Consideration for effectively handling parallel workloads on public cloud system

Kazuichi Oe
National Institute of Infomatics
Japan
koe@nii.ac.jp

Abstract
We retrieved and analyzed parallel storage workloads of the FUJITSU K5 cloud service to clarify how to build cost-effective hybrid storage systems. A hybrid storage system consists of fast but low-capacity tier (first tier) and slow but high-capacity tier (second tier). And, it typically consists of either SSDs and HDDs or NVMs and SSDs. As a result, we found that 1) regions for first tier should be assigned only if a workload includes large number of IO accesses for a whole day, 2) the regions that include a large number of IO accesses should be dynamically chosen and moved from second tier to first tier for a short interval, and 3) if a cache hit ratio is regularly low, use of the cache for the workload should be cancelled, and the whole workload region should be assigned to the region for first tier. These workloads already have been released from the SNIA web site.

1 Introduction
Cloud services are rapidly spreading because they can speed up software development for users, reduce a user’s operational costs, and enable agile development. These services are built on virtual machine (VM) environments, and these VMs often compete for input/output (IO) performance [14]. It is important for us to improve the cost-performance of cloud services by resolving the conflict of IO performance.

The FUJITSU K5 cloud service [2] is supported by more than 13,000 servers and 640 business systems and is built using the OpenStack [4] and VMware platforms. Customer’s applications might be executed in parallel on the same VMware platform. And, we installed a capture system in the TCP/IP network between servers running on hypervisor and storage systems in a K5 data center in Japan [13] and retrieved the parallel workloads, which consisted of 3088 virtual storages, by using the capture system. These workloads have already been released from the IO trace web-site of the Storage Networking Industry Association (SNIA) [5].

Our goal was to clarify how to build cost-effective hybrid storage systems for cloud service platform. A hybrid storage system consists of fast but low-capacity tier (first tier) and slow but high-capacity tier (second tier). Of course, the cost for first tier is much higher than that for second tier. And, it typically consists of either solid state drives (SSDs) and hard disk drives (HDDs) or non-volatile memories (NVMs) and SSDs. Therefore, we analyzed these parallel workloads from the viewpoint of both temporal and spatial access locality.

We first examined the bias of the number of IO accesses among the 3088 workloads and found that only 38 workloads included 50% of all IO accesses. We then analyzed these 38 workloads because of easy and quick analysis.

For temporal access locality, we classified these workloads into two IO access patterns when we analyzed them over the course of a day. One was that the number of IO accesses is high only for a specific time, and the other is that the number of IO accesses is almost stable. When we analyzed them on a daily basis, the number of IO accesses for each workload often varied every day.

For both temporal and spatial access locality, we executed the sim-ideal [6] cache simulator to investigate page-level access regularities. As a result, these cache hit ratios varied with the workload, but almost half of the workloads had low cache hit ratios because these workloads included few page-level regularities. Moreover, we found that almost all workloads concentrated IO accesses on a narrow region. This narrow region was drastically bigger than the page unit and moved in a short interval. Automated Tiered Storage with Fast Memory and Slow Flash Storage (ATSMF) [12] may effectively handle these concentrated IO accesses because its replacement algorithm may be fit for the concentration.

Therefore, we had the following ideas for building a
cost-effective hybrid-storage system. A preferable hybrid storage system should dynamically optimized across workloads by using the following ideas because multiple workloads with different characteristics were running in parallel.

- Assign regions for first tier only if a workload includes a large number of IO accesses for a whole day.
- Dynamically choose the regions that include a large number of IO accesses and move them from second tier to first tier for a short interval.
- Check the cache hit ratio of each workload. If a cache hit ratio is regularly low, the use of the cache for the workload should be cancelled, and the whole workload region should be assigned to the region for first tier. If a cache hit ratio increases according to the increase of the cache size, the convergence point for the cache hit ratio should be searched for, and the corresponding cache size should be set. If the cache hit ratios differ among the candidate cache replacement algorithms, a more preferable algorithm should be chosen.
- Use the feature for concentrated IO accesses on a narrow region. ATSMF is one candidate system.

2 How to retrieve trace logs from FUJITSU K5 cloud service

The FUJITSU K5 cloud service operates in over 25 data centers across four continents and includes more than 5,300 cloud customers with over 10,000 expert cloud employees. It is also supported by more than 13,000 servers and 640 business systems and is built using OpenStack technology, including VMware and Bare Metal stacks for specific workloads. It uses OpenStack technology to avoid vendor lock-in, and a user develops applications more easily by using pre-defined services with Cloud Foundry [1]. The K5 service consists of both Infrastructure as a Service (IaaS) and Platform as a Service (PaaS).

We inserted some network taps [3] into the TCP/IP network between servers running on hypervisor and storage systems in a K5 data center in Japan [13] (See Figure 1). The monitor’s servers were operating some databases, mail server, and some Fujitsu internal services on IaaS. We connected these network taps to a capture system. The capture system consisted of two servers and 110 TB storage. In order to analyze the captured data, we should gather the data from the capture system to the merge server installed in Fujitsu Labos. We also should merge these two data into one data. This merged data consisted of the timestamp, virtual storage volume ID, read/write, offset, and length information per request. Each virtual storage volume was assigned to a VM, and there were 3088 workloads.

We gathered these trace logs from Monday to Sunday but not continuously because one day’s trace logs often consumed the storage capacity of the capture system and the merge functions spend more than two days. We divided these discontinuous seven days of trace logs by each virtual storage volume ID. In this paper, we call this divided trace log a “workload”. We retrieved the three sets of Monday–Sunday workloads (See Table 1) and analyzed the first set (dataset1) of these workloads. All the workloads already have been released from the IO trace web site of the Storage Networking Industry Association (SNIA) [5].

3 Analysis of parallel workloads

3.1 How to analyze the parallel workloads

Our goal was to clarify how to build cost-effective hybrid storage system for cloud service platform. To achieve our goal, it was important for us to understand the access locality for the retrieved parallel workloads. Then, we analyzed these workloads from the viewpoint of both temporal and spatial access locality by using the dataset1 of Table 1.

First, we investigated the number of IO accesses among the 3088 parallel workloads, and we selected the 38 parallel workloads because these workloads included half of all IO accesses for 3088 workloads. We executed the rest analysis by using the 38 parallel workloads.

Table 1: dates for the trace logs getted (2017/10/03–2018/03/29)

| dataset | Sun | Mon | Tue | Wed | Thu | Fri | Sat |
|---------|-----|-----|-----|-----|-----|-----|-----|
| dataset1 | 01/07 | 12/04 | 01/16 | 01/24 | 01/16 | 12/15 | 12/22 |
| dataset2 | 02/25 | 03/05 | 03/13 | 03/21 | 03/13 | 02/16 | 02/10 |
| dataset3 | 02/25 | 03/05 | 03/13 | 03/21 | 03/13 | 02/16 | 02/10 |
Second, we analyzed temporal access locality to clarify the bias for IO access in the day. Third, we analyzed temporal and spatial access locality of a microscopic view. Microscopic view meant the analysis by page unit. This analysis was focused whether the traditional cache replacement algorithms were effective or not for each workload. Last, we also analyzed temporal and spatial access locality of a macroscopic view. Macroscopic view meant the analysis by 1-GB unit.

### 3.2 Selection of 38 parallel workloads

We first examined the bias of the number of read, write, and read+write IO accesses among the 3088 workloads and found that a small number of workloads included most IO accesses. Therefore, we selected 38 workloads whose percentage of the number of IO accesses was more than 50 with either read, write, or read+write and analyzed these 38 to quickly obtain both the temporal and spatial locality of all 3088 workloads (see Figure 2).

Figure 3 illustrates the volume sizes of the 38 workloads. We regarded the furthest footprint of IO access as the volume size of each workload because we could not obtain the volume size information. These volumes sizes were between 19 and 4000 GB. The x-axis of Figure 3 shows the virtual storage volume IDs, which have almost the same mean as the workload. Figure 4 illustrates the IO access size of each virtual storage volume ID. The top ten workloads mainly had an IO size of more than 16 KB. However, the IO sizes of the remaining workloads were mainly less than 8 KB.

![Figure 2: Bias of number of IO accesses among 3088 workloads](image)

![Figure 3: Volume size (GB)](image)

![Figure 4: IO access size](image)

### 3.3 Analysis for temporal and spatial access locality

#### 3.3.1 Temporal access locality

First, we analyzed the workloads for temporal access locality. We counted the number of IO accesses at 15-second intervals, saved these values, and created a box-plot diagram (Figure 5). The red line of Figure 5 is the median, the top of Figure 5’s box is the upper quartile, and the bottom of Figure 5’s box is the lower quartile. We found that the number of IO accesses drastically varied for almost half the workloads, whereas it was almost stable for the remaining workloads. In order to show the actual access patterns, we chose two day’s data and analyzed the number of IO accesses for the top five workloads. Figure 6 illustrated the results. We found that some workloads (especially v.1) drastically increased the number of IO accesses only at certain times. We also observed that these times changed depending on the day. On the other hand, the v.4 workload had a regular access pattern.

#### 3.3.2 Temporal and spatial access locality of a microscopic view

We investigated the temporal and spatial access locality of a microscopic view by using the sim-ideal cache simulator [6].

The sim-ideal was developed at the University of Minnesota, and its default page-size was 4-KB. We set 1, 5, and 10% as each workload size for each workload’s cache size. The cache replacement algorithms of the sim-ideal are Adaptive Replacement Cache (ARC) [8].
and Least Recently Used (LRU). We believe that ARC is the most effective cache replacement algorithm because it determines a replacement by using both recency and frequency. These algorithms have already been implemented in the sim-ideal.

Figure 7 shows these results. These cache hit ratios varied with the workload, but almost half the workloads had low cache hit ratios (less than 20%), and these ratios were almost the same even when we increased the cache size from 1 to 10%. This means that these workloads included few 4-KB page level regularities and could not be handled effectively with LRU and ARC.

Cache hit ratios of v.8, 12, and 17 increased according to the increase of the cache size (See Figure 8). We should search their convergence points for cache hit ratios and set the corresponding cache size. For example, 5% was convergence point when v.17 was executing. Moreover, we should choose the more desirable cache replacement algorithm among the simulated algorithms if these cache hit ratios were differ. For example, when both v.8 and 12 were executing, the cache hit ratio of ARC was always better than that of LRU.

3.3.3 Temporal and spatial access locality of a macroscopic view

We investigated temporal and spatial access locality of a macroscopic view. We then divided the workloads into 1-GB pages, counted the number of IO accesses to each page at 15-second intervals, sorted the pages in descending order of IO accesses at 15-second intervals, calculated the ratio to total IO accesses at these intervals, and averaged the ratios. Figure 9 shows the results. We found that almost all workloads concentrated IO accesses in only a few pages because the top ten pages often included more than half the total number of IO accesses.

We then investigated these concentrated IO accesses that occurred on consecutive pages. Figure 10 illustrates the duration of the above concentrated IO-access pages. We now explain how we retrieved the concentrated IO-
access pages. First, we sorted pages in descending order of IO accesses and integrated the number of IO accesses in order of the sorted pages. If the integrated number of IO accesses was more than half the total number of IO accesses, we stopped the above integration and selected the pages used for this integration. These concentrated IO accesses continued on consecutive pages for more than 15 seconds because one slice on the y-axis is 15 seconds. Moreover, some of these concentrated IO accesses continued for more than 150 seconds. Some values from the upper quartile to the maximum continued for more than 1500 seconds.

Next, we investigated the repeatability of the concentrated IO access pages. We now explain how we determined repeatability. First, we counted the number of concentration judgments per page and calculated the ratio of all judgments per page. If this ratio was less than 5%, a page was judged as unpredictable. Figure 11 shows the results. Almost all workloads had more than 50% unpredictable pages. Therefore, it was difficult for us to predict the appearance of the concentrated IO access pages.

The results of these concentrated IO access pages were almost the same as those of IO concentration, which was shown in already published documents [11, 12].

4 How to handle parallel workloads for hybrid storage systems

Section 3.2 shows that IO accesses for only 38 workloads included more than 50% of IO accesses for 3088 workloads. Therefore, a preferable hybrid storage system will carefully select the workloads. Specifically, it should assign the regions for first tier only when a workload includes a large number of IO accesses.

Section 3.3.1 shows that the number of IO accesses drastically varied for almost half the workloads. Figure 6 also shows that some workloads drastically increased the number of IO accesses only at certain times. Therefore, a preferable hybrid storage system will monitor a change in IO accesses for a short interval. It should dynamically assign the regions for first tier if the number of IO accesses for a workload is drastically increased.

Section 3.3.2 shows that almost half the workloads had a tiny effect on applying caching. A preferable hybrid storage system then should use two approaches for handling these workloads. The first approach is to assign a whole workload area to regions for first tier if one would like to improve the performance of these workloads. The second is not to assign first tier’s regions for the workload if one would not like to improve the performance. Some cache hit ratios (e.g., v.8, 12, 17) increased according to the increase in the cache size. Their convergence points for cache hit ratios should be searched for, and the corresponding cache size should be set. For example, 5% was the convergence point when v.17 was executing. A more preferable cache replacement algorithm should be chosen among the candidate algorithms if their cache hit ratios differ. For example, when both v.8 and 12 were executing, the cache hit ratio of ARC was always better than that of LRU.
Section 3.3.3 shows that concentrated IO accesses often occurred on a 1-GB page unit, and these features were almost the same as those of IO concentration. IO concentration targets narrow regions of storage volume and can continue for up to an hour. These narrow regions occupy a few percent of the logical unit number capacity, are the target of most IO accesses, and appear at unpredictable logical block addresses. ATSMF [12] is a hybrid storage system for effectively handling IO concentration. We will check whether ATSMF is adequate for these parallel workloads in the near future.

5 Related work

Sundaresan et al. [14] proposed Multi-Cache, a multi-layer cache management system that uses a combination of cache devices of varied speed and cost such as SSDs and non-volatile memories (NVMs), to dynamically allocate cache capacities among different VMs. Multi-Cache partitions each device dynamically at runtime in accordance with the workload of each VM and its priority. It uses a heuristic optimization technique that ensures the maximum utilization of caches, resulting in a high hit ratio. We think that Multi-cache can improve its performance by using the knowledge of this research.

We also showed previous workload studies for IO concentration because the results for Section 3.3.3 indicated some characteristic for IO concentration. IO concentration often included various applications on shared file systems, mail servers, and web servers [10, 9, 7, 11]. IO concentration appeared in narrow regions of a storage volume and continued for durations of up to about an hour. These narrow regions occupied only a small percentage of the storage volume and either remained for a long time or shifted to a neighboring area of the storage volume after several minutes on average. Furthermore, these narrow regions included most IO accesses and appeared in unpredictable logical block addresses (LBAs).

6 Conclusion

We retrieved and analyzed parallel storage workloads of the FUJITSU K5 cloud service to clarify how to build cost-effective hybrid storage systems for cloud service platform. A hybrid storage system consists of fast but low-capacity tier (first tier) and slow but high-capacity tier (second tier). And, it typically consists of either SSDs and HDDs or NVMs and SSDs.

We then investigated these workloads from the viewpoint of both temporal and spatial access locality and had the following ideas for building a cost-effective hybrid storage system. A preferable hybrid storage system should dynamically optimized across workloads by using the following ideas because multiple workloads with different characteristics were running in parallel.

- Assign regions for first tier only if a workload includes a large number of IO accesses for a whole day because some workloads may include a tiny number of IO accesses.
- Dynamically choose the regions that include a large number of IO accesses and move them from second tier to first tier for a short interval because some workloads drastically increase the number of IO accesses only at certain times.
- Check the cache hit ratio of each workload. If a cache hit ratio is regularly low, the use of cache for the workload should be cancelled, and the whole workload region should be assigned to the region for first tier. If a cache hit ratio increases according to the increase of the cache size, the convergence point for the cache hit ratio should be searched for, and the corresponding cache size should be set. If the cache hit ratios differ among the candidate cache replacement algorithms, a more preferable algorithm should be chosen.
- Use the features for concentrated IO accesses on a narrow region. These features are almost the same as those of IO concentration. ATSMF is one candidate system because it can effectively handle IO concentration.

7 Future work

To be satisfied the ideas described in Section 6, the preferable hybrid storage system should dynamically analyze the temporal and spatial access locality of workloads with many IO accesses, decide the preferable cache replacement algorithm including ATSMF and capacity of caching for each workload, and replace the decided cache replacement algorithm and capacity of first tier from the previous algorithm and capacity for each workload. We will implement and evaluate this hybrid storage system in the near future.

References

[1] Cloud Foundry. https://en.wikipedia.org/wiki/Cloud_Foundry.
[2] Fujitsu Cloud Service K5. http://www.fujitsu.com/global/services/hybrid-cloud/k5/
[3] Network tap. https://en.wikipedia.org/wiki/Network_tap.
[4] OpenStack. https://en.wikipedia.org/wiki/OpenStack.
[5] Parallel Traces for SNIA IOTTA Repository. http://iotta.snia.org/tracetypes/4
[6] sim-ideal. https://github.com/arh/sim-ideal.
[7] SNIA trace data MSR Cambridge. http://iotta.snia.org/traces/388.

[8] Megiddo, N., and Modha, D. S. ARC: A SELF-TUNING, LOW OVERHEAD REPLACEMENT CACHE. In Proc. 2th USENIX conference on File and Storage Technologies (FAST2003) (March 2003).

[9] Narayanan, D., Donnelly, A., and Rowstron, A. Write Off-Loading: Practical Power Management for Enterprise Storage. In Proc. of 6th USENIX Conf. on File and Storage Tech (Feb 2008).

[10] Oe, K., Honda, T., and Kawaba, M. Samba workload analysis and consideration for hybrid storage system. In IPSJ SIGOS, Tokyo, Japan (in Japanese) (Dec 2012).

[11] Oe, K., Nanri, T., and Okamura, K. Analysis of storage workloads of input-output access locality and designing of hybrid storage system. In Proc. of the 5th IIAI International Congress on Advanced Applied Informatics (July 2016).

[12] Oe, K., Sato, M., and Nanri, T. ATSMF: Automated Tiered Storage with Fast Memory and Slow Flash Storage to Improve Response Time with Concentrated Input-Output (IO) Workloads. IEICE Transactions on Information and Systems (VOL.E101-D No.12) (December 2018).

[13] Oghara, K. Generating block IO trace data from a cloud site using packet capture and analyzing the IO trace data. In 10th International Workshop on Advances in Networking and Computing (WANC’19), Nagasaki, Japan (Nov 2019).

[14] Rajasekaran, S., Duan, S., Zhang, W., and Wood, T. Multi-Cache: Dynamic, Efficient Partitioning for Multi-Tier Caches in Consolidated VM Environments. In Proc. of Cloud Engineering (IC2E), 2016 IEEE International Conference, Berlin, Germany (April 2016).