Towards Dynamic Load Balancing Policies in Software-Defined Storage

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ABSTRACT

TODO

1 INTRODUCTION

Key-Value stores scale because they support (1) fine scale annotation and (2) flexible, extensible formats. Science applications are structured, entropy increases over time (e.g., Figure 1 shows key distribution and key popularity changing over time). Our hypothesis is that re-distributing keys requires dynamic load balancing policies, similiar to distributed file systems. A one-size-fits all policy is not sufficient. Our contributions are:

(1) an analysis of the ParSplice keyspace
(2) using a modern distributed key-value store
(3) positive effects of Mantle

2 BACKGROUND

2.1 ParSplice

ParSplice [6] is a molecular dynamics simulation developed at LANL. It has 4 phases, as depicted in Figure 2:

(1) splicer (S) tells producers (P) to compute segments for state s_i
(2) P's pull initial coordinates $\{x_i, y_i\}$ from database
(3) a P inserts completed coordinates for segment s_i into database and S broadcasts next segment(s) s_j
(4) P's pull new segment coordinates $\{x_j, y_j\}$

The database is single node (LevelDB or BerkeleyDB) with caches in front. Our goal is to replace this architecture with a distributed key-value store to solve the immediate sync problems that the ParSplice team is facting. Sliding in something like MDHIM [2]

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[*]Dr. Trovato insisted his name be first.

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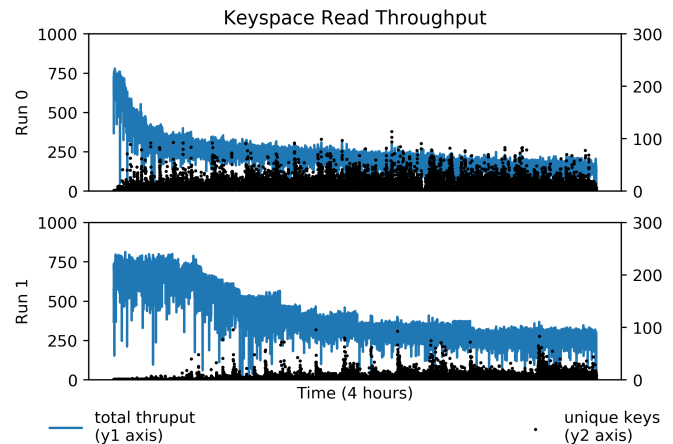

Figure 1: Caching the 100 most recently accessed keys is sufficient for run 1 but more active keyspaces like run 0 need dynamic load balancing policies.
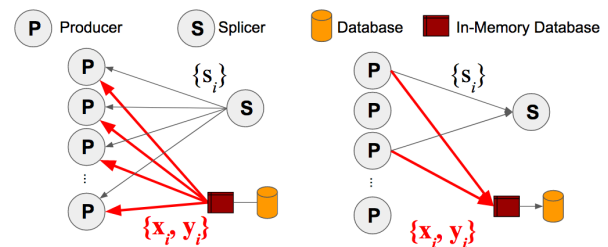
Figure 2: ParSplice is a ready-heavy HPC application where producers use a database for consistency. Replacing the single-node database with HXHIM improves performance with load balancing.

has the added benefit of enabling load balancing. ParSplice has distinct workload phases and a well-known keyspace (Figure 4) so its performance should improve with better load balancing.

2.2 MDHIM: Key-Value Store for HPC

MDHIM is a key-value store designed for HPC architectures and multi-dimensional data. It is based off MDHIM [2], the multi-dimensional

Figure 3: The MDHIM architecture.

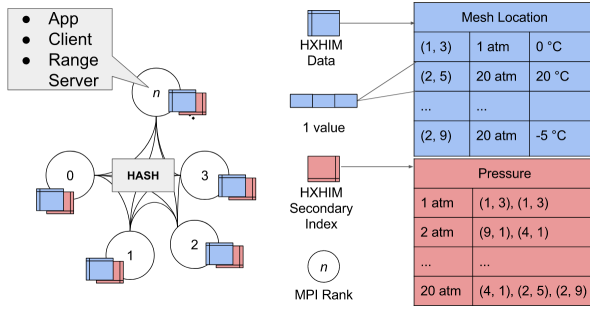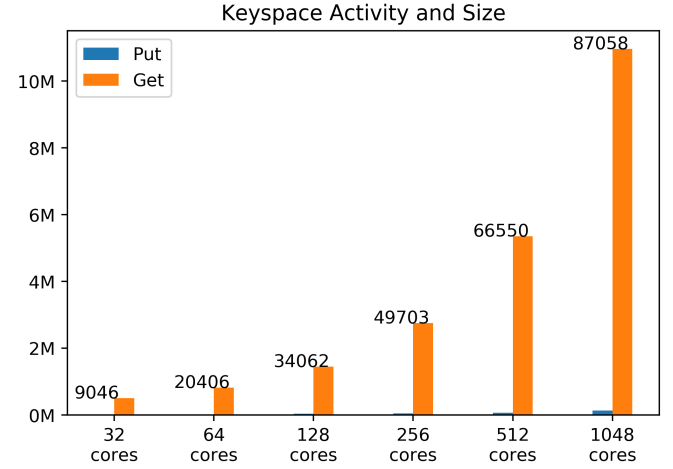

Figure 4: The ParSplice keyspace is small (numbers above bars) but must satisfy many reads as workers calculate new segments. The active keyspace is difficult to predict a priori but the optimal load balancing strategy strikes a good balance between preformance and utiization.

indexing middleware. Figure 3 has a crude sketch of the MDHIM architecture. Each MPI rank has an instance of the application, which has the client library linked in. An MPI rank can also have a "range server", which stores the key-value pairs in a local databse (either LevelDB or MySQL). Data is located with a consistent hash, which is configurable.

The primary and secondary indices shown on the right side of Figure 3 are views of the data that the range server manages. The primary index is the same hash used by the global partitioner. The secondary index or indices are user-defined tables organized in a different way from the primary index. The goal of the secondary indices is to speed up queries that need to aggregate dat (*e.g.* find the maximum values). In the example, the range server and the key in the primary index is located with a hash of the mesh location. The secondary index is organized by pressure, so queries asking for a certain atmosphere can be serviced in O1, consisting of one lookup in the pressure index and one lookup into the primary index.

MDHIM tailors its mechanisms and policies to HPC, showing improved performance over cloud-based key-value stores like Cassandra. It has cursor types for walking the key-value store, bulk operations for exploiting data locality, per-job server spawning, and pluggable backends for its local database and network type (infiniband/RDMA). Its policies are flexible, supporting customized partitioning strategies and user-defined secondary indices. This allows the system to choose whether to send load to the client or server.

3 METHODOLOGY

IT HAS 8K keys!

3.1 Contribution 1: ParSplice Keyspace Analysis

Part 2: As Parsplice simulates, entropy increases resulting in keyspace inbalance (Figure ?? shows how imbalance controlled by "growth rate")

3.2 Contribution 2: Positive Effects of Load Balncing

3.3 Contribution 3: The Need for Dynamic Load Balancing Policies
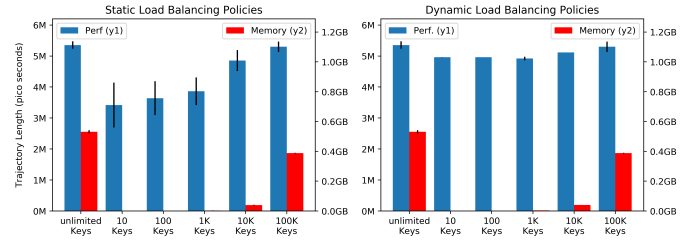
Why doesn't 1 policy fit all?

Figure 5: The optimal cache size must strike a balance between performance and resoure utilization. Here we show the trade-off for a static load balancing policy that evicts keys when the cache reaches a certain size. For this configuration, a 100K key cache has the best performance/utilziation, despite the keyspace being 250K keys.

- keyspace gets less active
- beginning: levelDB can't handle it
- end: levelDB can handle it
(1) fix DB size to 4GB
(2) trajectory default (1M and 100K)
(3) trajectory with naiive balancer
- Mantle (approach/API) to explore dynamic load balancing policies
  - quantifies effect of load balancing
  - formalized effective FS balancers
  - debugging tool
- HXHIM is a good fit because it has migration mechanisms for load balancing
  - bulk operations (`put/get()`)
  - key partitioners
  - secondary indices

- we need a way to learn these regimes
  - Figure **??** shows the same phases as 100K but that the timestamps affected by delay

Mantle is an API that lets admnistrators control file system metadata load balancing. Mantle speeds up file systems by making metadata access faster, leveraging the fact that file system metadata IO imposes small and frequent accesses on the underlying storage system. Since data IO does not scale like metadata IO [8], finding optimal ways to measure, migrate, and partition metadata load is a relatively new field, but has been shown to lead to large performance increases and more scalable file systems [1, 3, 5, 7, 12]. Mantle can use strategies from these papers to control how to distribute or concentrate file system metadata.

It was built on CephFS, the file system above Ceph, so it inherits many of characteristics of the CephFS architecture, like the dedicated metadata cluster and heartbeat mechanisms shown at the top of Figure 6. Each metadata server manages differently sized subtrees of the logical namespace and migration decisions are made synchronously, every 10 seconds. CephFS already had the mechanisms for load balancing, namely the ability to measure the load on a subtree, to migrate subtrees, and to partition subtrees into smaller subtrees, but it had hard-coded, ad-hoc policies for guiding the migrations. Mantle reads user-defined policies written in Lua and returns decisions for how load should be migrated given the state of the cluster and the behavior of the workload. The hooks in Figure 6 show where CephFS calls out to the Mantle library to make decisions. While the decisions were made by Mantle, CephFS used its internal mechanisms to do the load balancing.

The Mantle paper implemented three balancers and tested them under metadata-intensive workloads. The Greedy Spill balancer, which was based on [5], sheds have its load aggressively when there are avaiable servers. Part of the Lua code for implementing this balancer is shown in 7. The Fill and Spill balancer, which was based on [4] sheds a fraction of the load only when the server is overloaded. Finally, the Adaptable balancer, which was based on [10, 11], sheds a fraction of the load frequently.

It was merged[1] and is starting to get users who are frustrated with the hard-coded load balancing policies that are shipped with CephFS. It was re-implemented using the "programmable storage" approach [9] to reduce lines of code for doing things like versioning and distributing balancer version. Although Mantle is heavily integrated the daemons that compose an Ceph cluster, using Ceph's naming conventions and internal libraries like Ceph's version of protocol buffers, there is no reason that it cannot be extracted.

3.4 Contribution 4: Machine Learning Keyspace Activity

We can't find the optimal keypsace size for every permuation, finding the key threshold changes with

- number of nodes
- size of delay
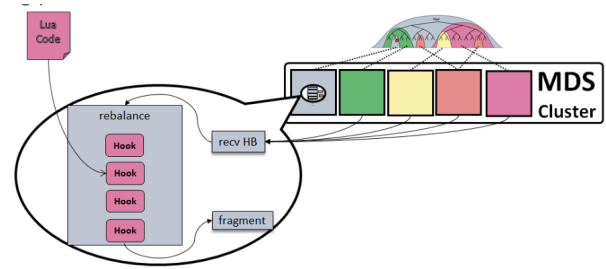
4 CONCLUSION

(1) analysis of Parsplice keyspace

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[1] https://github.com/ceph/ceph/pull/5155

Figure 6: The Mantle API lets admnistrators control load balancing by changing the poicies for how to distribution or concentrate file system metadata. It was merged into CephFS and inherits many aspects of that architecture. Although it has the load balancing structure and logic from CephFS (gray boxes), the actual API is not dependent on that code base.

```
-- Balancer when policy
if MDSs[whoami]["load"]>.01 and
    MDSs[whoami+1]["load"]<.01 then
-- Balancer where policy
targets[whoami+1]=allmetaload/2
```

Figure 7: The Greedy Spill balancer written in Lua using the Mantle API.

(2) using a modern distributed kv store
(3) positive effects of Mantle

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