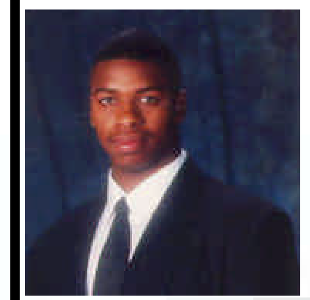
Making the Archive Real



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Global-Scale Archival Goals

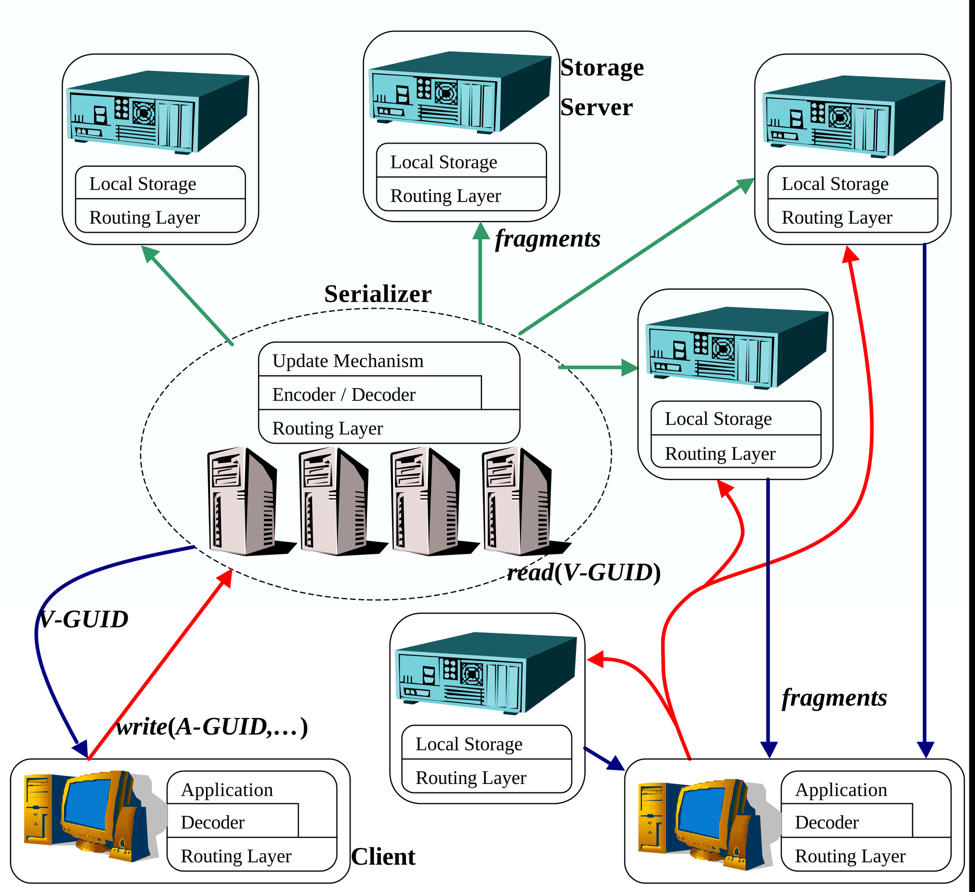
- Durability
  - Data is stored for centuries or longer.
- Verifiability.
  - Data is not subject to substitution attacks.
- Availability.
  - Data is accessible *most* of the time.
    - Where *most* is defined in *n* 9's of availability.
- Maintainability.
  - System recovers from server and network failures.
  - Efficiently incorporates new resources.
- Atomicity.
  - Updates are applied atomically.
- Privacy.
  - Information is only visible to those who have access rights.
- Performance.
  - Response time is bounded.

Archival Model

- Archive Data Structures.
  - *Archive* is a linearly ordered sequence of *versions*.
  - Each version is a read-only sequence of bytes.
  - E.g. an archive might be a *file*, a *directory*, or a *database record*.
- Naming.
  - Globally-Unique IDentifier (GUID).
  - Archives are uniquely specified by *archive GUIDs* (*A-GUIDs*).
  - Within an archive, each version is specified by a *version GUID* (*V-GUID*).
    - Versions are immutable and provide for *time-travel*.
- Operations.
  - *Update* Operations.
    - Add versions to the end of the version sequence of a given archive.
  - *Read* Operations.
    - Read data from a specific version.
- *Serializer* provides consistency.
  - Entity in network that provides *atomicity*.
  - Provides an A-GUID to V-GUID mapping.
  - Creates a serial order over simultaneously submitted updates.
  - Verifies that the *client* has update privileges.
  - Atomically applies update to the archive and generates a new V-GUID.
  - Sends fragments from an update to *storage servers*.

Interface

- Generate new archive interface.
  - create(name, identity, keys) => A-GUID.
- Query Interface.
  - query(A-GUID, Specifier) => V-GUID.
    - Specifier => timestamp, version#, etc.
- Read interface.
  - read(V-GUID, offset, length) => data.
- Write interface.
  - write(A-GUID, data) =>V-GUID.
  - append(A-GUID,data) =>V-GUID.
  - replace(V-GUID,offset,data,allowbr) => V-GUID or null.
    - *allowbr* denotes whether operation allowed to generate branch.



Durability

Case for Erasure Codes

Background

- Erasure codes provide redundancy without overhead of replication.
  - Divide an object into *m fragments.*
  - Recode them into *n fragments.*
  - A *rate* $r = m/n$ code increases storage cost by a factor of $1/r$.
  - Key property is that original object can be reconstructed from *any m* fragments.
  - E.g. using an $r = ¼$ code, divide a block into $m = 16$ fragments, and encode the original m fragments into $n = 64$ fragments.
    - Increases storage cost by a factor *four*.
- Example implementations
  - Reed-Solomon Codes.
  - Tornado Codes.
  - Interleaved Reed-Solomon.

Assumptions

- An archive is implemented on a collection of independently failing disks.
- Failed disks immediately replaced by new, blank ones.
- Each archival fragment for a given block is placed on a unique, randomly selected disk.
- A repair epoch.
  - Time period between a global sweep, where a repair process scans the system, attempting to restore redundancy.

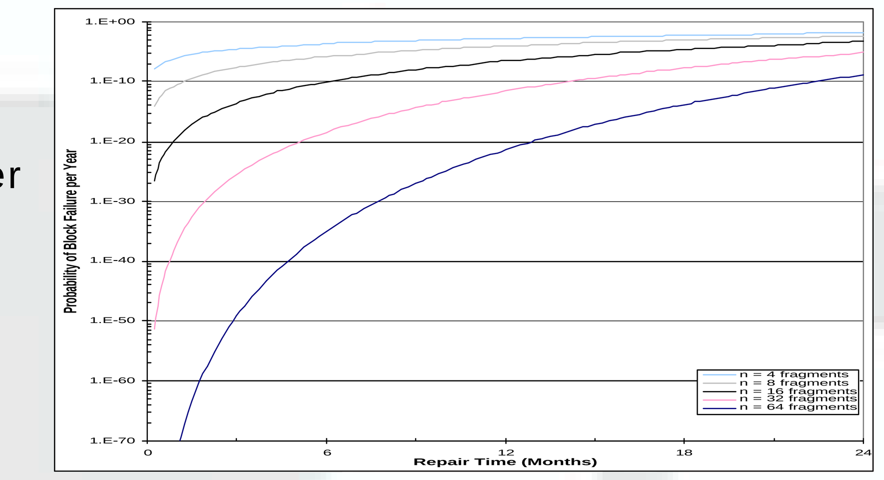
Availability

- Exploits the statistical stability of a large number number of components

$$P_o = \sum_{i=0}^{n-m} \frac{\binom{M}{i}\binom{N-M}{n-i}}{\binom{N}{n}}$$

» P_o - Probability that an object is available.
» n - total number of fragments.
» m - number of fragments needed for reconstruction.
» N - total number of machines in the world.
» M - number of currently unavailable machines.

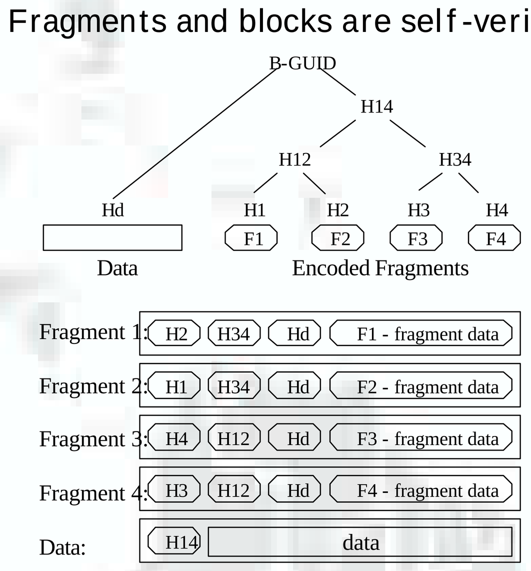
- E.g. given 90% of a million machines availability:
  - $n = 16$ fragments, rate $r = ½$, yield 5 9's of availability.
  - $n = 32$ fragments, rate $r = ½$, yield 8 9's of availability.



- Fraction of Blocks Lost Per Year (FBLPY)*
  - $r = ¼$, erasure-encoded block. (e.g. $m = 16$, $n = 64$)
  - Increasing number of fragments, increases durability of block
    - Same storage cost and repair time.
  - $n = 4$ fragment case is equivalent to replication on four servers.

Archival Process: Data Integrity

- Top hash is a *block GUID* (*B-GUID*).
  - Fragments and blocks are self-verifying.

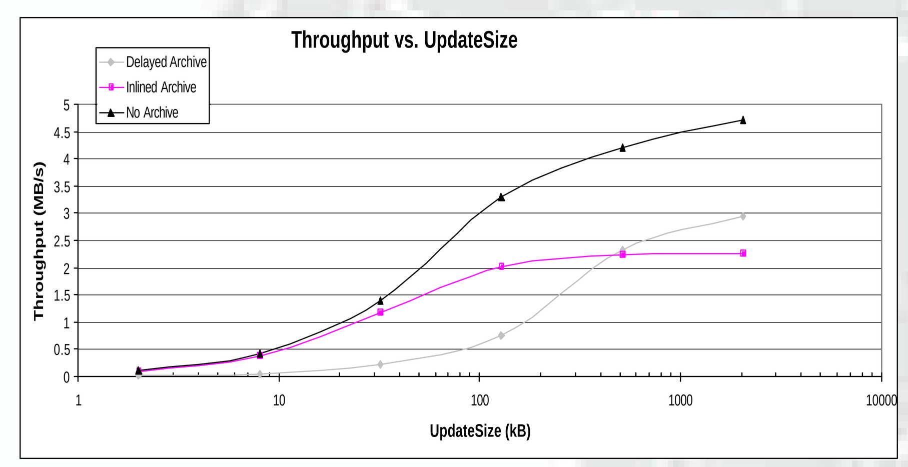


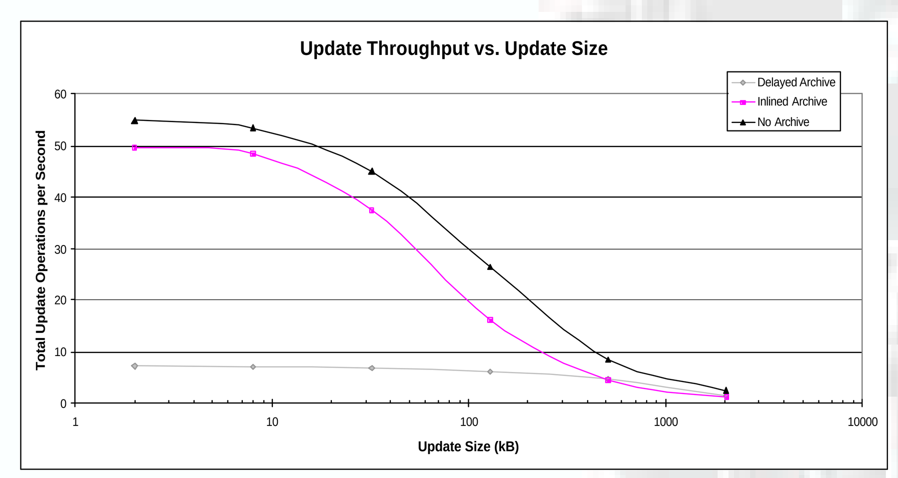
Archival Mode

- No archiving
- Inlined archiving
  - Synchronous
  - m = 16, n = 32
- Delayed archiving
  - Asynchronous
  - m = 16, n = 32

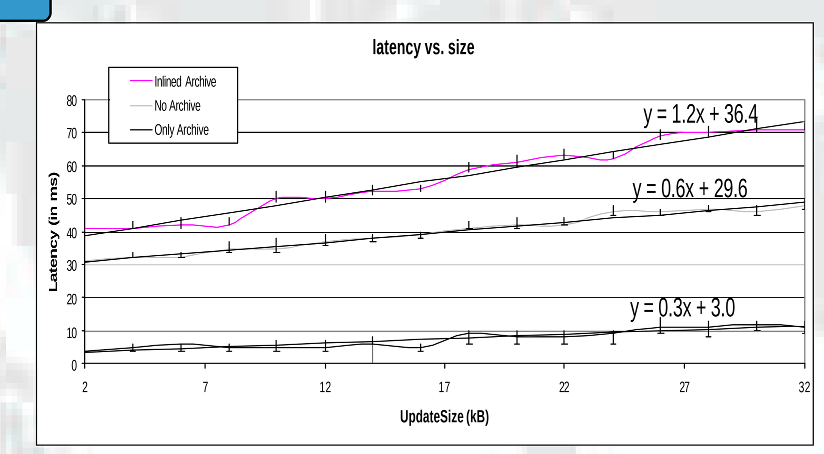
Performance

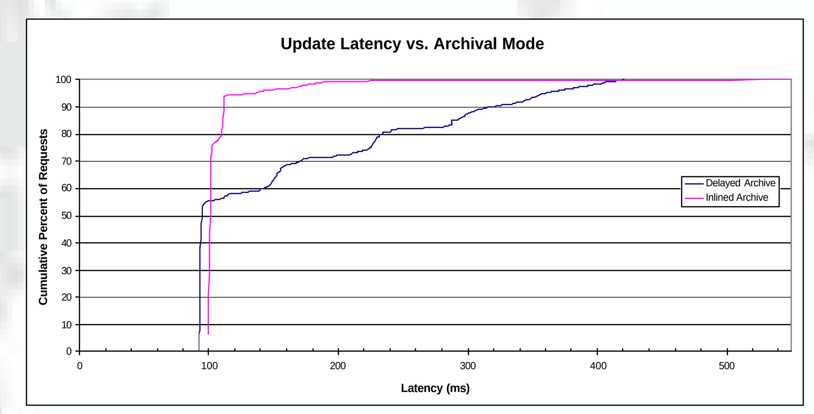
Throughput

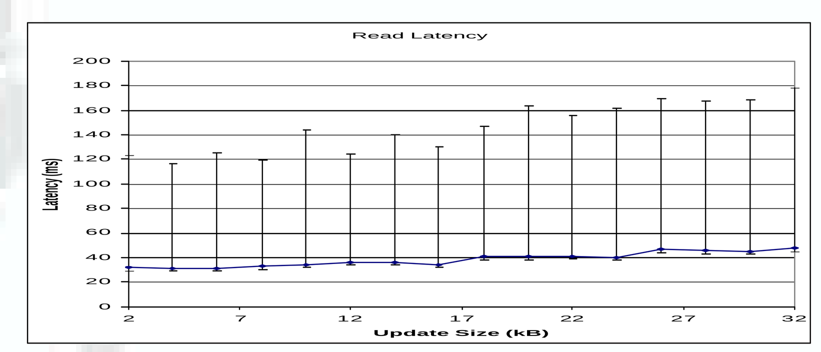




Latency





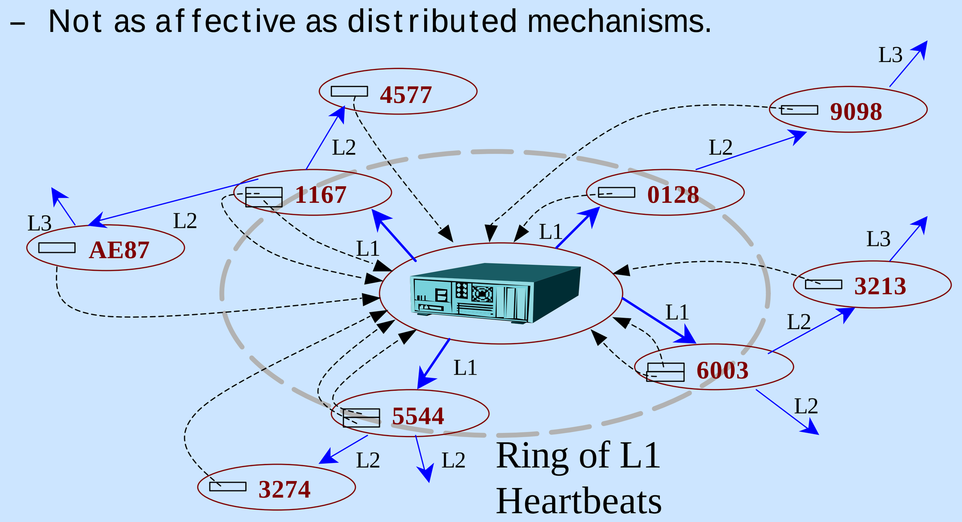


Conclusion

- The OceanStore archive combines several techniques to satisfy the goals of a global-scale archival system.
  - Erasure codes provide durability and availability.
  - Verification trees provide verifiability
  - Introspective failure analysis, automatic repair, and location independent routing promote maintainability.
  - The serializer provides atomicity.
  - End-to-end encryption (not discussed in this poster) provides privacy.
- Result.
  - Archival storage that is online and inline.
    - Data is durable and accessable.
  - Archival storage that has good user perceived latency.

Efficient Repair

- Local.
  - Durability enhancement techniques such as RAID.
  - Servers proactively copy data to new disk.
  - Servers periodically verify the integrity of local data.
- Distributed.
  - Exploit Tapestry's distributed information and locality properties.
- Global.
  - Not as affective as distributed mechanisms.

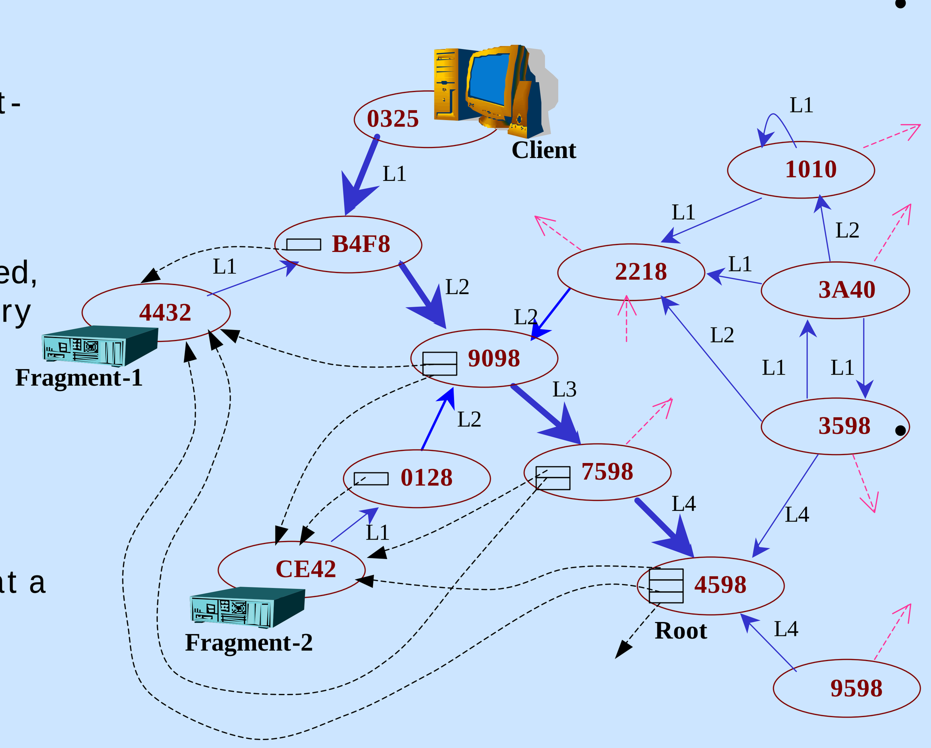


Ring of L1 Heartbeats

Future Directions

Enabling Technology: Tapestry

- Tapestry is a *location-independent* routing infrastructure.
  - Fragments and serializers are both named by opaque bit-strings (GUIDs).
  - Tapestry can perform location-independent routing of messages directly to objects using only GUIDs.
  - Tapestry is an IP overlay network that uses a distributed, fault-tolerant architecture to track the location of every object in the network.
  - Tapestry has two components: a *routing mesh* and a *distributed directory service*.
- Routing in Tapestry.
  - Nodes are connected to other nodes via neighbor links.
  - Any node can route to any other by resolving one digit at a time:
    - e.g. 1010 => 2218 => 9098 => 7598 => 4598
  - Each GUID is associated with one particular *Root* node.



- Publish.
  - send a message toward the *root*.
  - leaving back-pointers at each hop.
  - E.g node 4432 stores a fragment with GUID name 4598.
    - Publish steps: 4432 => B4F**8** => 90**98** => **7598** => **4598**
- Look-up.
  - Clients and serializers locate fragments by sending a message toward a root.
  - until they encounter enough pointers.
  - E.g. Client 0325 can locate two fragments after only two hops: 0325 => B4F8 => 9098.