COLLABORATE:

Building a Robust, Consistent, and Efficient Distributed Shared Storage System for Large Data Objects that Promotes Collaboration

Presented by: **Nicolas Nicolaou, Project Coordinator**

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In a nutshell!

- Distributed Storage – Problem Statement
- Fragmentation: How to handle Large Objects
  - Blocks
  - Erasure Coding
  - Hybrid Solutions
- Reconfiguration: dealing with failures
- DriveNest: a service to predict imminent node failures

What is a Distributed Storage System?

- How to share data **robustly** in a **message-passing** system?

Dropbox

OneDrive

Google Drive

Nextcloud

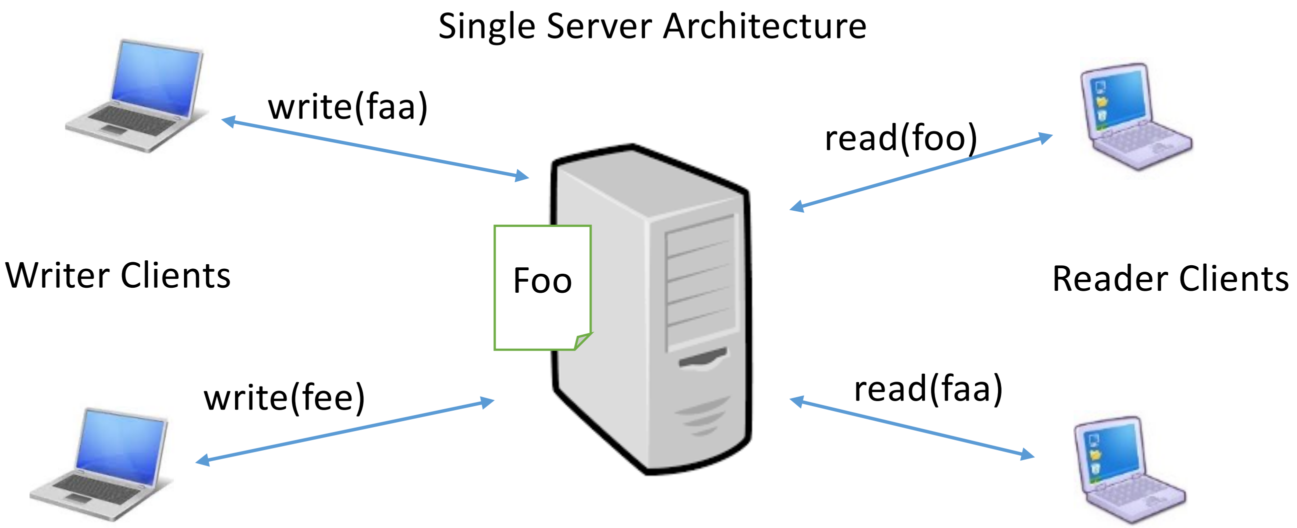
iCloud

Commercial Solutions:

- Cannot provide "sufficient guarantees" when shared objects are accesses concurrently
- Often rely on centralized solutions to enable collaboration
- Not offering "suitable guarantees" for application design

What is a Distributed Storage System

- How to share data **robustly** in a **message-passing** system?

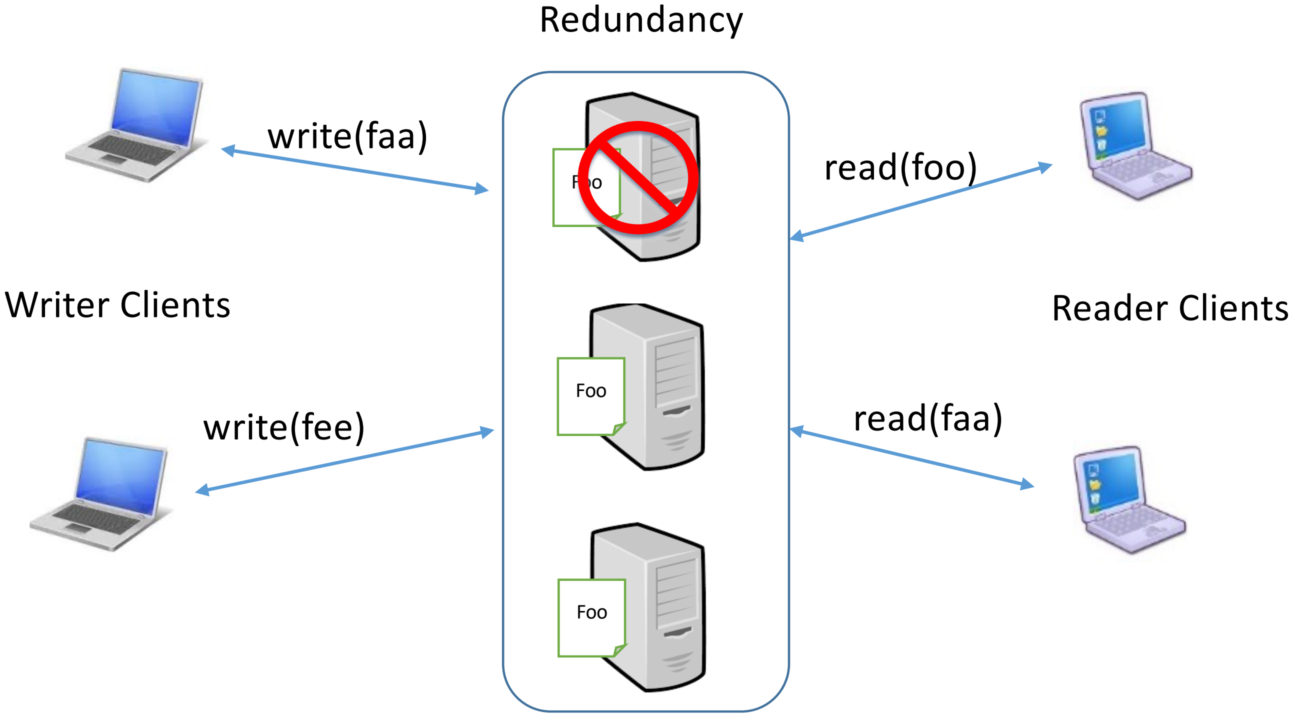


Pros:
- Easy to implement
- Strong consistency as the single server imposes the order of operations

Cons:
- Performance Bottleneck
- Single Point of Failure

What is a Distributed Storage System

- How to share data **robustly** in a **message-passing** system?



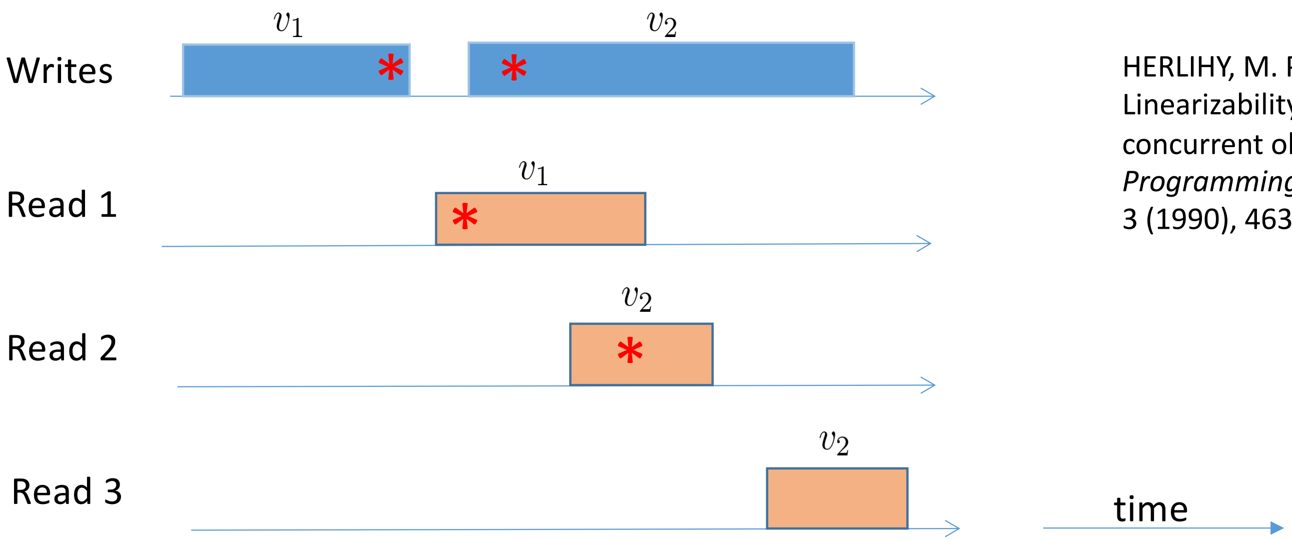
Shared read/write storage object

Implementing a fault-tolerant shared storage object in an asynchronous, message-passing environment:

- Availability + Survivability => use redundancy
- Asynchrony + Redundancy => concurrent operations
- Behavior of concurrent operations => consistency semantics
  - Safety, Regularity, Atomicity [Lamport86]

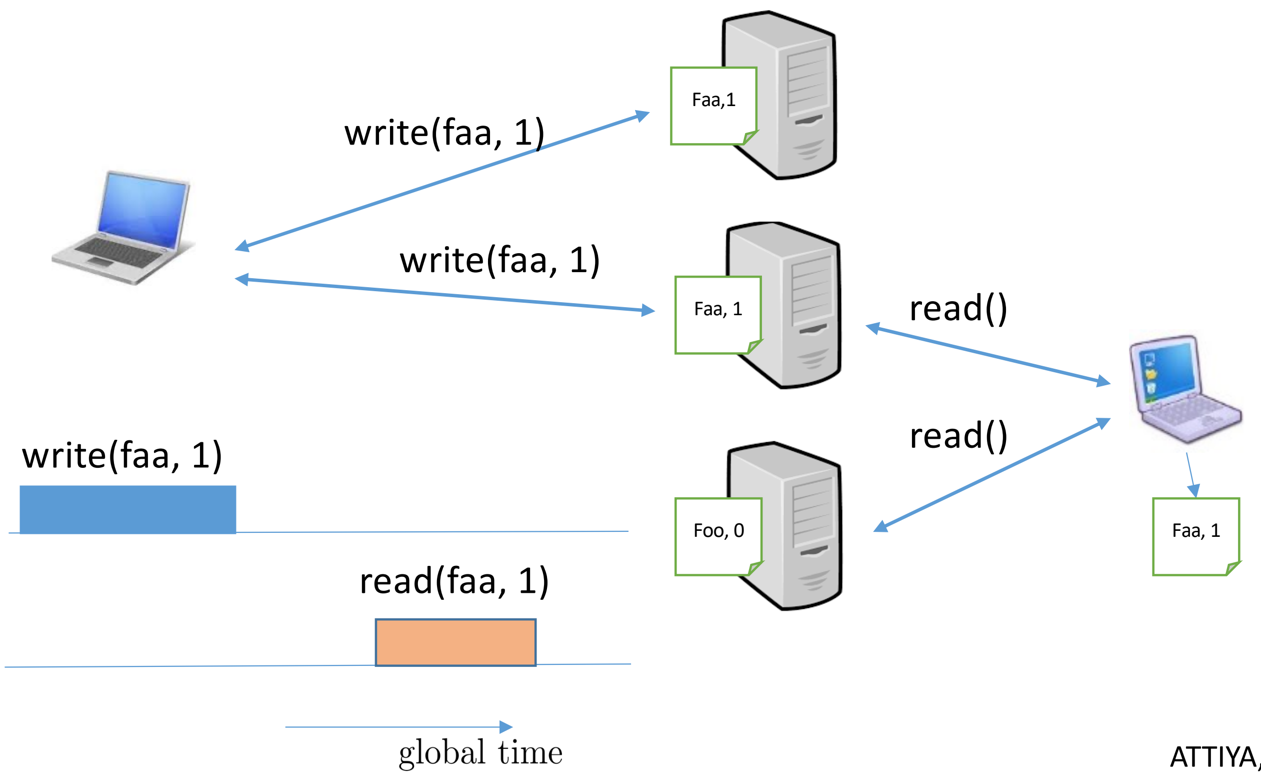
Atomicity/Linearizability

- Provides the illusion that operations happen in a sequential order
  - a read returns the value of the preceding write
  - a read returns a value at least as recent as that returned by any preceding read



HERLIHY, M. P., AND WING, J. M. Linearizability: a correctness condition for concurrent objects. *ACM Transactions on Programming Languages and Systems* 12, 3 (1990), 463–492.

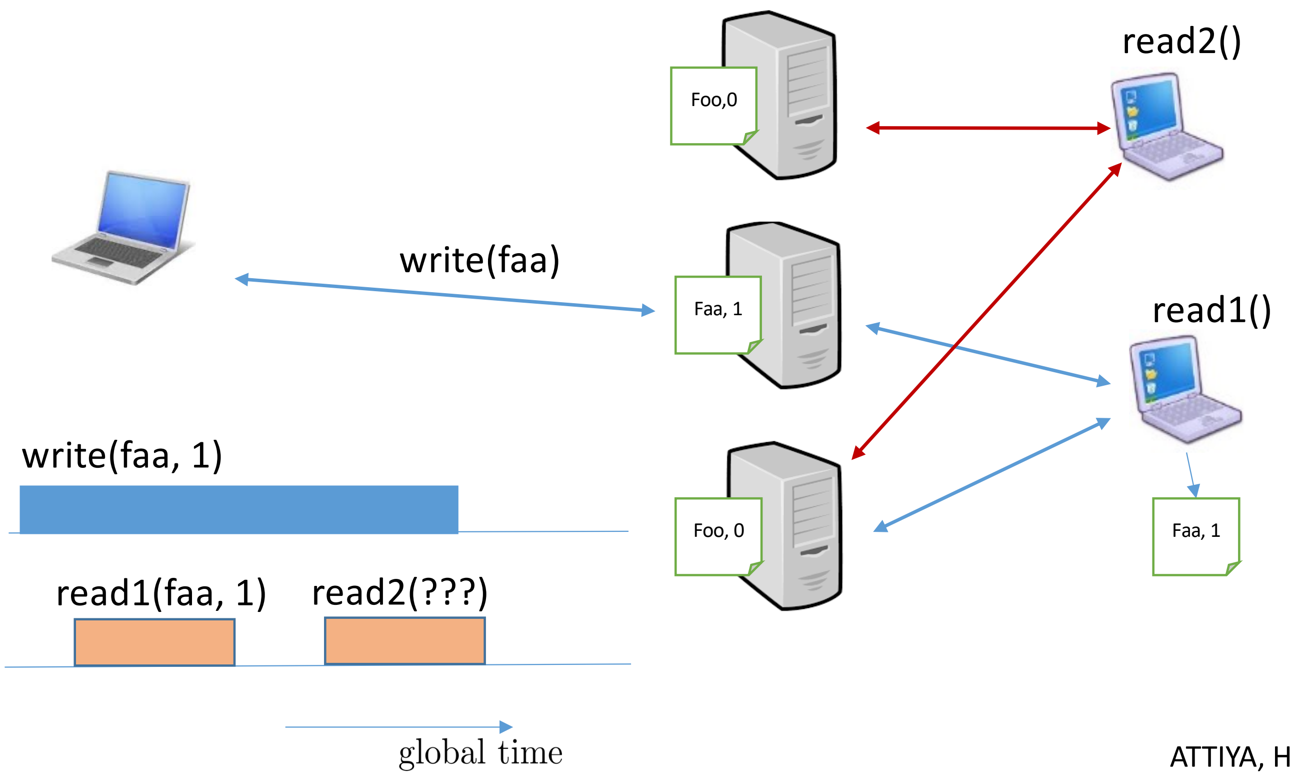
A Simple Solution - ABD



- Attiya, Bar-Noy, Dolev: an elegant, intuitive solution
  - Use the power of the majority
  - Assign logical timestamps to written values
  - Wait-free solution

ATTIYA, H., BAR-NOY, A., AND DOLEV, D. Sharing memory robustly in message passing systems. *Journal of the ACM* 42(1) (1996), 124–142.

A Simple Solution - ABD



- A "read" needs to "write"
  - Phase 1: query
  - Phase 2: propagate

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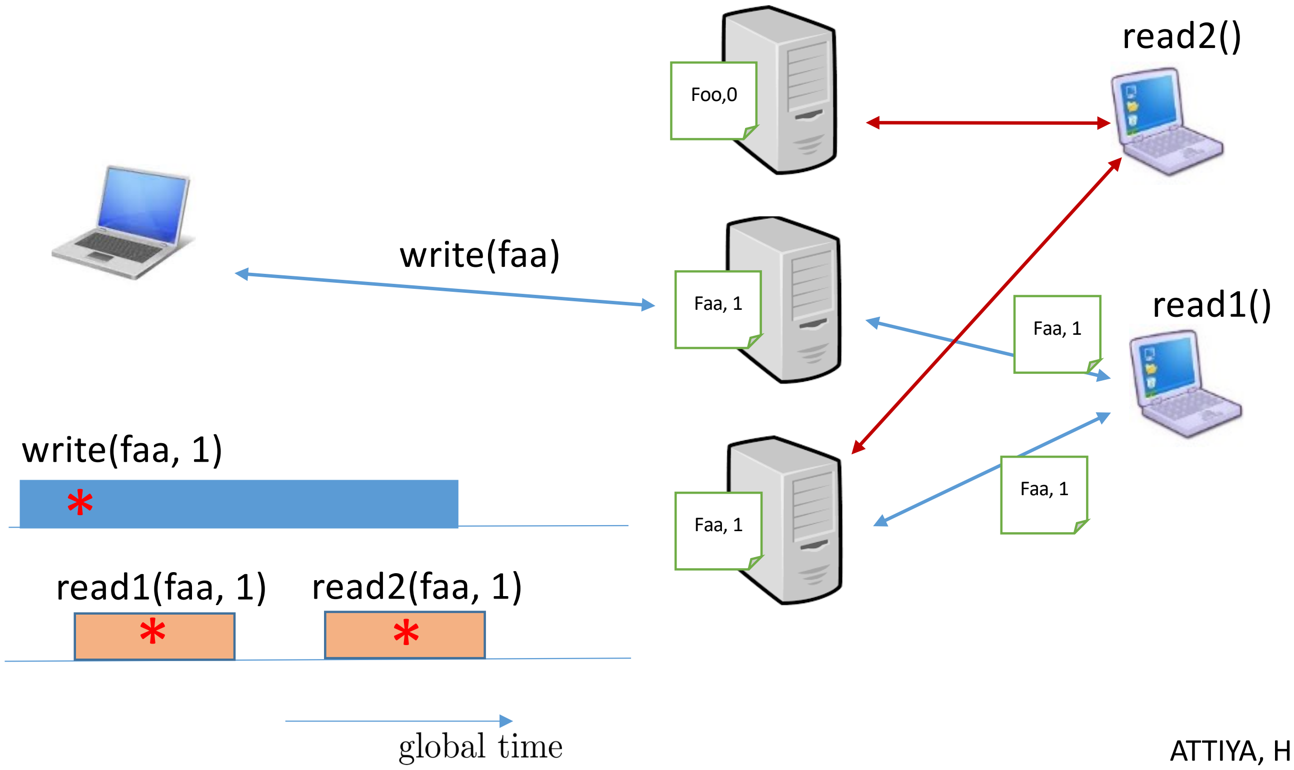

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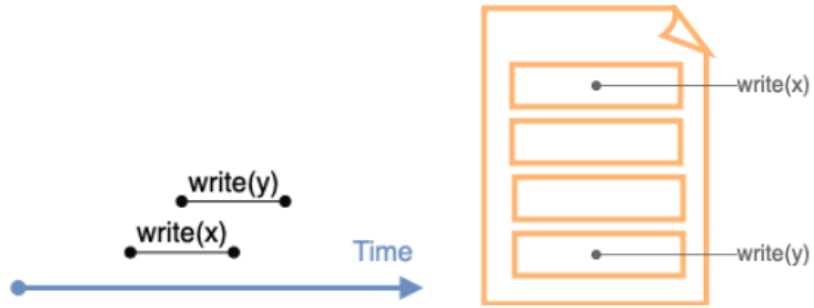
Solutions for Large Objects

- ABD efficient for small objects
  - Each write operation sends (S/2)+1 copies of the object
  - Each read operation sends S copies of the object

- Moreover concurrent write operations may overwrite one another
  - Unbale to handle write operations working on different parts of a large object

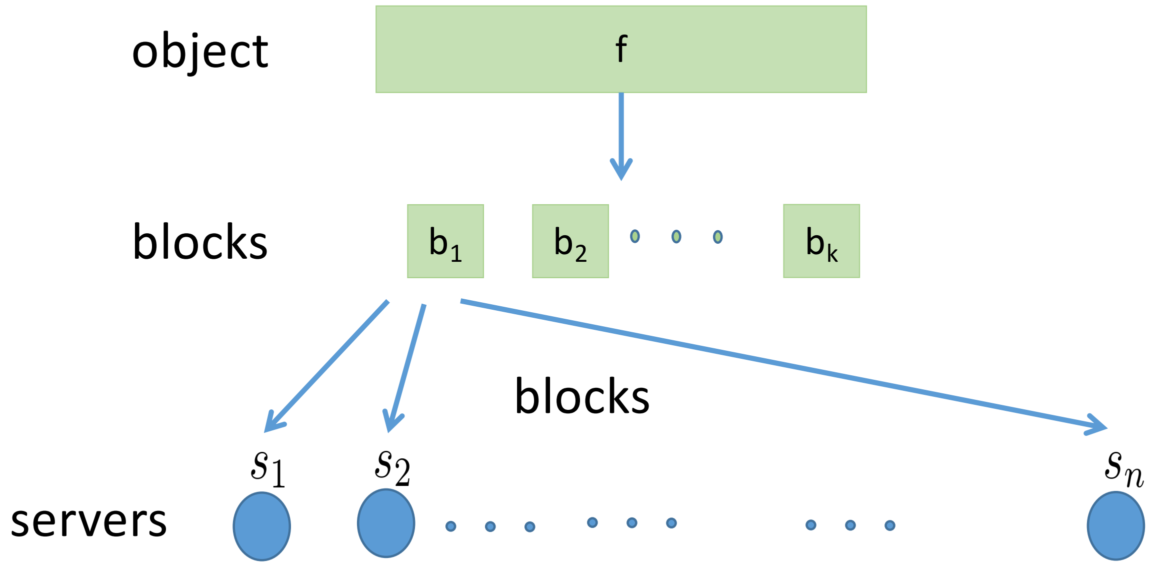


Main Project Goal

Develop practical and robust DSS in the message-passing, asynchronous, environment while allowing high concurrency and preserving strong consistency.

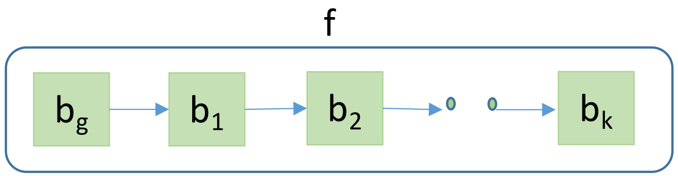
Solution 1: Fragmentation

- Most intuitive solution
  - Split large objects into smaller fragments
  - Treat each individual block as an atomic object



Solution 1: Algorithm CoBFS

- Fragmented Objects:
  - Connected list of blocks
  - Each block points to the next block



- Write Operation write(f)
  - Propagate only modified and new blocks

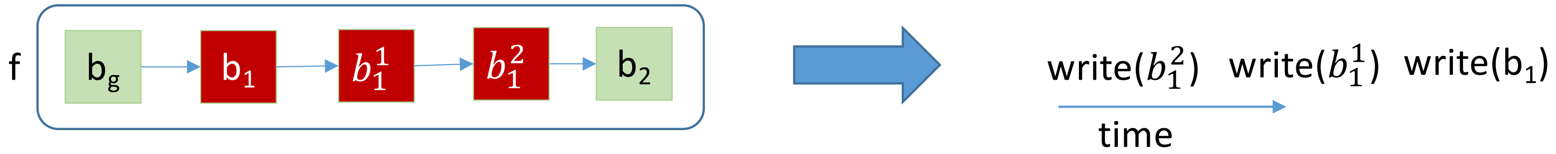
- Read Operation read(f)
  - Start from genesis block and read all the blocks
  - Optimization: Only blocks that have changed are send to the read

Solution 1: Algorithm CoBFS

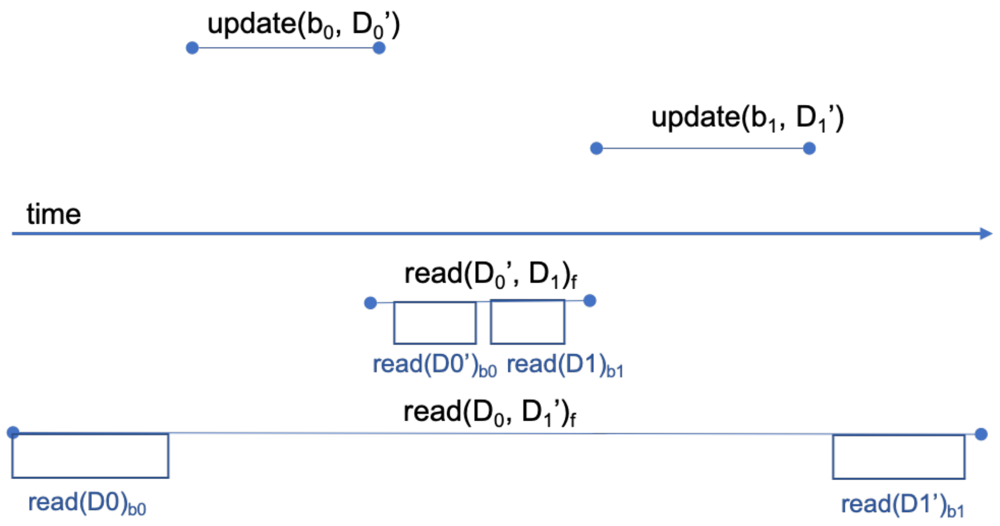
- Write/Update Operation:
  - Run fragmentation and block matching algorithms to determine
    - Modified blocks
    - New blocks

  - Case 1: Only a single block has changed

  - Case 2: Changed block overflowed and new blocks introduced

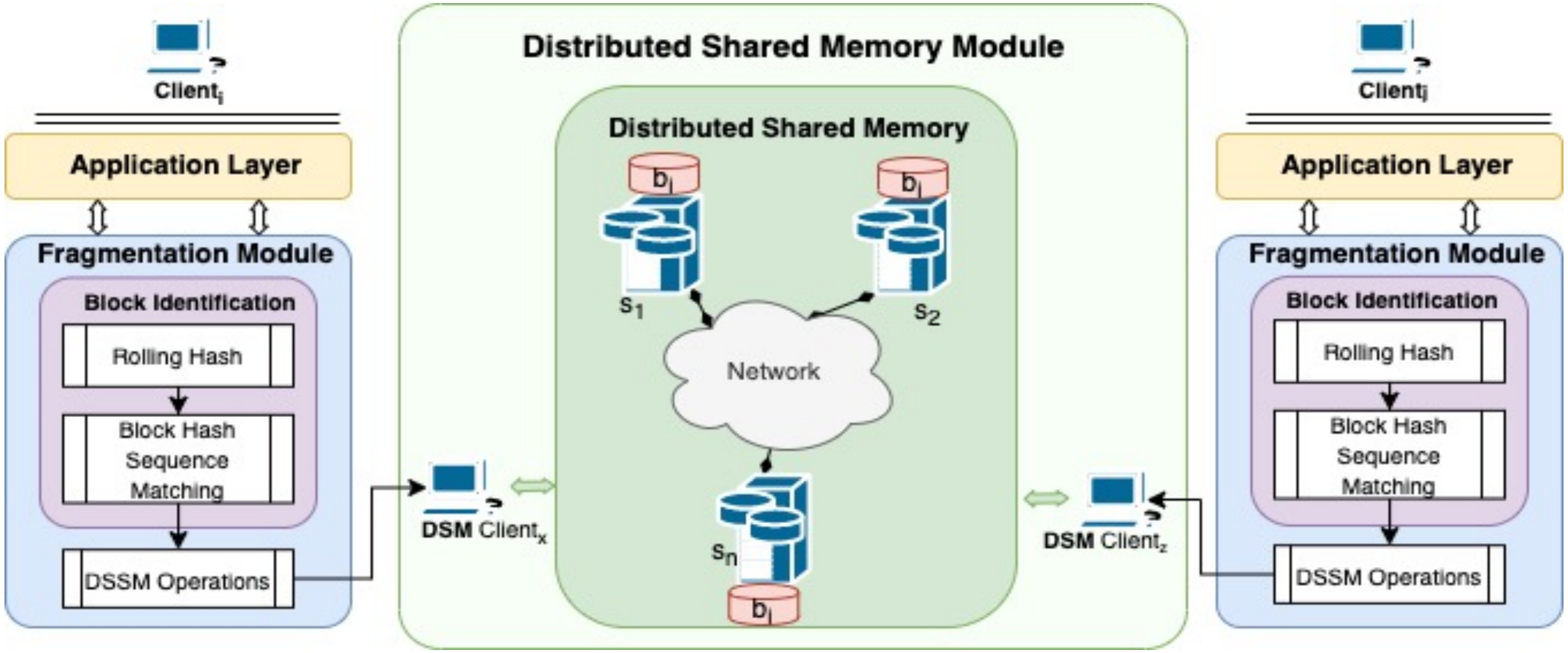


Solution 1: Fragmented Linearizability



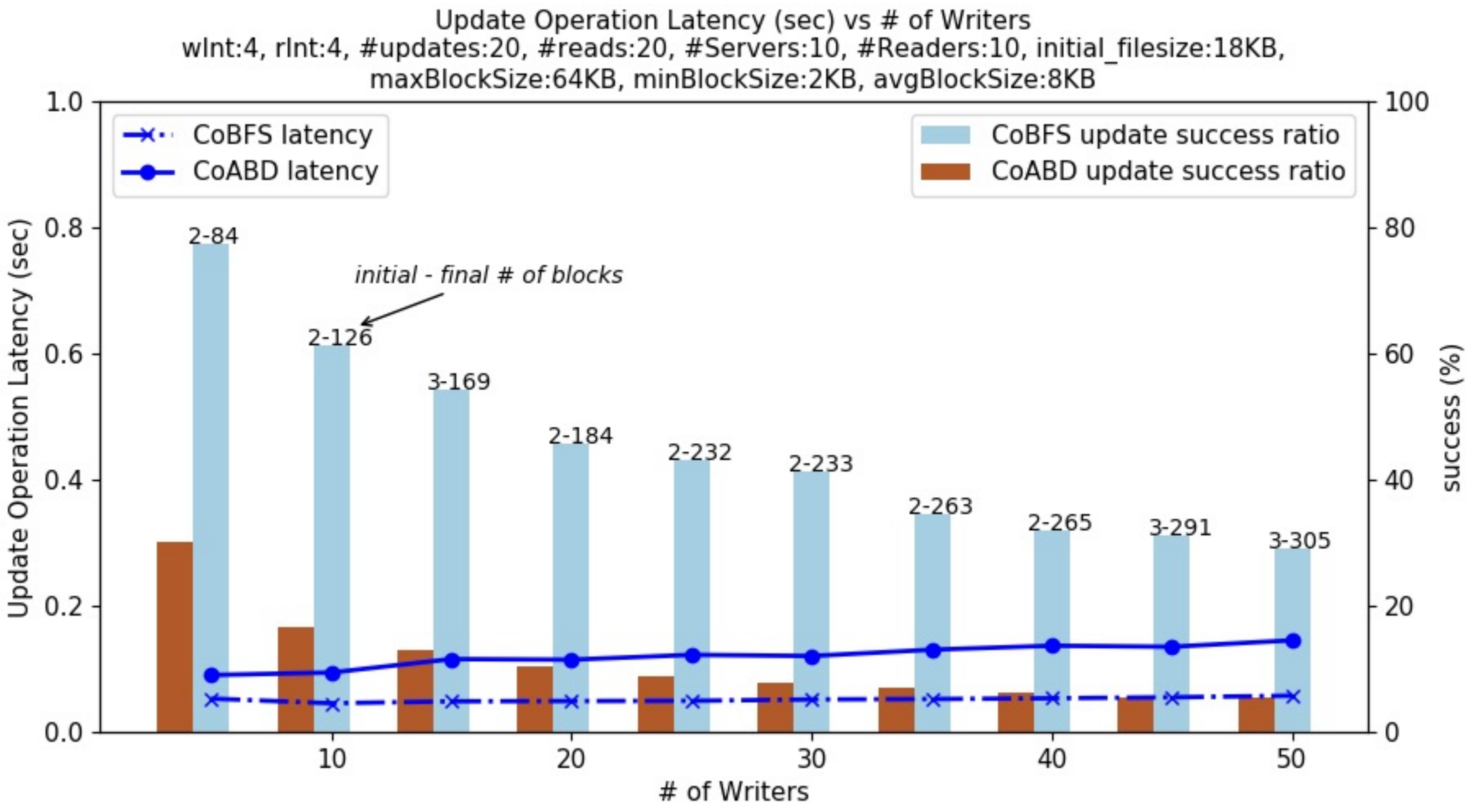
Fragmented Linearizability: all concurrent operations on different blocks prevail, and only concurrent operations on the same blocks are conflicting.

Solution 1: Basic Architecture

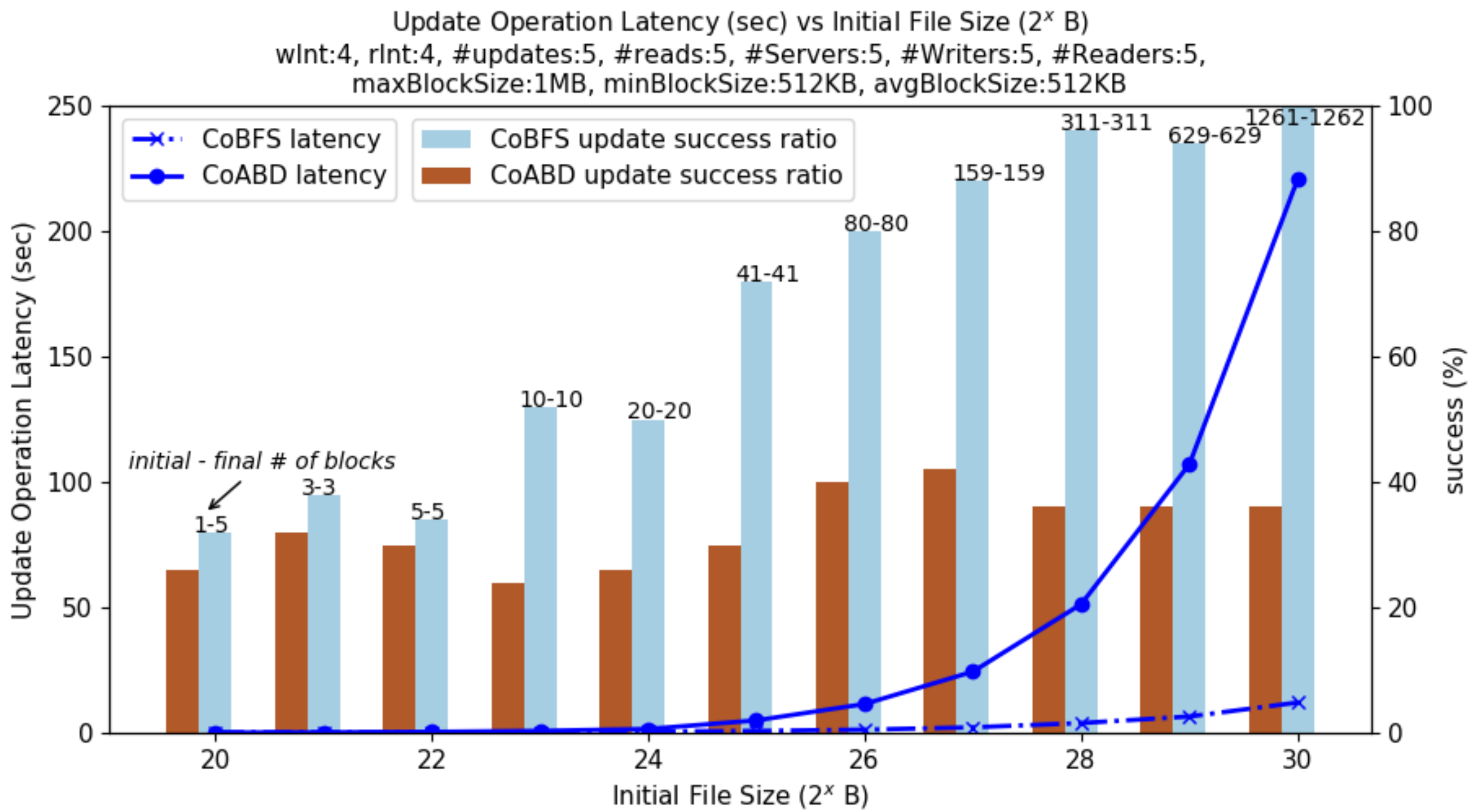


Rabin, M O. Fingerprinting by random polynomials, *Center for Research in Computing Techn., Aiken Computation Laboratory, Univ. , pp 15—18, 1981*

Solution 1: Experimental Results - Scalability

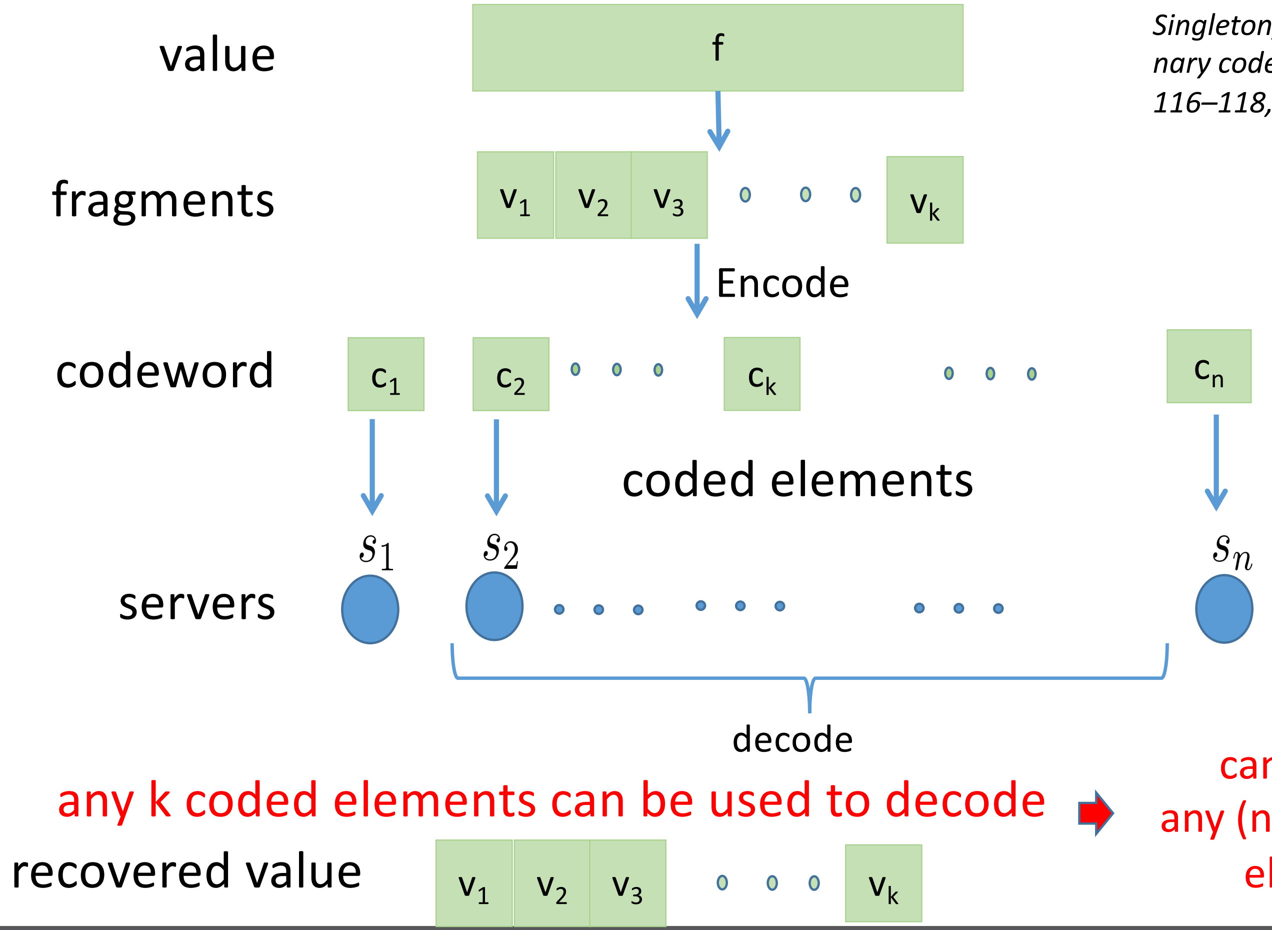


Solution 1: Experimental Results - Filesize



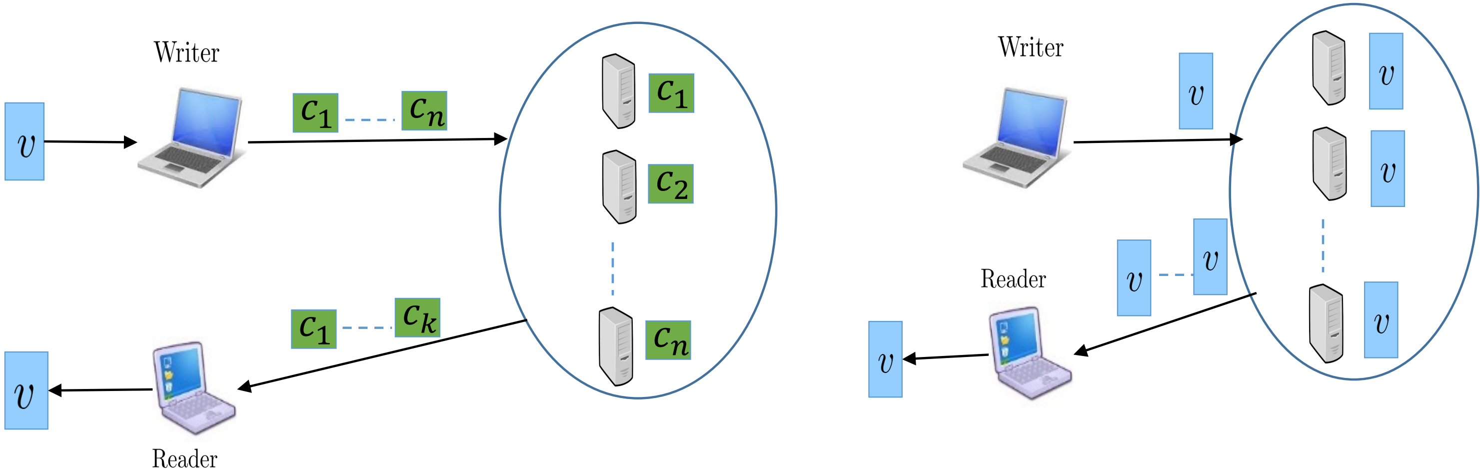
Solution 2: Erasure Coding ([n, k] MDS Codes)

*Singleton, R.C. (1964), "Maximum distance q-nary codes", IEEE Trans. Inf. Theory, **10** (2): 116–118, doi:10.1109/TIT.1964.1053661*



can tolerate any (n – k) missing elements

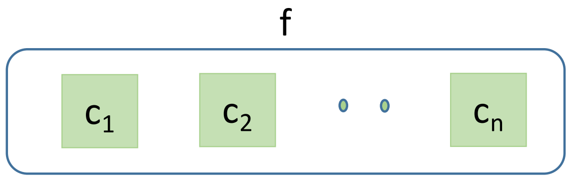
Solution 2: Erasure Coding vs Replication



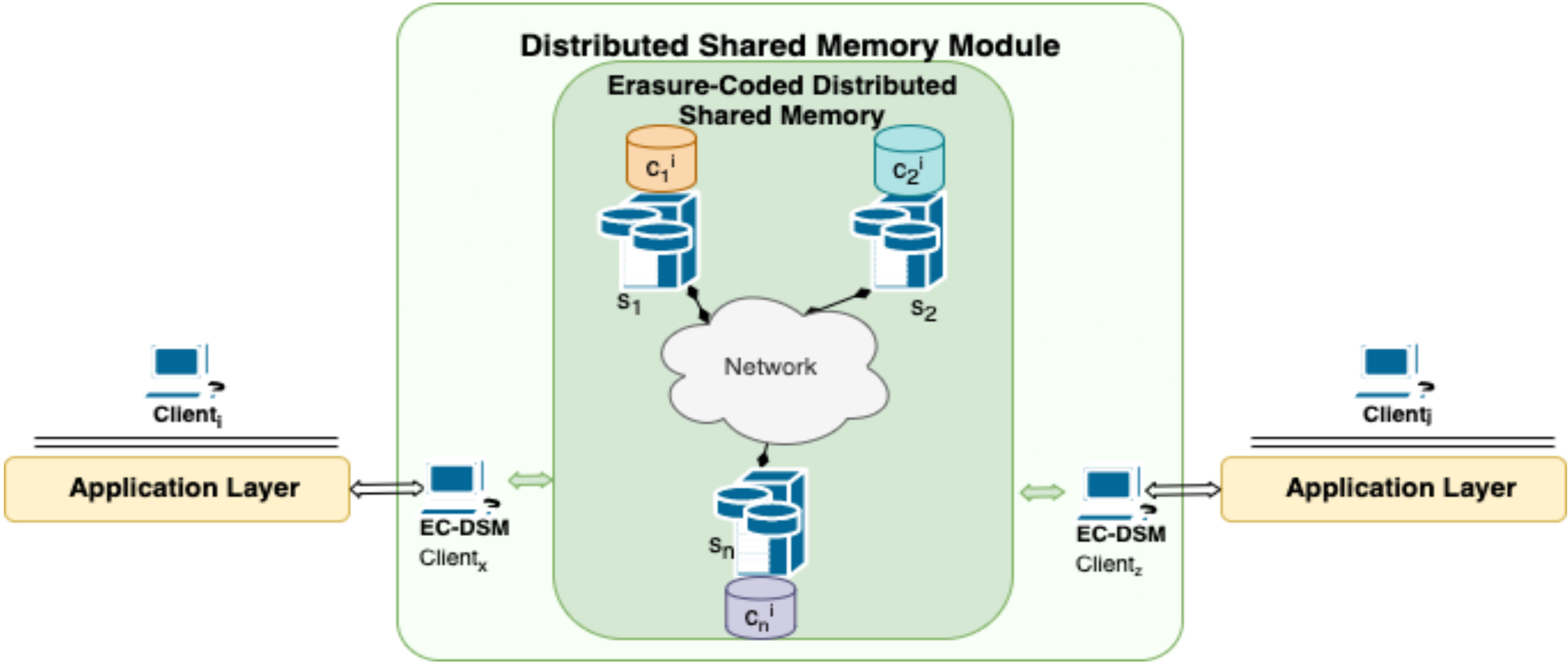
A well-designed algorithm has great potential to reduce storage and communication costs while using erasure codes

Solution 2: Algorithm CoEC

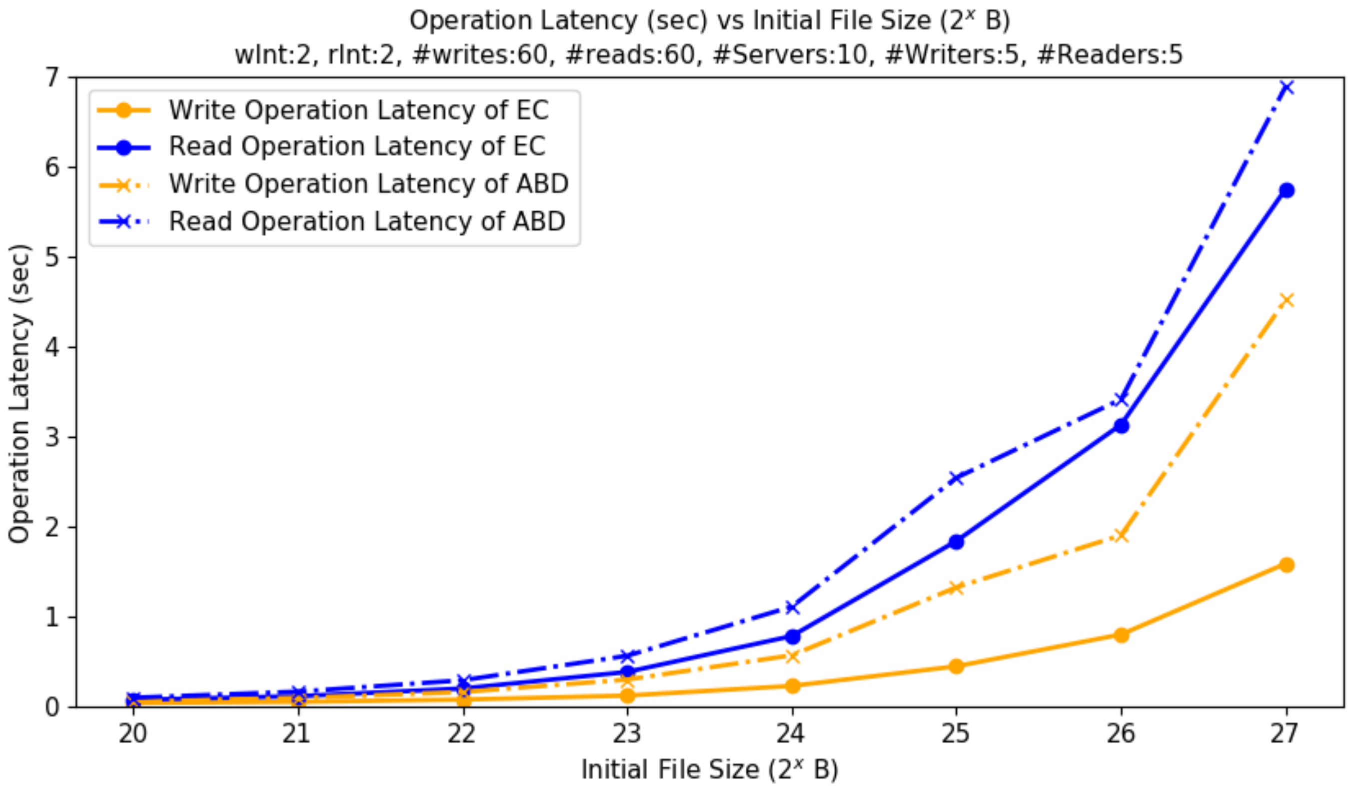
- Write Operation write(f)
  - Apply erassure coding on f
  - Send code c_i to server s_i
- Read Operation read(f)
  - Collect *k* codes from the servers
  - Decode and return the value of *f*
- Ensures Strong Consistency
- Does not prevent overwriting



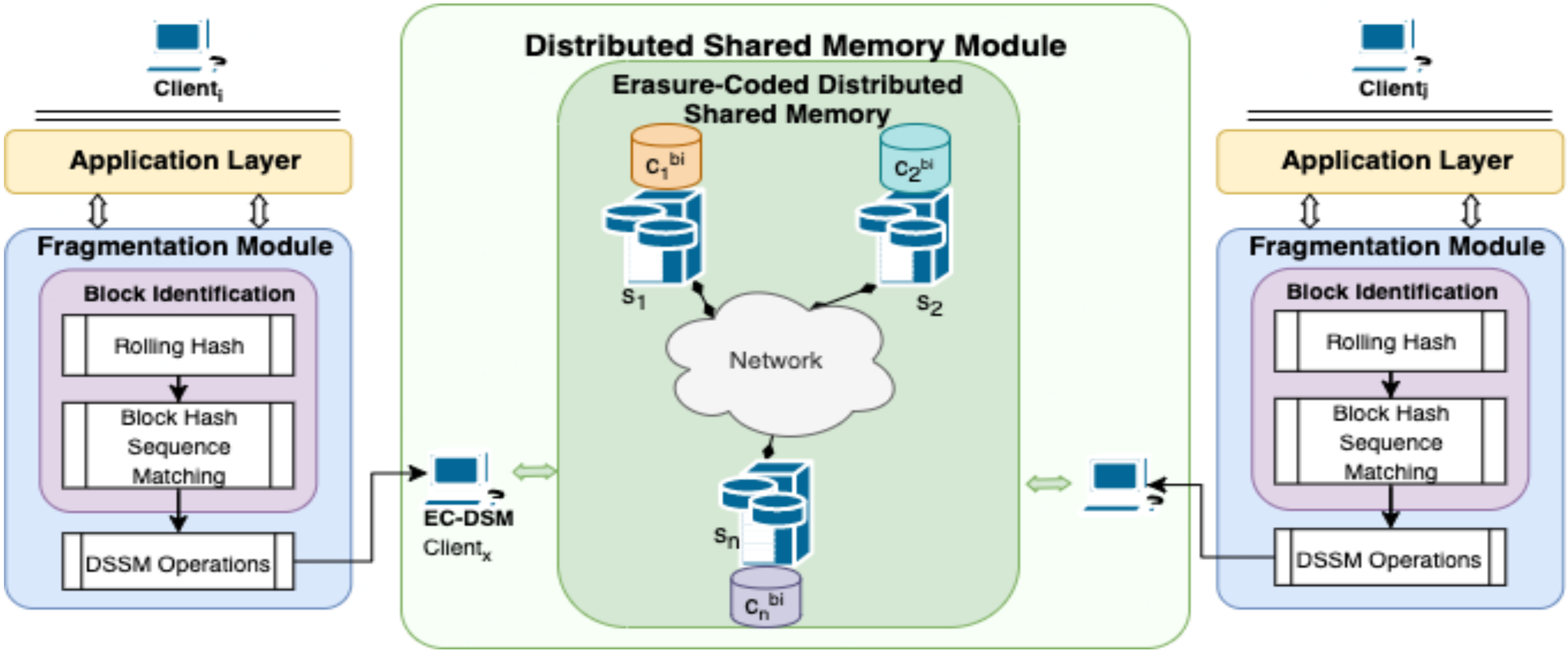
Solution 2: Erasure Coding Architecture



Solution 2: Experimental Results



Solution 3: Hybrid



What happens when things go wrong?

- Tolerate minority of failures

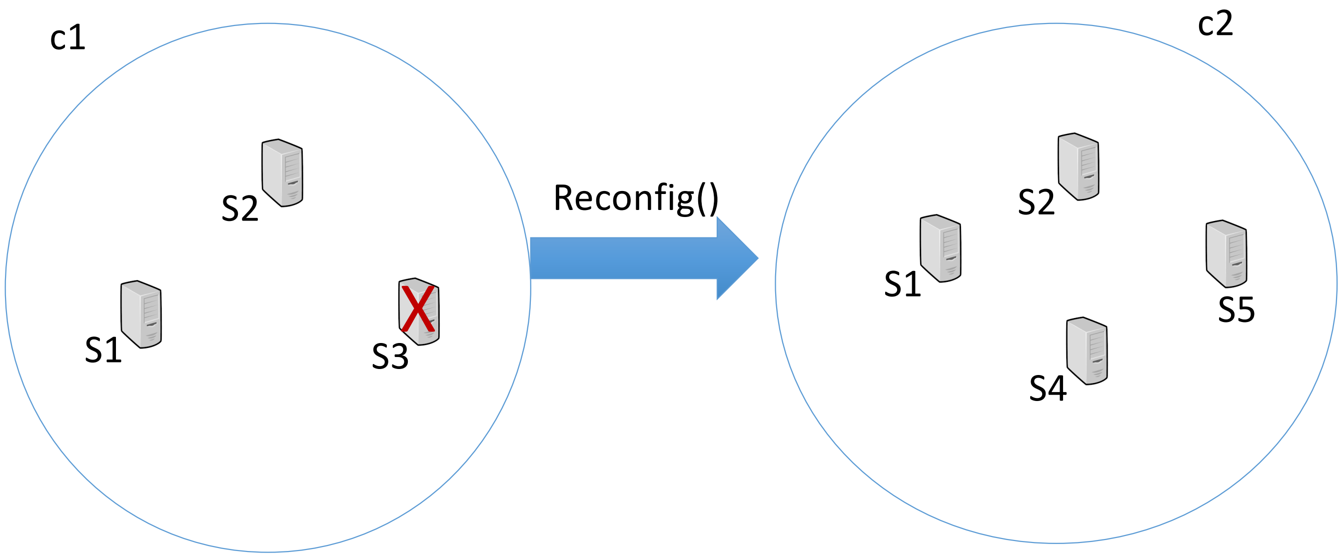
- What if more than minority fail?

- Replace failed with healthy servers => Reconfiguration

Challenge: Can we install a new configuration without stopping the service and without violating linearizability?

Re-Configuration Operation

- Change the configuration parameters (add/replace servers)
  - Due to failures
  - Due to admin maintenance



LYNCH, N., AND SHVARTSMAN, A. RAMBO: A reconfigurable atomic memory service for dynamic networks. *In Proceedings of 16th International Symposium on Distributed Computing (DISC)* (2002), pp. 173–190.

ARES: A modular and adaptive reconfiguration protocol

Modular

- Read/Write operations are not aware of the underlying shared memory implementation
  - They are using the same access primitives

Adaptive

- Different shared memory algortihm may be used in every configuration
  - Satisfying application demands

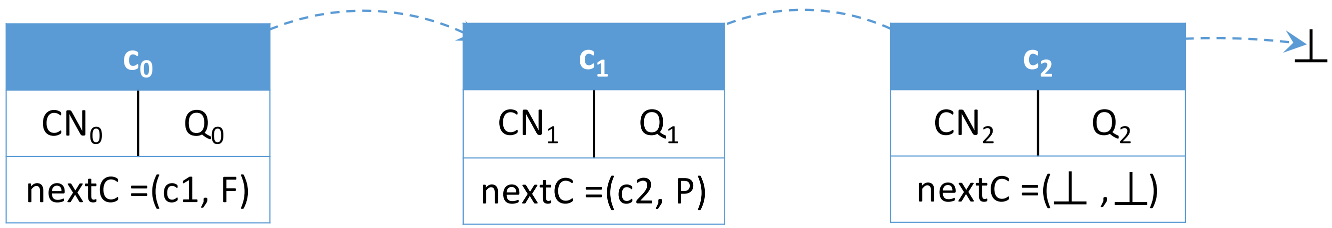
NICOLAOU, N., CADAMBE, V., KONWAR, K., PRAKASH, N., LYNCH, N., AND MEDARD, M. ARES: Adaptive, Reconfigurable,Erasure Coded, Atomic Storage. *In Proc. of ICDCS, pp. 2195–2205 (2018*)

Configuration Sequence

- Global configuration sequence G_L

- Flags {P, F}: pending, finalized
  - Pending: not yet a majority of servers received msgs
  - Finalized: new configuration propagated to a majority of servers

- nextC: each server points to the next configuration
  - Same nextC to all servers of a single config c (due to consensus)



Reconfiguration Service

- A recon operation performs 2 major steps:
  1) Configuration *Sequence Traversal*
  2) Configuration *Installation*
     - Transfers the object state from the old to the new configuration

```
operation reconfig(c)
  if c ≠ ⊥ then
    cseq ←read-config(cseq)
    cseq ← add-config(cseq, c)
    update-config(cseq)
    cseq ← finalize-config(cseq)
end operation
```

attempt get to the latest configuration } (1)

introduce the new configuration
migrate the data to the new config
let servers know it is good to be finalized } (2)

Reconfiguration Service Guarantees

For any two reconfig ops π_1, π_2 s.t. π_1 before π_2

- Configuration Consistency

π_1	c_0	c_1	c_2	…
π_2	c_0	c_1	c_2	…

- Sequence Prefix

π_1	c_0	c_1	
π_2	c_0	c_1	c_2

- Sequence Progress

π_1	<c_0, F>	<c_1, P>	<c_2, P>	
π_2	<c_0, F>	<c_1, P>	<$c_{2,}$, F>	…

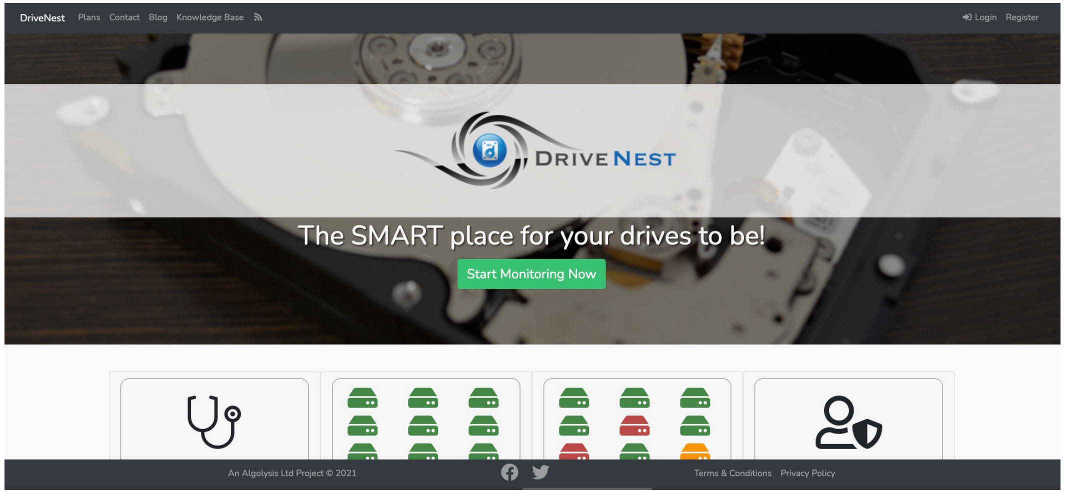
ARES: Experimental Results

When shall we reconfigure?

- Frequent reconfigurations => Slow Down the service
- Infrequent reconfigurations => May make the service anavailable

Challenge: How can we determine when is the best time to reconfigure?

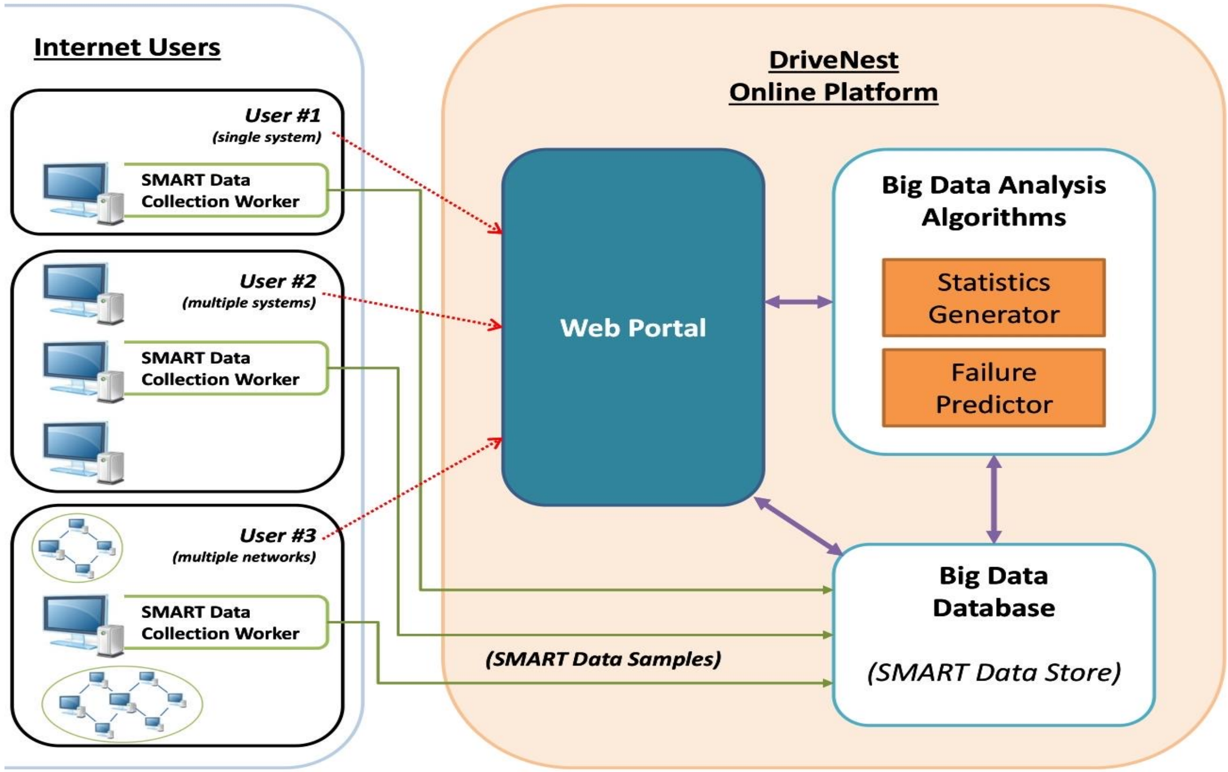
DriveNest: Monitoring Node Health



www.drivenest.com

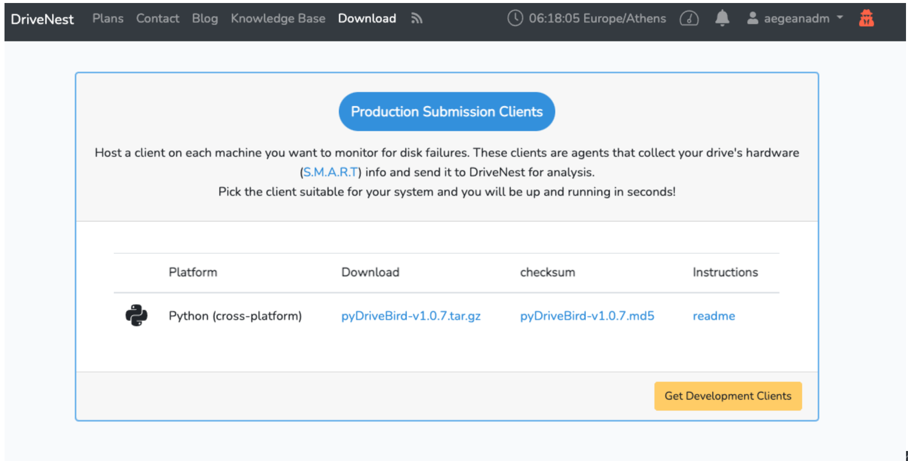
- Crowdsourcing Platform
  - Collects data from diverse setups, locations, conditions.
- Monitor storage device health by collecting S.M.A.R.T data
- Predict soon-to-fail drives
  - Prediction performance relies on the report of failed drives
- Integration with ARES
  - Initiate recon operation to remove drives that are predicted to fail
  - Replace them with healthy nodes and migrate data

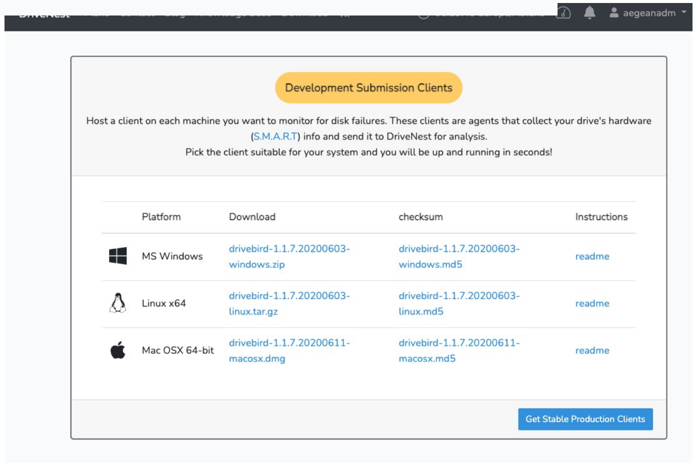
Drivenest: Architecture



- **DriveBird**: Data Collection Clients
- **Web platform**: View your drives
- **Prediction Engine**: Applies a number of machine learning/ deep learning algorithms to predict soon-to-fail drives

DriveNest: DriveBird Client





- Production Submission Clients
  - Python (cross platform)
- Development Submission Clients
  - GUI interface for all platforms
  - Tested up to Win 10 and MacOS Sierra

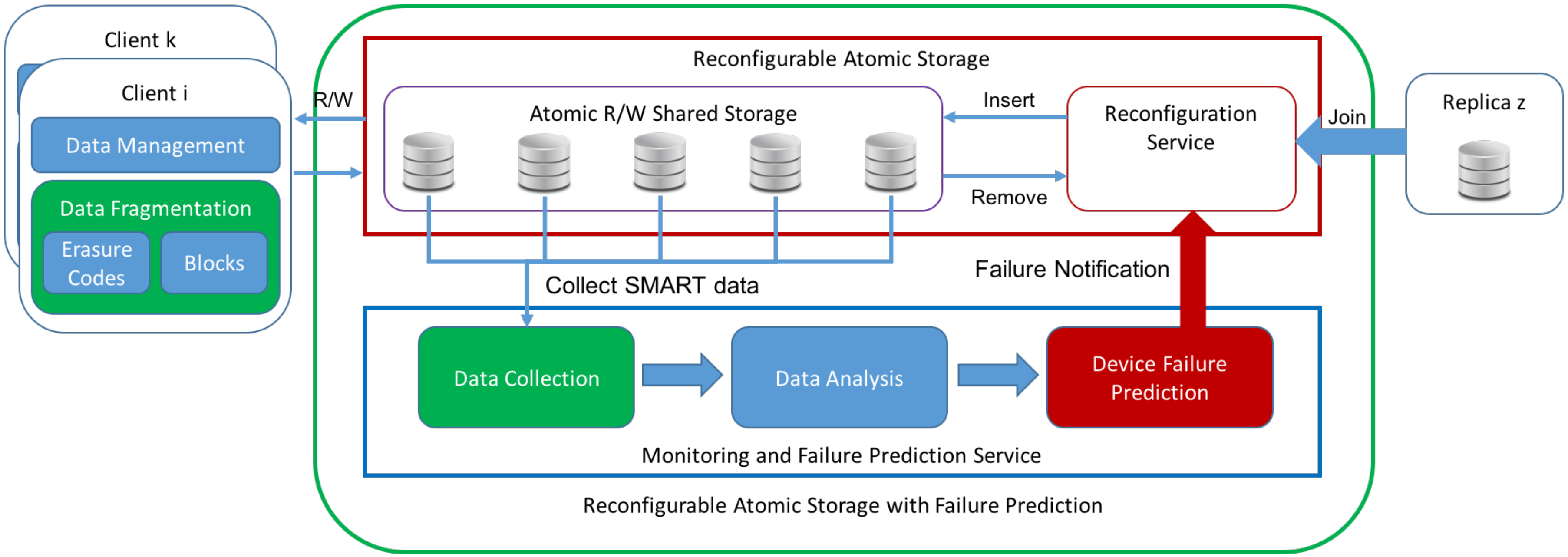
DriveNest: Status

- Drivenest Collection Clients: **Alpha Testing**
- Drivenest Web Platform: **Alpha Testing**
- Drivenest Predictions: **Development Stage**

Feel free to register and give the service a test **"drive"**. ☺

We would be glad to hear your feedback

COLLABORATE: Overall Architecture



COLLABORATE: What's ahead

- Improve the Machine Learning ourcomes of Drivenest for better failure prediction

- Embedd the developed algorithms in a production level Distributed Storage Service!

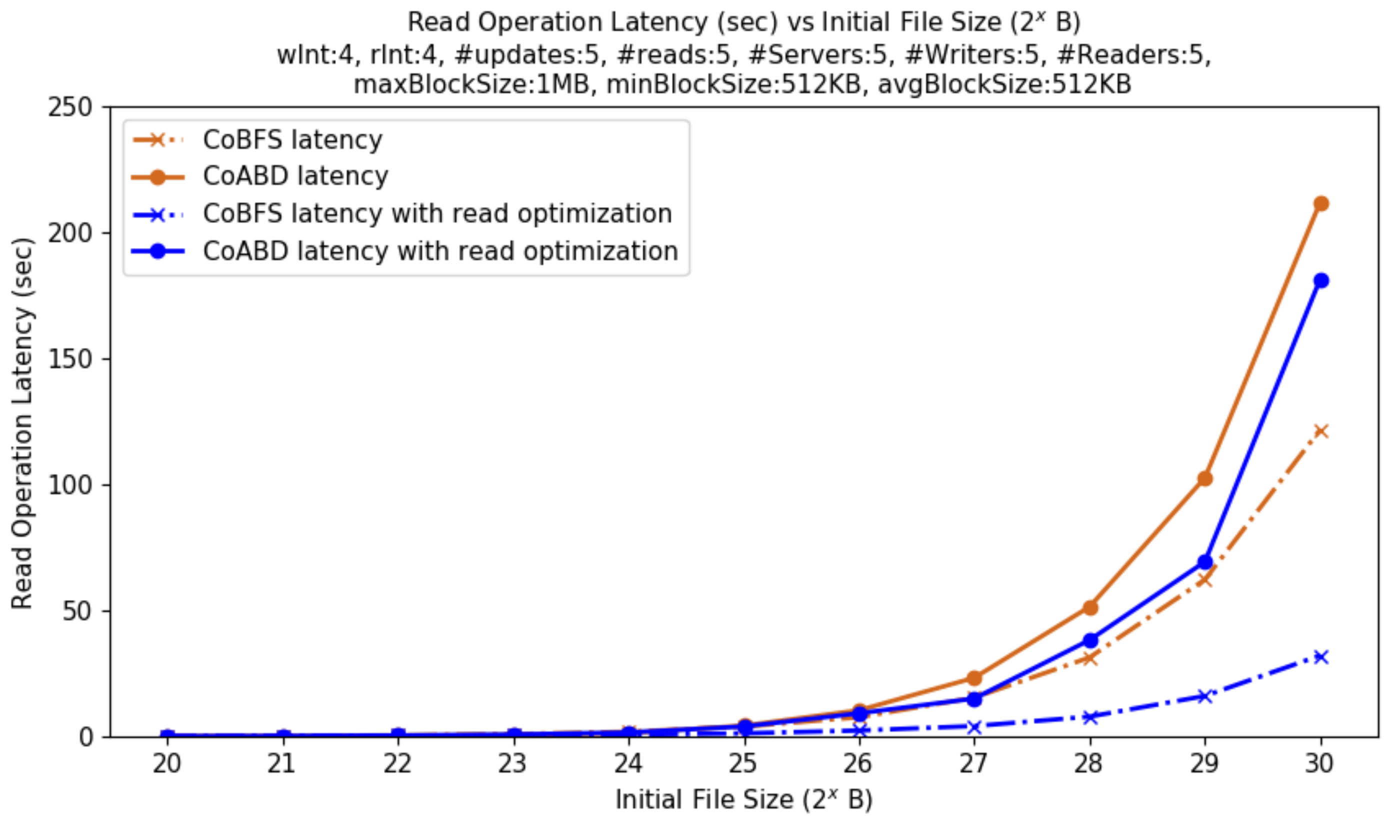
Thank you!

algolysis

algorithmic solutions

www.algolysis.com research@algolysis.com

Solution 1: Experimental Results – Read Optimization



Solution 1: Experimental Results – Block Size