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Performance Evaluation of MongoDB I/O access patterns

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September 07, 2017  
CLOUD DAYS’2017 - Nancy, France
## NoSQL databases

- Principle category of Big Data Storage
- Overcome the scalability issues of SQL DBs
- Almost Cloud-friend systems
- Different architectures and data-models

## MongoDB

- A document-based NoSQL database (JSON documents)
- It uses *sharding* for distributing data
- Different tools for easy-deployment and migration (Ex. mongorestore, mongodump)
- Simple to use and fit well with various kinds of apps.
Context

Querying data

- NoSQL flexibility: store data; think how to use after!
- No schema ⇒ not only one way to query the data

frequent need to create indexes on demand, on large-scale data!
Context

Querying data

- NoSQL flexibility: store data; think how to use after!
- No schema $\Rightarrow$ not only one way to query the data

frequent need to create indexes on demand, on large-scale data!

Problem statement

- MongoDB takes unjustified amount of time for making indexes on a pre-existed data

this problem could affect other NoSQL databases!
Benchmarking?

⇒ Tools such as *Yahoo! Cloud Serving Benchmarks* (YCSB) could:
  - report high level metrics (Ex. throughput, latency, ...) ✓
  - reduce the effort for comparing different systems ✓

But
  - could not reflect the complexity of production-like data 😞
  - are not suitable for explaining performance issues 😞

Research objectives

- Identifying the performance issue(s) of MongoDB while indexing data
- Introducing new experimental tools for explaining the causes of performance issue(s)
### Experiments

#### Datasets

<table>
<thead>
<tr>
<th>Dataset type</th>
<th>(min, avrg, max) in Kb</th>
<th>N. of data units</th>
<th>Size (Gb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDU₁</td>
<td>(1, 3, 6)</td>
<td>20,000,000 docs</td>
<td>71</td>
</tr>
</tbody>
</table>

- Every doc (int, date, 2 x string[min, max], array[1..4] x string[min, max])

---

**MongoDB’s storage engine: Wiredtiger**

- The default storage engine for persistent data.
- `_id`s for holding the collection’s records
- collection is a separate file
- Btree data structure on disks
- Contiguous allocation on disk, but unspanned
- Default page size is 4 KB

---

**Figure** — a) Spanned & b) Unspanned allocation
Experiments

Experimental setup

- Experiments are performed on Grid’5000 testbed Machines x 2 CPUs Intel Xeon E5-2630 v3, 8 cores/CPU, 128GB RAM, 2x558GB HDD, 10Gbps ethernet
- Ubuntu 14.04, Linux 4.9.13, MongoDB v3.4
- wiredTiger cache = 2Gb, replicas are disabled, sharding key is \_id
- Considering only hash sharding in this talk ⇒ load balancing

Figure – Experimental scenarios
Experiments: Performance results with $SDU_1$

![Standalone MongoDB Performance Graphs]

- **Execution time (secs)**
- **Throughput (MBps)**
- **Utilization (%)**

Legend:
- **Read**
- **Write**
Experiments: Performance results with $SDU_1$
Experiments: Performance results with $SDU_1$

⇒ Indexing is a 100% read workload
⇒ I/O bounded operations
⇒ Data distribution issue
⇒ Benchmarking is not sufficient to look beyond!
Experiments: Performance results with $SDU_1$

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Experiments: Performance results with $SDU_1$

- **Standalone MongoDB**
  - Execution time (secs)
  - Throughput (MBps)
  - Utilization (%)

- **Distributed MongoDB**
  - Execution time (secs)
  - Throughput (MBps)
  - Utilization (%)

⇒ Indexing is a 100% read workload
⇒ I/O bounded operations
⇒ Data distribution issue
⇒ Benchmarking is not sufficient to look beyond!

⇒ How to get the main reason behind these results?
## Dynamic tracing with eBPF

**extended Berkeley Packet Filter (eBPF)**

- Connect to all Linux data sources: (Kprobes, Uprobes, tracepoints, ...)
- Almost no overhead (4 ns per syscall) [A. Starovoitov]
- In-kernel verifier, JIT-compilation, mapping (kernel-userspace exchange)
- Processing, tracing, filtering inside Linux kernel.
- Suitable to work with system in-production & real data.

**BPF compiler collection (BCC)**

- Like-standard frontend project for eBPF tools
- No more byte code! ⇒ write your BPF code in restricted C
- Write your frontend code using Python or Lua
- Towards script-driven tracing
Dynamic tracing with eBPF, our tool

An eBPF tool is built to evaluate the I/O patterns

- I/O access are no longer considered as black boxes!
- A generic tool, works on VFS layer
- It traces all I/O read requests
- It reports all files offsets, req. latencies & data size
- Could filter the results by file

Tracing impact on our experiments

- Overhead cost is lower than 0.8% of execution time in all Experiments.
- Basically, it depends on the number issued I/O requests.
Experiments: eBPF results with $SDU_1$

I/O access pattern and latency on standalone config.
Experiments: eBPF results with $SDU_1$

I/O access pattern and latency on standalone config.
Experiments: eBPF results with $SDU_1$

- I/O access pattern and latency on standalone config.

⇒ Acceptable access pattern on standalone
⇒ Almost random access on shards!
⇒ Data distribution is poorly done

First shard results in two-shards config (50.9% of data)

Second shard results in two-shards config (49.1% of data)
Experiments

The exact issue

- Mismatch between the scanning table vs data stored on disk

Collection _ids:
used by MongoDB process and WiredTiger

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allocated regarding the key sharding (hashed _id)

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Figure – MongoDB scanning table Vs records order on the disk
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Collection file on disk: allocated regarding the key sharding (hashed `_id`)

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**Figure** — MongoDB scanning table Vs records order on the disk
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**The exact issue**

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Collection file on disk:
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Collection file on disk:
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Figure – MongoDB scanning table Vs records order on the disk
Experiments

The exact issue

- Mismatch between the scanning table vs data stored on disk

![Diagram showing mismatch between scanning table and disk order]

Collection _ids: used by MongoDB process and WiredTiger

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Collection file on disk: allocated regarding the key sharding (hashed _id)

**Figure** – MongoDB scanning table Vs records order on the disk
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_id 19 _id 20 _id 27 ...
```

1) Get this doc

Collection file on disk:
allocated regarding the key sharding (hashed _id)

```
_id 1   _id 3   _id 7   _id 5   _id 8   _id 10 _id 2   _id 19 _id 11 _id 20 _id 30 _id 27
rec 1   rec 2   rec 3   rec 4   rec 5   rec 6  rec 7   rec 8   rec 9   rec 10  rec 11  rec 12
```

**Figure** – MongoDB scanning table Vs records order on the disk
Experiments

The exact issue

- Mismatch between the scanning table vs data stored on disk

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Collection _ids:
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2) Which doc is next?

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<tr>
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<td></td>
<td></td>
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**Figure** – MongoDB scanning table Vs records order on the disk
Experiments: an ad hoc solution

**MongoDB integrated tools?**

- RepairDatabase ⇒ verifying the coherence of data. 😞
- Rebuilding the _id index ⇒ consider the pre-existed ordering. 😞
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**Our ad-hoc solution**

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The worst case example!

- Data on one shard in a four conf. experiment (1/4 out of data)
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**Figure** – I/O access pattern a) before & b) after applying the solution
Conclusion

- A performance study on MongoDB I/O access pattern is done
- A generic tool for testing I/O access patterns is introduced
- An ad hoc solution is proposed to correct MongoDB I/O access patterns

- We showed how a trivial data management issue could affect the performance
- We demonstrated how it is worthy to use dynamic tracing to go beyond benchmarking results

Future works

- Including other solutions like Cassandra in those tests.
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Questions are welcome!