Understanding Rack-Scale
Disaggregated Storage

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Storage Disaggregation

Common in the cloud:
- Compute racks
- Storage racks
- Network

Improves performance/cost:
- Independent resource scaling
- Rack hardware specialization

Does not happen in HDD storage racks:
- Shared-nothing Servers
- Direct-attached Storage (DAS)

Strict HDD Ownership Principle:
- HDD always managed by the server to which it is physically attached

Do we need rack-scale storage disaggregation?

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Rack-Scale HDD Storage Disaggregation

• Relaxing the HDD Ownership Principle
  • At a given time, a HDD is managed by one server...
  • ...but it is possible to reconfigure which server it is.

• Enables 4 types of disaggregation:
  • Configuration Disaggregation
  • Failure Disaggregation
  • Dynamic Elastic Disaggregation
  • Complete Disaggregation

No reconfiguration during normal operation
Reconfiguration part of normal operation
No Reconfiguration during Normal Operation

• **Configuration Disaggregation**
  • One rack for all workloads
  • Configure once at deployment
  • Optimized offline for workload

• **Failure Disaggregation**
  • Reconfigure on server failure
  • Move HDDs, not data
Reconfiguration is part of Normal Operation

• **Dynamic Elastic Disaggregation**
  - Dynamically adapt HDD-to-server ratio
  - High load: each server gets its fair share of HDDs
  - Low load: most HDDs attached to few servers

• **Complete Disaggregation**
  - Reconfigure at IO granularity
  - Any server can IO to any file on any HDD
### Summary of Disaggregation Scenarios

<table>
<thead>
<tr>
<th></th>
<th>Configuration Disaggregation</th>
<th>Failure disaggregation</th>
<th>Dynamic Elastic Disaggregation</th>
<th>Complete Disaggregation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage stack redesign</td>
<td>No</td>
<td>Small</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Online controller</td>
<td>No</td>
<td>Not necessarily</td>
<td>Yes</td>
<td>Yes (on IO path)</td>
</tr>
<tr>
<td>Reconfiguration frequency</td>
<td>$O$(rack lifetime)</td>
<td>$O$(server failures)</td>
<td>$O$(hours-days)</td>
<td>$O$(IO rate)</td>
</tr>
<tr>
<td>Reconfiguration overhead</td>
<td>None</td>
<td>Not under normal operation</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

**Flexibility**

- Low
- High

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A Fabric to Explore Rack-Scale Disaggregation

- Storage switch
  - Custom hardware design
  - Circuit switch abstraction
  - 160 ports @ 6 Gbps/port
- Benefit of the design: extreme flexibility
Experience with Configuration Disaggregation

• Easy to enable
  • No controller
  • No reconfiguration overhead
  • Unmodified software on servers

• Simplifies management & operation
  • One storage rack for all workloads

• Also very useful for development
  • We use it on a daily basis!
  • Fast instantiation of test configurations

Our test setup for configuration disaggregation
Experience with Failure Disaggregation

• Hardware trends impact data availability:
  • HDD and SSD capacities grow
  • Servers can have a LOT of direct-attached storage
  • e.g.: Petabytes of data per Pelican (cold storage) server
  • On failure, amount of data and time to recover increases

• Failure disaggregation improves availability
  • Reduces data unavailability to tens of seconds or less
  • No resources used to rebuild data
  • No reconfiguration overhead for normal operation

Pelican prototype has:
• 1152 HDDs/rack
• 2 servers
Exploring Dynamic Elastic Disaggregation

- **Ongoing work**
- **Storage workloads are bursty**
  - Average server utilization is low
  - Load skew across servers
- **Online controller**
  - Monitors storage traffic in the rack
  - Adapts HDD-to-server ratio
  - Not on the data path
- **Better server utilization**
  - Allows storage tiering within the rack
  - Some servers can host background jobs, spot VM instances
Complete Disaggregation, seriously?

- Can we reconfigure per IO?

Time to switch and mount SATA SSD:

- Driver
- NTFS + Mount

Impact on throughput of switching after every IO:
(no File system mount)

Max SSD bandwidth

Cost of reconfiguration

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Experience with Complete Disaggregation

• A lot of pain:
  • Ecosystem challenges
  • Redesign of the storage stack
  • High overhead for small IO
  • Meta data service on the IO path
  • Hard to implement/debug

• Benefits
  • Fine-grain load balancing
  • Server failure tolerance by design

Complete disaggregation setup
  • 120 SATA SSDs
  • 4 servers, 3 SATA ports/server
Conclusion

• In the cloud today: no disaggregation in storage racks
  • Fixed drive-to-server mapping

• We designed a storage fabric to explore in-rack disaggregation

• Rack-scale storage disaggregation can be useful and affordable
  • Configuration disaggregation
  • Failure disaggregation
  • Dynamic elastic disaggregation
  • Substantial benefits
  • No/small reconfiguration overheads
  • Little or no software/hardware changes

• Can become a challenge
  • Complete disaggregation
  • High reconfiguration overhead
  • Hard to implement and maintain