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Performance Evaluation of MongoDB I/O access patterns

Abdulqawi Saif\textsuperscript{1,2,3,4}  
abdulqawi.saif@loria.fr

Lucas Nussbaum\textsuperscript{1,2,3}  
lucas.nussbaum@loria.fr

Ye-Qiong Song\textsuperscript{1,2,3}  
ye-qion.song@loria.fr

\textsuperscript{1}Inria, Villers-les-Nancy, F-54600, France  
\textsuperscript{2}Université de Lorraine, LORIA, F-54500, France  
\textsuperscript{3}CNRS, LORIA - UMR 7503, F-54500, France  
\textsuperscript{4}Xilopix SAS, F-88000, France

September 07, 2017  
CLOUD DAYS’2017 - Nancy, France
**Context**

**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!
Benchmarks?

⇒ 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>SDU\textsubscript{1}</td>
<td>(1, 3, 6)</td>
<td>20,000,000 docs</td>
<td>71</td>
</tr>
</tbody>
</table>

- Every doc x: (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\textsubscript{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](image)
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 \(_{id_s}\)
- Considering only hash sharding in this talk ⇒ load balancing

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

Graphs showing throughput (MBps) and utilization (%) over execution time (secs) for Standalone MongoDB.
Experiments: Performance results with $SDU_1$
Experiments: Performance results with $SDU_1$

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

- **Distributed MongoDB**
  - Execution time (secs)
  - Throughput (MBps)
  - Utilization (%)
  - Shard1 (50.9% of data)
  - Shard2 (49.1% of data)

⇒ 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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- **Benchmarking is not sufficient to look beyond!**
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!

⇒ 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
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)
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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**Figure** – MongoDB scanning table Vs records order on the disk
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- Mismatch between the scanning table vs data stored on disk

![Diagram showing the mismatch between the scanning table and data stored on disk.](image)

Collection _ids:
used by MongoDB process and WiredTiger

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Collection file on disk:
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**Figure** – MongoDB scanning table Vs records order on the disk
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Collection file on disk:
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**Figure** – MongoDB scanning table Vs records order on the disk
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**Figure** – MongoDB scanning table Vs records order on the disk
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The exact issue

- Mismatch between the scanning table vs data stored on disk

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

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

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| _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(n-1) | rec (n) |

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:
used by MongoDB process and WiredTiger

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_id 1   _id 2   _id 3   _id 5
_id 7   _id 8   _id 10  _id 11
_id 19  _id 20  id 27  ...
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1) Get this doc
2) Which doc is next?

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Collection file on disk:
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## Experiments: an ad hoc solution

### MongoDB integrated tools?

- RepairDatabase ⇒ verifying the coherence of data. 😞
- Rebuilding the `_id` index ⇒ consider the pre-existed ordering. 🙁
Experiments: an 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.
- Trying to enrich eBPF tools which explain specific issues.
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Questions are welcome!