Hierarchical Erasure Coding: Making Erasure Coding Usable

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Today’s Presenters

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What are we covering and not covering

◈ What are we covering
  ◆ Hierarchical erasure codes – A combination of an outer code and an inner code

◈ What are we not covering
  ◆ Different types of erasure codes
  ◆ Tradeoffs between these codes
Industry Dynamics

- Disk drives are increasing in size – reaching double digits sizes in a few years

- Bit error rates are much worse –
  - SMR drive error rates are an order of magnitude worse (10 times worse than enterprise drives)

- Drive profiles are changing
  - Some can spin up & spin down without increasing failures
  - Some are IO limited
  - Some are great for sequential IO

- and the cost is lower
What is erasure coding?

Object: ABC

Striped and Erasure Encoded:

6 Data Fragments

3 Parity Fragments

Any 6 fragments re-constitute the original object
How is this different from RAID?
Example: 6+3 Reed Solomon

Erasure coding = RAID*(?) over the network (With some differences)

* RAID is a form of EC. This slide implies that they are different. This is not the case. The slide is attempting to explain implications rather than clarify definitions.
Let’s compare Apples to Apples (1/2)

- **Speed of repair is critical**: Repair before we lose surviving redundant data.

- **Slower repair rate results in need for greater protection** - Increase redundancy by adding parity

- **Speed of repair is dependent on rate at which**
  - Existing data can be read from surviving drives
  - New parity data can be generated
  - New parity data can be written back to disk(s)
## Lets compare Apples to Apples (2/2)

Assume:
- 1Gbps ethernet connection between different disks / nodes
- 4TB Drives

<table>
<thead>
<tr>
<th></th>
<th>Erasure Coding (8+2 over the network)</th>
<th>De-clustered RAID – Dual parity (8+2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data read + write Rate MB/s</td>
<td>80% of 1 Gbps ~ 100MB/s</td>
<td>800 MB/s * (~ 60 disk pool)</td>
</tr>
<tr>
<td>Data reconstruction speed MB/s</td>
<td>10 MB/s</td>
<td>80 MB/s*</td>
</tr>
<tr>
<td>Total data to be reconstructed</td>
<td>4TB</td>
<td>4TB</td>
</tr>
<tr>
<td>Time to reconstruct the data (Hours)</td>
<td>111 Hrs</td>
<td>13 Hrs</td>
</tr>
<tr>
<td>Mean time to data loss</td>
<td>~ 229,000 years</td>
<td>~ 1.8 million years</td>
</tr>
</tbody>
</table>

- **At similar parity levels Erasure coding has**
  - Worse time to data loss
  - Generates an immense amount of network traffic and resulting system latency

* Based on actual data. 64 Disk pool, 778 MB/s throughput, 99.64 MB/s repair speed
But, isn’t erasure coding supposed to be better than RAID?

▶ It is..
  ♦ Increasing parity dramatically increases reliability E.g 8+2 to 6+3 (~ triple parity RAID)

▶ And it is not..
  ♦ Extremely large network load impacts
    › Latency
    › System throughput & performance
  ♦ Memory & compute intensive server side processing
  ♦ System reliability is subject to law of diminishing returns

▶ Erasure coding fits
  ♦ Extremely low IOPS data sets
  ♦ With a high bandwidth networking connection,
  ♦ and significant host side resources
But this is not the full story..

How many copies of your data do you store?

- a) 1
- b) 2
- c) 3+
Multi-datacenter use cases

<table>
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<tr>
<th>Site - A</th>
<th>Site - B</th>
<th>Site - C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra site: EC (6+3)</td>
<td>Inter site: Full copy</td>
<td>Overhead: 3x (1.5 + 1.5)</td>
</tr>
<tr>
<td>Intra site: RAID (8+2)</td>
<td>Inter site: Full copy</td>
<td>Overhead: 2.5x (1.25 + 1.25)</td>
</tr>
<tr>
<td>Intra site: -</td>
<td>Inter site: EC (6+3)</td>
<td>Overhead: 1.5x (0.5 + 0.5 + 0.5)</td>
</tr>
</tbody>
</table>

- EC across multiple datacenters is the key use case
- Network rebuild: orders of magnitude more expensive, Data access requires Wan access and makes latencies worse, Significant availability challenges across multiple datacenters
Hierarchical EC – The next generation

3rd Level EC

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Hierarchical EC – The next generation

- Sufficient redundancy to resolve majority of disk loss events at node level - Node level erasure coding
- Protects against rare and catastrophic failures
- Create a logical separation between single site failure domains and multi-site issues

Top Level EC

2nd Level EC

Object
Why Hierarchical EC

- Repair where it is cheapest - Prevent local failures from becoming systemic problems

- Benefits
  - Reduction in overall rebuild traffic
  - Dramatically lower repair traffic over the WAN
  - Better support for small object sizes
  - Better latencies
  - Better storage efficiency for similar reliability
  - Operational tasks are much simpler unlike flat codes
  - System reliability is mostly constant
Repair where it is cheapest & quickest

Local repairs with Node level EC

Remote repairs for catastrophic failures

Massive reduction in repair traffic

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Support for smaller object sizes & more number of objects

1/3 smaller objects, 3x number of objects

1 MB object = 9 x 111 KB Chunk

1 MB object = 3 x 333 KB Chunk

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Better read latencies – due to WAN performance

Application Visible Latency = 100ms

- Probability of slow nodes = 1/3
- Slow node latency = 100ms

Application Visible Latency = 25ms

Top Level EC

2nd Level EC
Better reliability for similar storage efficiency

Overhead = 1.5x

Overhead = 1.5 \times 1.17 = 1.76
Flat codes do not reflect real world failure domains

In the event of a site loss
- Loss of even ONE drive results in DATA LOSS
- Minimum usable spread is 7+5

Overhead = 1.5x

Overhead = 1.71x
Better reliability & storage efficiency tradeoffs

MTTDL = 21 Million billion years
Overhead = 1.71x

- MTTDL for one stripe
- Number of stripes = (failure domains / node * number of nodes) 60^12 ?
- More stripes = Increased probability of data loss
- Actual MTTDL much lower

(Refer: Usenix 2013 paper on Copysets: Reducing the frequency of data loss in cloud storage)
Better reliability & storage efficiency tradeoffs

**Hierarchical EC**

**Top Level EC: 6+3**
- Disk Reconstructed @ 11MB/s
- Object
- SITE A: JBOD (240TB), JBOD (240TB), JBOD (240TB), JBOD (240TB), JBOD (240TB), JBOD (240TB)
- SITE B: 7+5 EC
  - Overhead = 1.71x
  - MTTDL = 4 Billion years
  - Disk Reconstructed @ 8MB/s

**2nd Level EC (17+3)**
- Disk Reconstructed @ 80MB/s
- Object
- SITE A: JBOD (240TB), JBOD (240TB), JBOD (240TB), JBOD (240TB), JBOD (240TB), JBOD (240TB)
- SITE B: 7+5 EC
  - Overhead = 1.71x
  - MTTDL = 130,000 better than flat
- SITE C: FLAT EC
  - MTTDL = 21 Million billion years
  - Overhead = 1.5 x 1.17 = 1.76
  - Disk Reconstructed @ 11MB/s
Availability determined by stripe width
- If any one of the 9 nodes suffers a temporary outage, all writes fail

Example Workaround
- Write to 6+1 nodes and DEFER 6+3
- Dramatically affects MTBF

MTTDL – 138 Years
Disk Reconstruction @ 11MB/s

MTTDL – 540,000 Years
Disk Reconstruction @ 11MB/s
Write Availability - Hierarchical
Designing for Availability & Reliability at the same time is hard

- Hierarchical separation enables ‘Site level’ availability domains

Top Level EC: 6+3

2nd Level EC (17+3)

Disk Reconstructed @ 11MB/s

Disk Reconstructed @ 80MB/s

Per site “Availability” domains
Growing storage pools is hard (1/3)

- Consider
  - Single node with 60 x 4TB Drives
  - Node size = 240TB
  - Number of sites = 3
  - Infrastructure size = 2PB

- The below is perfect fit
Growing storage pools is hard
(2/3)

- Consider
  - What if the Infrastructure has to grow 750TB (3 nodes)
- EC spread has to change to accommodate the growth
  - Wider spread is required: 6+3 becomes 8+4
  - Wider spread is good for reliability – it is bad for everything else
  - Wider spread is worse for object size, latency, repair traffic
Growing storage pools is hard (2/3)

- **Hierarchical**
  - Identical issues for EC only use cases, but
  - Multi-use case scenarios become possible: replicated + EC
Summary

- **Erasure coding is the future of reliable storage**
  - In an ideal world, with 0ms latency, infinite bandwidth & CPU – wide spreading flat codes are fantastic

- **Multi-site use cases are key for erasure coding**
  - Majority of storage overhead required for site failure protection – Can’t get away from it (e.g 2x for two site, 1.5x for 3 site)

- **Hierarchical erasure coding solves real world problems better than flat erasure codes in multiple dimensions**
  - Prevent local failures from becoming systemic problems
  - Dramatically lower WAN repair traffic
  - Support smaller object sizes
  - Better latencies
  - Better storage efficiency & reliability tradeoffs
  - System reliability is mostly constant
  - Enable support for multiple use cases
After This Webcast

- This webcast and a copy of the slides will be posted to the SNIA Cloud Storage Initiative (CSI) website and available on-demand
  - [http://www.snia.org/forum/csi/knowledge/webcasts](http://www.snia.org/forum/csi/knowledge/webcasts)
- A full Q&A from this webcast, including answers to questions we couldn't get to today, will be posted to the SNIA-CSI blog
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Conclusion

Thank You