
  - Provide APIs to data store users? Risky?
- Cluster management: effortless UX, low perf. overhead.

# Brought to you by the Deuxfleurs association

## **deuxfleurs.fr** – a libre hosting association with a vision

"Shifting the current structure of the Internet from a world of a few very large service providers, to a world where services are hosted by a variety of smaller organisations."

## Our goals

- To propose performant & reliable libre services for the masses
- To host and administer our infrastructure ourselves
- To allow members to contribute storage/compute nodes
- Resilience: for availability & the sysadmins' sleep
- Conceptual simplicity to ease onboarding & demistify hosting

# The lacking state of the practice

## Object storage fitted our needs

- Distributed by design
- Objects are replicated
- Conceptually simple

## Existing object stores did not

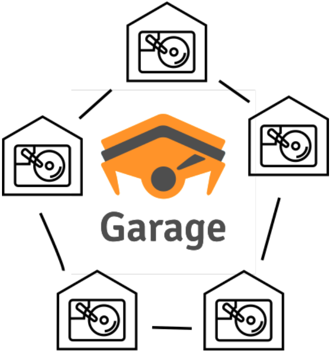
- Too specific / complex
- Resource hungry
- Hidden constraints

We developed Garage, an object store with minimal functionality.
It works, and serves our static sites and media.

# Introducing Garage

`garagehq.deuxfleurs.fr`

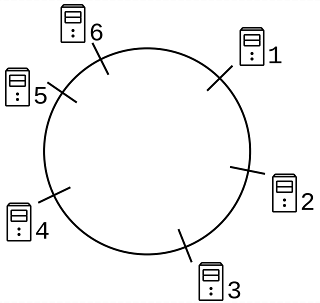
`git.deuxfleurs.fr/Deuxfleurs/garage`




- Distributed data store
- Based on DynamoDB object store (P2P!)
- Modular data types/protocols with CRDTs:
  - Done: objects (media, static sites, backups...) via S3 API
  - To do: e-mails via IMAP protocol, and more

# The RING

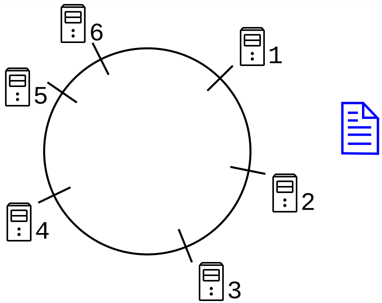
G. DeCandia et al. "Dynamo: Amazon's Highly Available Key-Value Store". In: *ACM SOSP*. New York, USA, 2007




Each node is assigned a unique ID on the circular address space.

# The RING

G. DeCandia et al. "Dynamo: Amazon's Highly Available Key-Value Store". In: *ACM SOSP*. New York, USA, 2007




When a new object is added to the store...

# The RING

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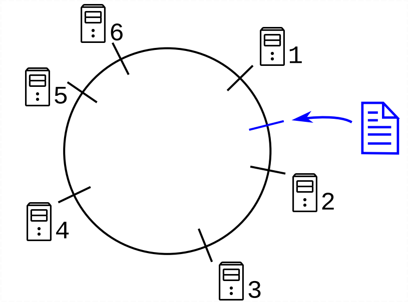
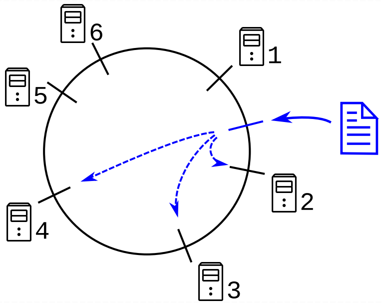



When a new object is added to the store...
It is assigned a unique ID (its *key*) on the address space.

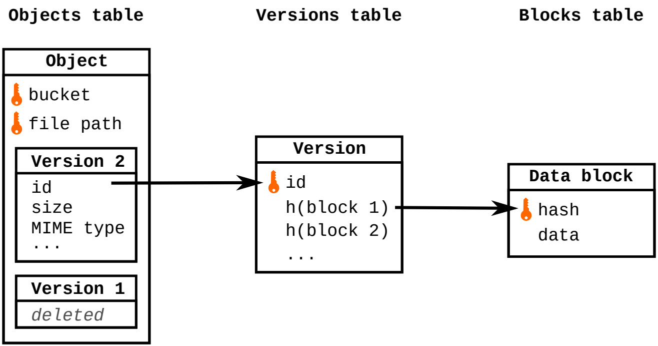
# The RING

G. DeCandia et al. “Dynamo: Amazon’s Highly Available Key-Value Store”. In: *ACM SOSP*. New York, USA, 2007




The *R* nodes after the object are in charge of replicating it.

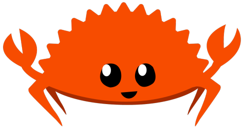
# Distributed metadata




The objects, versions and blocks are all stored in the ring.

# Written in Rust

Entirely written in Rust!



**Pros:**

- Compiled and fast
- Features prevent usual mistakes: strongly typed, immutable by default, ownership instead of GC...
- Best of several paradigms: imperative, OO, functional
- Good libraries for network programmings: serialization, http, async/await...

**Cons**:

- Steep learning curve
- Long compilation times
- Compiler rage

# The future is cooler when we bend it our way

Contributions welcome! :D

Thank you for your attention.

Now let's chat!