Intelligent Cache Hinting

3x Improvement in Small File Performance with I/O Hinting in Lustre*

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Why Provide Caching in Lustre*?

What problems are users experiencing?

- Small file and random I/O
- Complex to managing multiple file systems
- Pure SSD storage is expensive

Problems with traditional Caching

- Caches are inefficient at keeping “important” data
- Application context is lost in storage interfaces
  (e.g., SCSI, REST)
- End-to-end Quality of Service is increasingly difficult

Conceptual Approach

I/O Classification

#1 Classification

Application data

Classify each storage I/O request (in-band)

#2 Policy assignment

Storage policies

Assign policies to I/O classes (out-of-band)

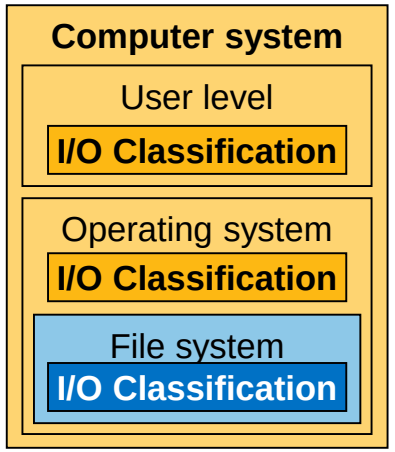
#3 Policy enforcement

*Lustre**

Enforce policies in storage system

Classification Architecture

Classification



Policy assignment

Classifier	Group #
Metadata	*0*
Boot files	*1*
Small files	*3*
Media files	*2*
...	...

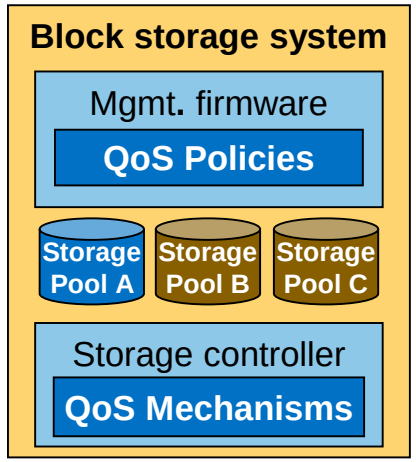
(offline)

Table 75 — WRITE (10) command

Byte \ Bit	7	6	5	4	3	2	1	0
0	OPERATION CODE (2Ah)							
1	WRPROTECT			DPO	FUA	Reserved	FUA_NV	Obsolete
2	(MSB)	LOGICAL BLOCK ADDRESS						
5								(LSB)
6	Reserved			GROUP NUMBER				
7	(MSB)	TRANSFER LENGTH						
8								(LSB)
9	CONTROL							

Classify each I/O in-band (e.g., in SCSI command descriptor block)

Policy enforcement



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Cache Implementation – How do we pass hints?

Classifying I/O using SCSI Command Descriptor Block

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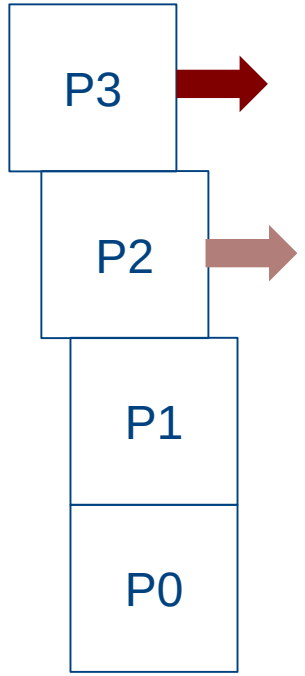
5 bits → up to 32 classes

Cache Implementation – What do we need?

Caching HW/SW must do the following –

1. Implement a ***selective allocation*** algorithm
   - Multiple LRUs, each with for a unique class (priority)
   - I/O is assigned to LRUs (based on their class)
   - Low priority I/O is “fenced off” under cache pressure

2. Implement a ***selective eviction*** algorithm
   - Data classes can be soft-pinned (priority-based eviction)
   - Data classes can be hard-pinned (never evicted)



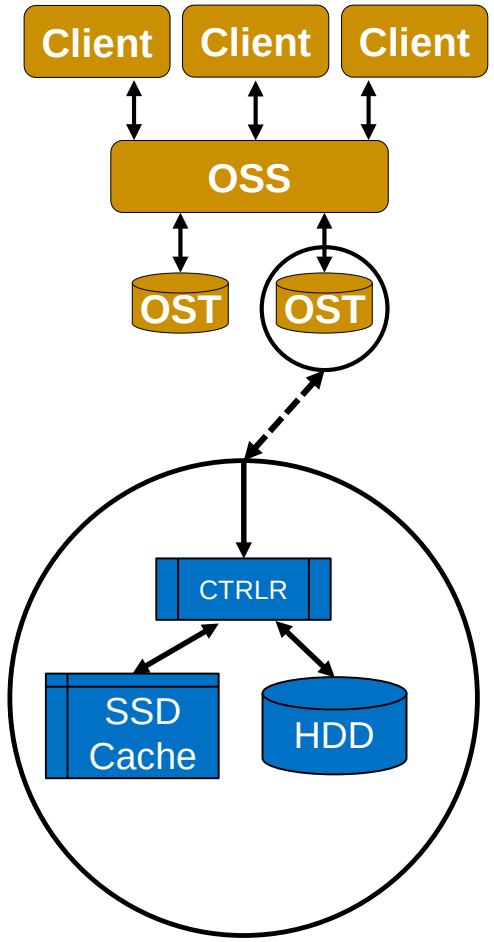
Cache Implementation – Where do we cache?

Client-side Caching is Difficult

- More clients increases the cost
- Cache Coherency Issues
- Moving data from cache to storage can cause problems without QoS

Caching on the Server is Preferable

- Fewer devices, reduced cost
- Transparent to Lustre*
- Fails over with OST



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Integration with Lustre*

Ldiskfs changes

- Add classifier to I/O requests
- Only coalesce like-class requests
- Copy classifier into SCSI CDB
- 18 classes identified →
- Optimized for a file server
  - ➢***Small files & metadata***

One-time change to FS

Ldiskfs Class	Group Number	Cache priority
Unclassified	0	12
Superblock	1	0
Group desc.	2	0
Bitmap	3	0
Inode	4	0
Indirect block	5	0
Directories	6	0
Journal	7	0
File <= 4KB	8	1
File <= 16KB	9	2
File <= 64KB	10	3
…	…	…
File > 1GB	18	11

Performance Analysis - Objective

Combine traditional Lustre* IO (IOR) with Small File and Random I/O (Postmark) to assess the benefits of Cache Hinting

- Is 10% Cache storage significant?
- Performance compared to LRU cache?
- Performance gap to pure SSD?

What is the impact on overall Lustre performance?

Test Cluster Configuration

All nodes R2000GZ* servers

- 2-socket Intel® Xeon® processors - E5-2680 v2 @ 2.8 GHz, 96 GB DRAM
- 10 GbE network
- SSD system disk
- 10 TB additional storage
- Centos* 6.4, 2.6.32 kernel, Lustre* 2.5.x

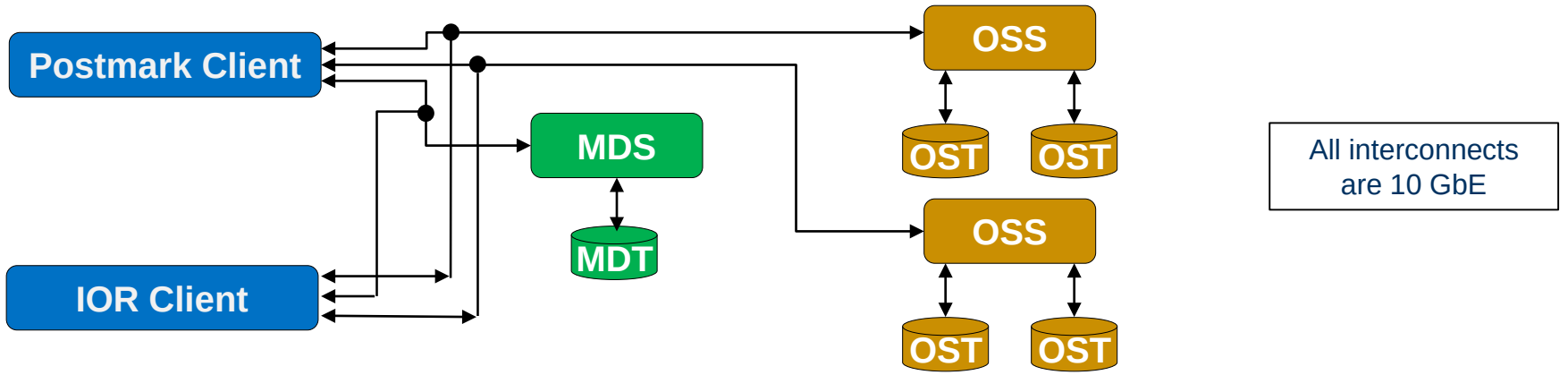
OSS(s) have 2 12TB RAID-6 OSTs (via JBOD)

2 Clients, 1 MGS/MDS, 2 OSS X 2 OSTs

Initial testing

- 1 OSS with single OST; 1 OSS with 2 OSTs
- Results are consistent for both configurations

Benchmark Configuration



All interconnects are 10 GbE

Postmark

- For our tests
  - 300,000 Files (1KB to 32MB)
  - 10,000 Subdirectories
  - 30,000 Transactions

The SPECsfs file server configuration

- ~180 GB of data created

IOR (Interleaved-Or-Random)

For our tests:

BEGIN_LOOP
- Write 20GB “checkpoint” file
- Write 8MB “data set 1” file
- Write 8MB “data set 2” file
- Read checkpoint file
- Read data set 1
- Read data set 2

END_LOOP

Runs concurrently with Postmark

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Caching – Results and Optimization

Caching vs. HDD

3.9x
Performance

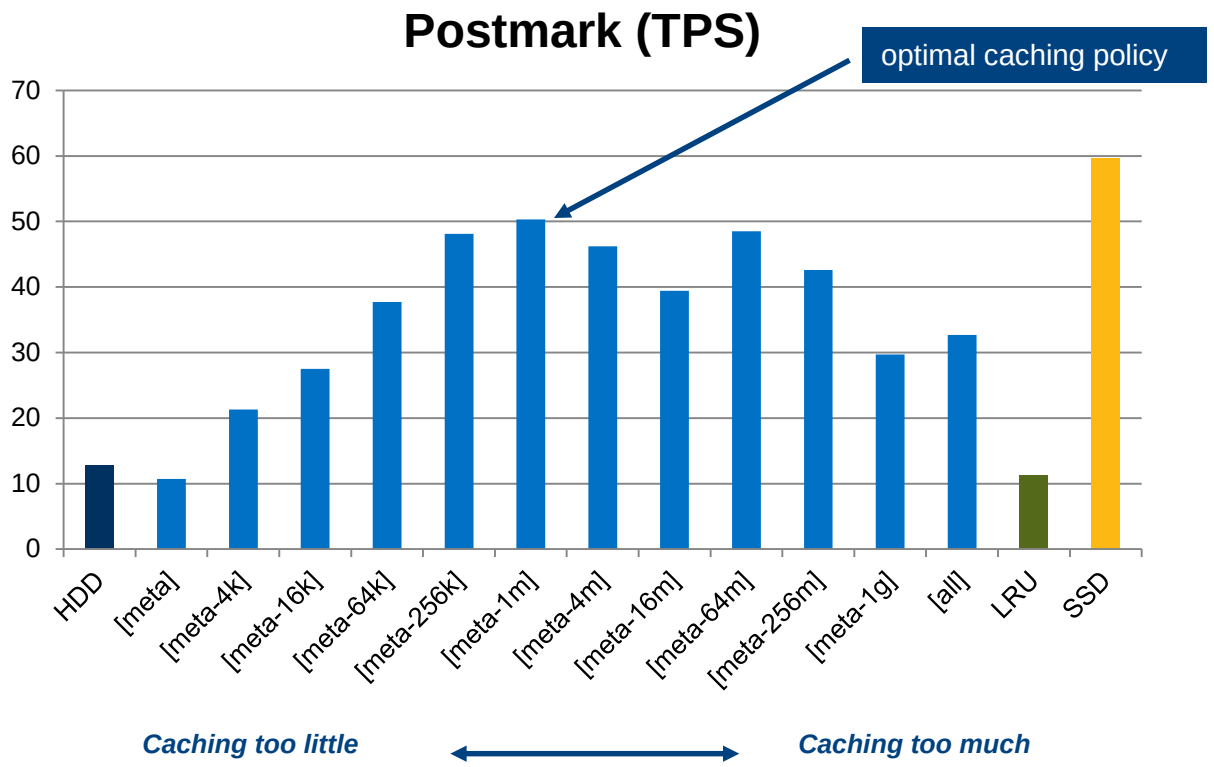
Cache too little?

-Underutilized SSD

Cache too much?

-Reduced HDD parallelism

-Cache thrash



I/O hints enable "hill-climbing" optimization

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Potential Future Enhancements

Future Improvements – Standardization

Standardize reference classifications with T10

- Standard set of base classifiers and group numbers for cache Hinting
- Reference schemas certified
- Provides vendors requirements to use for development

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Upstream hinting capabilities into Linux kernel

Future Improvements

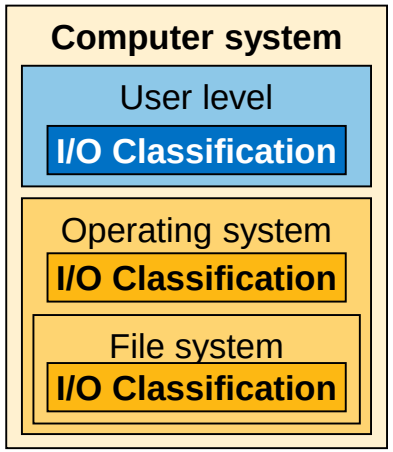
Provide Hints directly from User Applications

Files tagged with cache priority by specific applications

- Further optimization of hinting
- File system hints can still be used in lieu of application hints
- Difficult to assess for proprietary apps

What would be helpful in this space?

Classification



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- Michael Mesnier – Intel Labs
- John Keys – Intel Labs
- Andreas Dilger – Intel HPDD
- Hongchao Zhang – Intel HPDD

More Information –

- Emerging SCSI standard for I/O hinting – SBC-3: Accessible LBA Access Hints (12-061r0).
- Christian Black, Michael Mesnier, Terry Yoshii. Solid-state Drive Caching with Differentiated Storage Services. Intel Whitepaper (IT Best Practices). July, 2012.
- T. Luo, R. Lee, M. Mesnier, F. Chen, and X. Zhang. hStorage-DB: Heterogeneity-aware Data Management to Exploit the Full Capability of Hybrid Storage Systems. PVLDB 5(10):1076-1087,2012.
- Michael Mesnier, Jason Akers, Feng Chen, Tian Luo. Differentiated Storage Services. 23rd ACM Symposium on Operating Systems Principles (SOSP). October 2011.

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