On Using Non-Volatile Memory in Apache Lucene

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ABSTRACT

Apache Lucene is a widely popular information retrieval library used to provide search functionality in an extremely wide variety of applications. Naturally, it has to efficiently index and search large number of documents. With non-volatile memory in DIMM form factor (NVDIMM), software now has access to durable, byte-addressable memory with write latency within an order of magnitude of DRAM write latency.

In this preliminary article, we present the first reported work on the impact of using NVDIMM on the performance of committing, searching, and near-real time searching in Apache Lucene. We show modest improvements by using NVM but, our empirical study suggests that bigger impact requires redesigning Lucene to access NVM as byte-addressable memory using loads and stores, instead of accessing NVM via the file system.

KEYWORDS
Non-Volatile Memory (NVM), Storage Class Memory (SCM), text-search, information-retrieval, Lucene

1 INTRODUCTION

Non-Volatile Memory (NVM) [15], also called Persistent Memory (PMEM) or Storage Class Memory (SCM), is a disruptive trend in the compute technology landscape. In addition to providing data durability (traditionally provided by HDDs/SSDs), these devices also behave like memory (DRAM) by providing byte-addressability, thus giving applications the ability to access durability via load/store operations. Moreover, NVM provides access speeds closer to that of DRAM1 2, much faster than traditional secondary storage technologies, including SSDs.

Apache Lucene [2] is very widely used, open source, Java based3, high-performance information retrieval library. Since it is not a complete application by itself, applications implement search functionality (such as indexing, querying, and highlighting) by using the APIs exposed by Lucene. Being a text search library, Lucene has to efficiently handle a large number of documents being written and indexed (and subsequently searched). As we describe later in Section 2 that in order for faster performance, Lucene does not necessarily commit the data to durable storage, thus sacrificing persistence of data to some extent. This, coupled with the fact that Lucene is the search library used by the highly popular search engines (e.g., Elasticsearch [5] and Apache Solr [4]), it is a natural to ask, "What is the impact of using non-volatile memory on Apache Lucene?"

To the best of our knowledge, this is the first work that explores the use of NVM in Apache Lucene. There is some prior work on the effect of persistent memory on distributed storage systems. Islam et al. [13] used NVM with RDMA in HDFS [1] to utilize the byte-addressability of NVM. There has been some work [3, 10, 12] on designing database systems to take advantage of NVM. However, these are not directly relevant to the work presented in this paper.

Our contributions in this paper are as follows:

- We present the first reported study of using NVM in Apache Lucene.
- We quantify the impact of using NVM on indexing, searching, and near-real-time searching in Apache Lucene.
- We identify fundamental changes needed in the operational model of Apache Lucene to maximize the impact of NVM on Lucene’s performance.

The rest of the paper is organized as follows. We provide an overview of Apache Lucene in Section 2. Section 3 presents the details of the evaluation and we draw conclusions in Section 4.

2 LUCENE OVERVIEW

In this section we give a brief overview of Lucene; the interested reader can refer to citations [11, 14] for more detailed descriptions. Here we focus mostly on the parts that are relevant to this paper.

2.1 Indexing

Figure 1 shows the typical processing done by Lucene to documents fed to it by the encompassing application; Lucene itself cannot acquire content. During indexing, the text is extracted from the original content and a Document is created that contains Fields holding the content. The contents of the Fields is passed through the Analyzer to generate a stream of tokens, which are passed through the Indexer to generate an inverted index. Finally, the index is written to either a new index file or the information is added/removed_UPDATED to an existing index file. These index files are stored in a user specified directory.

In order to be fast, index files are immutable, thus having no requirement of locking and hence avoiding any costly synchronization between multiple writer threads. However, immutability usually means that in order to update an index (say a particular document no longer has a term it initially contained), an entirely new index would have to be created and the old one deleted. In
In order to be efficient, a Lucene index is made up of multiple immutable index segments. On a search, Lucene searches over all segments for an index, filters out any deletions\(^1\), and finally, merges the results from all the segments. As explained in the next section, the immutability of segments has implications on search.

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**Figure 2:** Index updates in Lucene. Even after a flush, data is not committed to durable storage.

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2.2 Searching

The basic search process is quite straightforward. Once indexing of a document is complete, searching takes in a directory (Section 2.1) and a term = \{\text{name}, fvalue\}, which is the basic unit for searching, and searches for documents that contain “fvalue” in a field with name “fname”.

However, there are some nuances of search due to the fact that index segments are immutable. Figure 2a shows a scenario in which the commit point refers to a state of the index segments that are committed in disk and hence are durable. However, in a live system, additional documents are constantly being analyzed and indexed, thus necessitating the creation of new index segments. The indexing information for new documents are first written in an in-memory buffer and then later committed to the underlying persistent storage, at which point an updated commit point is generated. As can be imagined, this process is expensive due to the requirement of fsyncing the data to disk.

Consequently, till the new segment is not stored in disk, the segment first, cannot be searched since uncommitted data cannot be part of the commit point and second, the indexing buffer is volatile since it is simply stored in DRAM. This makes the in-memory data (in a single Lucene instance) susceptible to system or power failure\(^2\), in addition to adding delay between processing a document and being able to search the document. This delay, though small (in the order of minutes), is not acceptable to many applications and led to the development of the Near Real Time (NRT) search as in Section 2.3.

2.3 Near Real Time (NRT) Search

As shown in Figure 2b, NRT search is achieved by ensuring that the new index segment is not written directly to the disk but instead to the filesystem cache — and only later committed to disk. Once the segment is written to the filesystem, for all practical purposes, the segment is made searchable. This allows newer files to be indexed and searched without requiring a full commit. This reduces the time between indexing a document and being able to search the document, though at the risk of losing the data in the event of a system failure. The application can force the flushing of the in-memory buffer (so that the data becomes searchable) by calling the reopen API.

3 EVALUATION

In this section we describe the experiments that we performed to quantify the impact of using NVM in Lucene. We start with describing our experimental setup.

3.1 Experimental Setup

We used a single machine with 2.6 GHz Intel Xeon CPU, with 28 cores, 56 vCPUs (hyper threading enabled), 1 TB DDR4 RAM (running at 2.4 GHz), a 2 TB SSD that is accessed over a SATA3.0 (6 Gbps) interface. Since NVDIMMs are not yet commercially available, we carved out a space of 768 GB from the 1 TB RAM for a pmem device at /dev/pmem using the kernel’s mmap settings as explained in the Persistent Memory Wiki \[8\]. On the pmem device we placed an ext4 filesystem with DAX extension. We could not use mmap (load/store) for our experiments as Lucene uses a file abstraction and not a device abstraction. Instead we used the filesystem abstraction, i.e., the pmem device was accessed via the kernel’s file system code. We used the trunk version of Lucene (i.e., > 7.2.1) and used the latest version of the luceneutil benchmark in our experiments.

*Luceneutil Benchmarking Tool.* The luceneutil \[7\] tool is the de-facto benchmark utility for Apache Lucene. It indexes the entire Wikipedia English export \[9\] file as the input dataset. It runs benchmarking tests for Indexing, Searching, NRT, Sorting, Geobench and a variety of other tests\(^3\). To investigate the effects of pmem on lucene, we chose to run a subset of benchmark tests from luceneutil. The set of benchmark tests executed were indexing performance benchmark, search performance benchmark, and NRT performance benchmark.

For regular case, index files are stored on ext4 file system backed by SATA3.0 SSD. While for PMEM case, index files are stored on ext4 file system backed by PMEM device.

3.2 Indexing Performance

This benchmark indexes the wikimedium500k\(^8\) from the Wikipedia English export \[9\]. We mapped the indexed file to regular (SSD) as well pmem backed files. As the indexing part itself is compute intensive and is not dependent on the underlying storage technology, we separated the total time for indexing as index computation time and commit time. In both the cases, the index computation times are same (we do not show the results here). As shown in Figure 3, with NVM, the commit times show improvement in the range of 20%–30% across all frequencies of commits (number of docs/commit).

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\(^1\)This is standard practice in doing preliminary evaluation using NVDIMM.

\(^2\)The results of the luceneutil benchmark run on the Apache Lucene trunk is reported on a nightly basis at https://home.apache.org/mikemccand/lucenebench/index.html.

\(^3\)A collection of 500k lines from the main source that has millions of lines.
The improvement is more pronounced with higher frequency of commits (100 docs updated/commit) since the amount of data to be written is smaller. With larger writes, even SSD shows good performance since entire, large segments can be written sequentially, thus eliminating much of the advantage of random and/or small writes to NVM.

3.3 Search Performance

Search performance benchmark of luceneutil covers families of search tests — BooleanQuery, ProximityQueries, FuzzyQuery, Faceting, Sorting, etc. We ran these search benchmark tests against indices stored in regular files and pmem files. As shown in Figure 5, we observed that for PMEM use case, 12 tests (out of 32 tests in the bench) achieved considerable gains (≥20%) in the query handles per second, while another 12 saw gains of ≤20%, and the remaining didn’t see any gain (or saw marginal loss in performance).

We noticed that some of the tests achieved significant gains, ≥25%. For instance, "BrowseMonthSSDVFacets" (marked with a star) is one of them. On closer inspection we found that this test executes a query over the summarized/aggregated data of month field. It essentially covers the Doc Values (DV) feature of Lucene.

Inverted index is good at finding documents that contain a term. It does not perform well in the opposite direction — determining which terms exist in a single document. Doc Values are a representation of documents (uninverted index), which aid in handling these queries. They are generated at index-time and serialized to disk. It relies on the OS file system cache to manage memory instead of retaining structures on the JVM heap. In situations where the “working set” of data is smaller than the available memory, the OS will naturally keep the doc values resident in memory. But when the data is much larger than available memory, the OS will begin paging the doc values on/off disk as required, making it much slower. In these cases, we can expect PMEM to deliver significant gains compared to regular disk.

3.4 NRT Search Performance

Finally, Figure 4 shows the results of our experiments with NRT using the NRT performance benchmark, included in the luceneutil tool. The test is run with one thread each for indexing, search, and reopen. As explained in Section 2.3, the reopen API call forces the in-memory buffer to be emptied and the contents made searchable though not committed to disk yet. The documents are updated at a constant rate of 1000 docs/sec whereas one reopen() request is done every second. The entire test is run for 60 seconds and we vary the commit (the step that actually makes the data durable by writing to either SSD or PMEM) frequency from 100 docs/commit (frequent commits) to 1000 docs/commit (infrequent commits). We measure how many queries/second can be handled and how long it takes to perform the reopen call.

Figure 4a shows that the number of queries per second that the system can support increases as the frequency of commits decreases. This can be explained by the fact that every time a commit is done, the in-memory buffer gets flushed to a segment and the segment is written (fsync’ed) to the underlying storage. This then leads to the creation of a new Commit point. Thus doing commits frequently hurts the ability to respond to queries quickly.

Figure 4b shows the time it takes to complete a reopen call, i.e., to flush the in-memory buffer to a segment in the file system cache (but not yet committed to storage). Here frequent commits help because the in-memory buffer gets cleared out more frequently when the commit frequency is higher (100 docs/commit) and hence a reopen call has to copy less information from the in-memory buffer to form a segment in the file system cache. This allows the reopen call to complete faster, thus improving the reopen time with more frequent commits.

However, the most important thing to note in both the NRT results is that there is negligible performance difference between storing the index file in SSD vs. a pmem device. In hindsight, the reason is clear — since Lucene uses a file system abstraction, the file system cache is able to service most of the search requests, thus masking the difference in speed between the pmem and the SSD device. Though committing frequently obviously would make the data durable faster, these benchmark tests cannot expose the benefit of durability. Future research in this area would have to figure out reliable benchmarks to quantify the impact of durability (or the lack thereof).

4 CONCLUSIONS AND FUTURE WORK

We presented a preliminary, and, to our knowledge, the first work that explores the impact of non-volatile memory in Apache Lucene, a very popular information retrieval library.

Our experiments show modest gains by pointing Lucene index segment files to the NVM device. However, this is just the tip of the iceberg and higher gains may be achieved by say, implementing index segments that bypass the file system entirely and instead is read/written directly into NVM using loads/stores. We believe that future work in this direction will lead to redesigning at least parts
of Lucene (and other similar libraries) to bypass the file system and directly access non-volatile memory using loads and stores.

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