SRCMap: Energy Proportional Storage using Dynamic Consolidation

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- Current power density of data centers is 100 W/sq.ft & increasing 15-20% per year.
- Storage consume 10-25% of computing equipment.
- Storage load low (10-30%), but still peak power consumed.
- CPUs are more energy proportionality than storage.
- Consolidation is a well known technique for energy proportionality in virtualized servers.

Storage Consolidation?

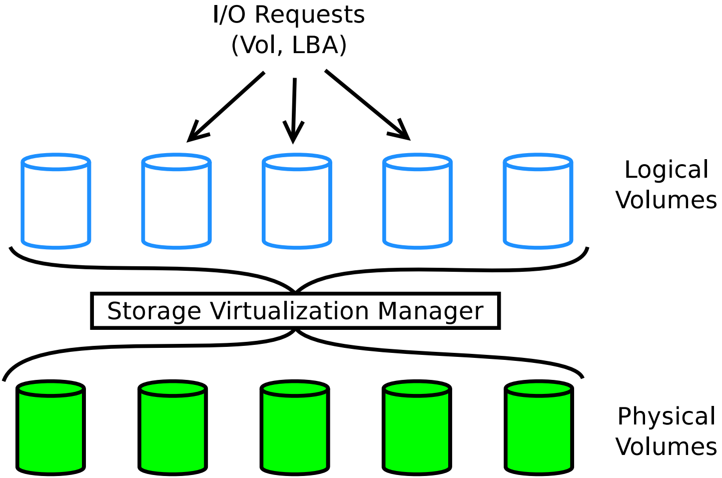
Can we use a storage virtualization layer to design a practical energy proportional storage system?

- Storage virtualization I/O indirection useful for consolidation.

Challenge

Moving logical volumes from one device to another is prohibitively expensive.

Background: Storage Virtualization



Outline

Workloads

- **mail** Our department mail server.
- **web-vm** Virtual machine hosting two web-servers: CS web-mail & online course management.
- **homes** NFS server that serves the home directories for our research group.

Block traces collected downstream of an active page cache for three weeks.

Observations

Observation 1

The active data set is only a small fraction of total storage used. (about 1.5-6.5%)

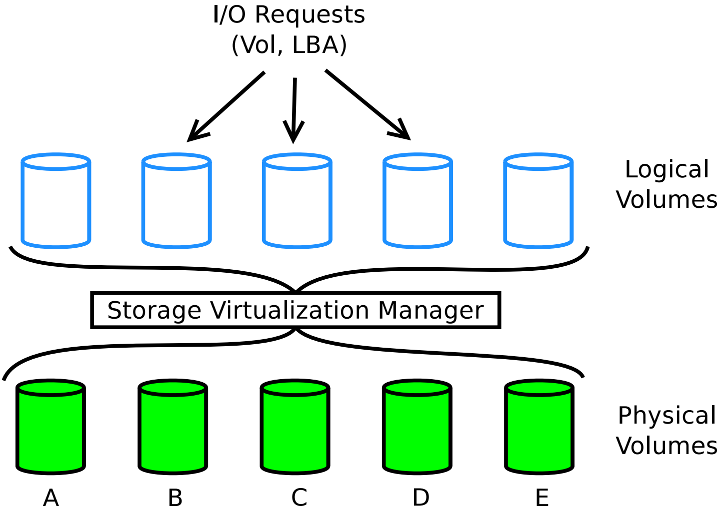
Observation 2

There is a significant variability in I/O load. (5-6 orders of magnitude)

Observation 3

More that 99% of the working set consist of *really popular & recently accessed* data.

Overview


I/O Requests
(Vol, LBA)
Logical
Volumes
Storage Virtualization Manager
Physical
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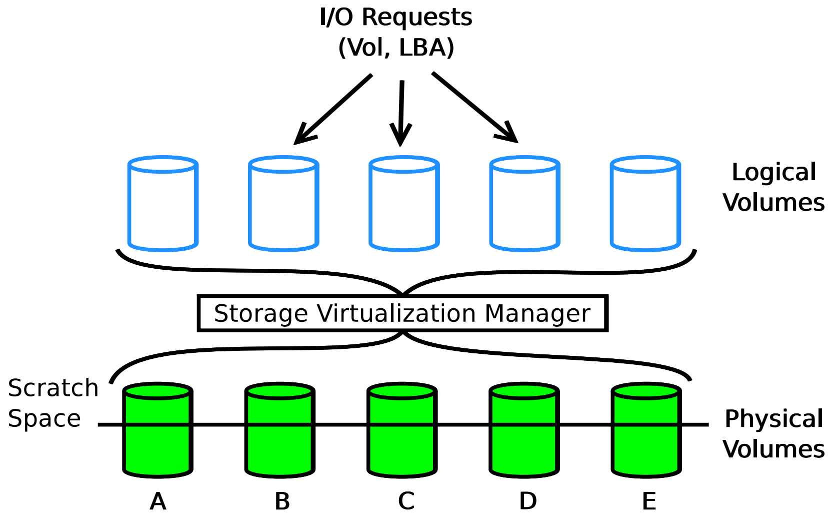
A
B
C
D
E

Overview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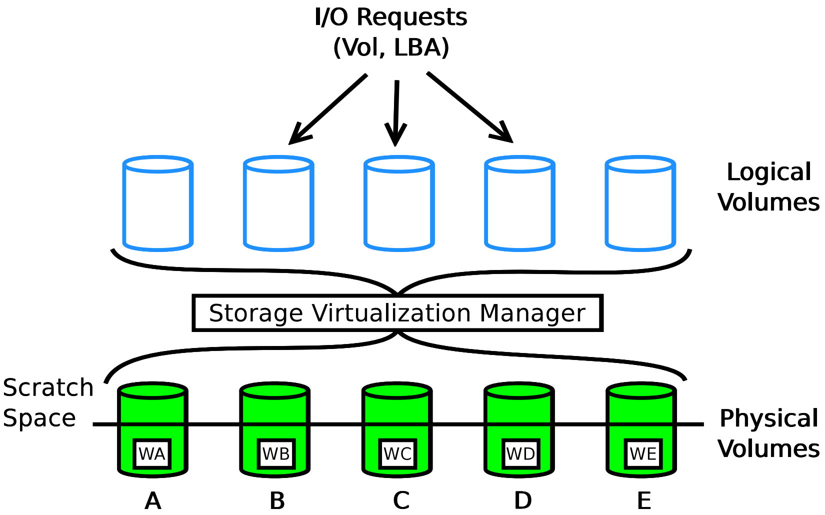
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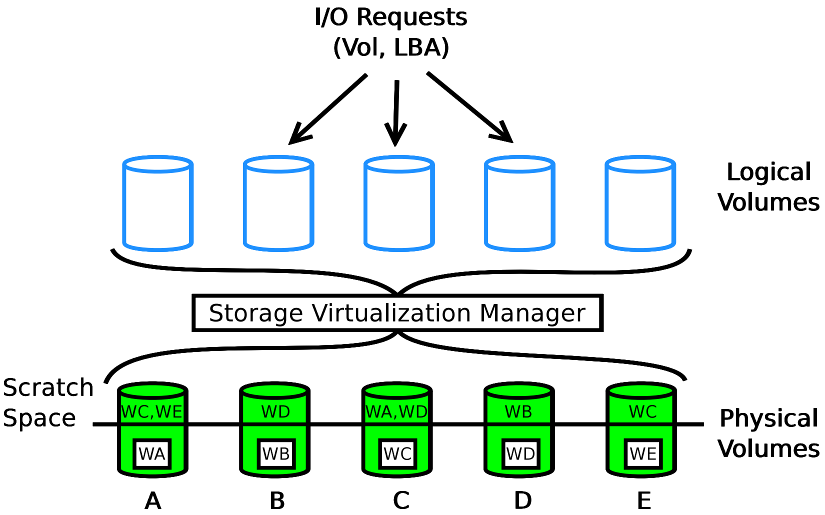
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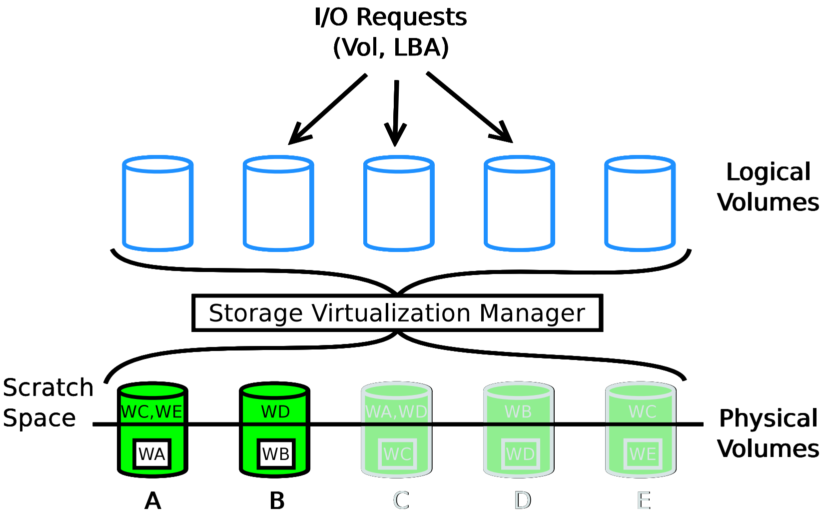
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Our Approach

Sample Characterize the logical volume to find the working set.

Replicate Create multiple working-set replicas in various physical volumes' scratch space.

Consolidate Based on I/O workload intensity, activate a sub-set of physical volumes and serve workloads either from original copies or working set replicas on these active disks.

Our Approach

Initialization

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Every H hours

Goals → Solutions

Goal
Fine grained proportionality
Low space overhead
Reliability
Workload Adaptation
Heterogeneity support

Goals → Solutions

Goal	Solution
Fine grained proportionality	Multiple replica targets.
Low space overhead	Instead of entire volumes, only working-sets are replicated.
Reliability	Coarse-grained consolidation intervals. (hours)
Workload Adaptation	Update working set replicas with new data that lead to read misses.
Heterogeneity support	Performance-power ratio accounted for in the replica placement benefit function.

SRCMap work-flow

Event	**Response**
Initialization	Detect working-sets of logical volumes & create replicas.
Every H hours	Identify what volumes and replicas to activate the next H hours.
Change in workload	Same as initialization.

SRCMap work-flow

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Every H hours	**Identify what volumes and replicas to activate the next H hours**.
Change in workload	Same as initialization.

Replica Placement

- Replication benefit based on:
  1. Working set stability
  2. Average load
  3. Power efficiency of primary physical volume.
  4. Working set size
- Assign space with priorities based on benefit.
- Update replica creation benefit as additional replicas are created.
- Algorithm executes until scratch spaces are full.

Active Replica Identification

- Calculate predicted aggregate workload IOPS.
- Compute minimum number of volumes to serve the aggregate IOPS.
- Identify replicas for inactive volumes.
- The number of active disks is incremented by one in case no active replica has been identified for some inactive volume.

Workloads & Configuration

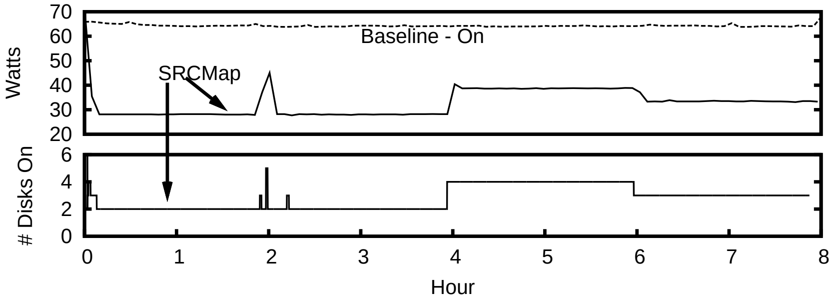
- 8 workloads to independent data volumes.
- Mix of web-servers of our CS department, and file server, SVN, and WiKi for our research group.

- $H = 2$. Change active replicas every 2 hours.
- Two minute disk time-outs.
- Working sets & replicas based on three week workload history.
- We report results of replaying the next 8 most active hours in the traces.
- We assume an oracle for estimation of load during each consolidation interval.

Storage test-bed

- One machine with 8 SATA ports.
- Intel P4 HT 3GHz, 1GB memory.
- Trace played back using *btreplay*.
- Dedicated power supply for disks connected to power meter.
- *Watts up? PRO* power meter: measures power every second with resolution of 0.1W.

Power



- Power consumption measured every second & active disks every 5 seconds.

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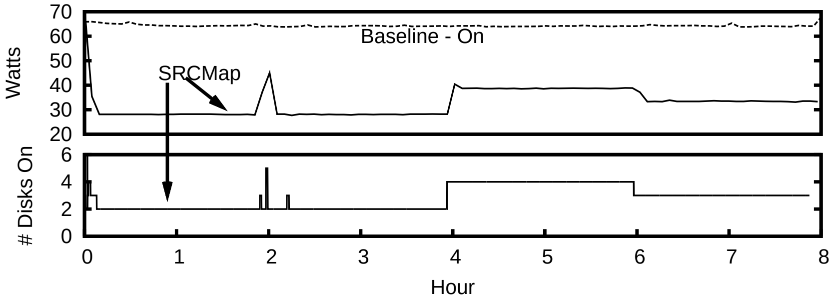

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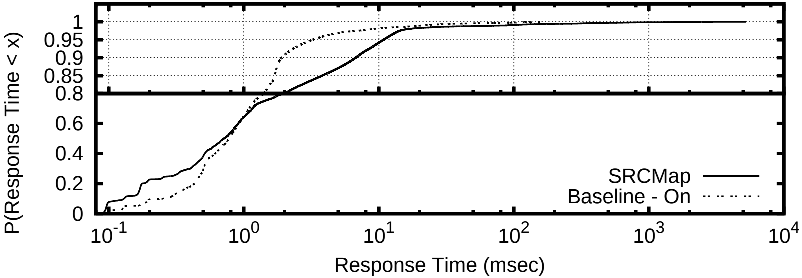
Disks off	Power Saved
4.33	23.5 (35.5%)

Response time



- After 1ms, Baseline - On demonstrate better performance.
- 8% of requests with latencies $\geq$ 10ms.
- 2% of requests with latencies $\geq$ 100ms.

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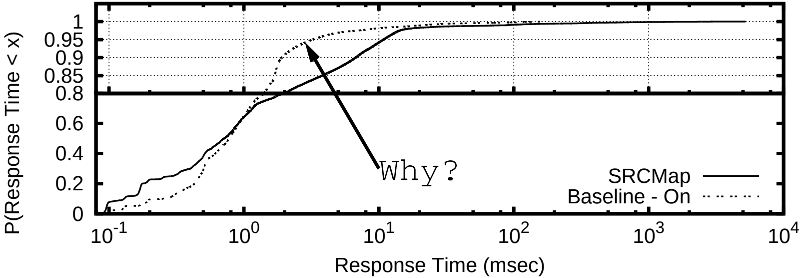

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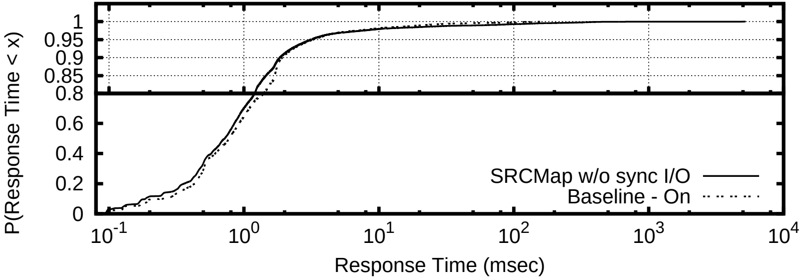

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- 8% of requests with latencies $\geq$ 10ms.
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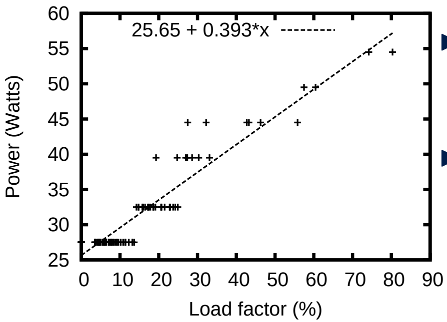
- Synchronization I/Os issued at beginning of each interval.
- Replaying without sync I/Os follows Baseline-On more closely.

Energy proportionality



- One point for each 2-hour interval in 24-hour duration.
- **Load Factor**: Load relative to the assumed volume maximum load capacity.

SRCMap is able to achieve close to N-level proportionality for a system with N physical volumes.

Conclusions

- We proposed and evaluate SRCMap, a storage virtualization solution for energy proportional storage.
- SRCMap establishes the feasibility of energy proportional storage systems.
- SRCMap meets all goals we set out to achieve energy proportional storage:
  - ✓ Low space overhead
  - ✓ Reliability
  - ✓ Workload adaptation
  - ✓ Heterogeneity support
  - ✓ Fine grain energy proportionality

Future Work

- Models to predict I/O workload intensity.
- Models that estimate the performance impact of storage consolidation.
- Investigate the presence of workload correlation for better workload estimation and consolidation decision.
- Optimizing the scheduling of synchronization I/Os to minimize impact on foreground requests.

http://dsrl.cs.fiu.edu/projects/srcmap/

Questions?

Related Work

- Singly redundant schemes: Spin down volumes with redundant data during low load.
- Geared RAIDs: Redundancy on several disks and each disk spun down represents a gear shift.
- Caching systems: Cache of popular data on additional storage.
- Write Offloading: Increase disk idle periods by redirecting writes to alternate locations.

Other Methods