Constructing and Analyzing the LSM Compaction Design Space

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Log-Structured Merge-tree
LSM-tree
LSM-tree
Why **LSM**?

- Fast writes
- Competitive reads
- Good space utilization
fast writes  competitive reads  good space utilization

COMPACCTION
COMPACTATION

- Space amplification
- Write performance
- Scan performance
- Delete performance
- Write amplification
- Lookup performance
workload

LSM tuning

COMPACTION

performance

Huh?
Our Goal

1. Roadmap to pick compactions
2. Answer to complex design questions
Our **Goal**

1. break the black box
2. learn from 2000+ experiments
buffer
level 1
buffer

level 1
buffer

level 1
buffer

level 1

level 2

compaction
buffer

level 1

level 2

level 3

level 4

compaction
compaction?
How many runs per level?

How much data to compact at once?
How many runs per level?

How much data to compact at once?
How much data to compact at once?

How many runs per level?
How much data to compact at once?

How many runs per level?
What are the **design choices**?

How does a choice **affect performance**?

- How many runs per level?
- How much data to compact at once?
What are the **design choices**?

How does a choice affect performance?
What are the **design choices**?

How does a choice **affect performance**?
What are the **design choices**?

How does a choice **affect performance**?
1. How to organize the data on device?
2. How much data to move at-a-time?
3. Which block of data to be moved?
4. When to re-organize the data layout?
Data Layout
1. How to organize the data on device?

Compaction granularity
2. How much data to move at-a-time?

Data movement policy
3. Which block of data to be moved?

Trigger
4. When to re-organize the data layout?
Data Layout

number of runs per level
Data Layout

number of runs per level

leveling [eager]

tiering [lazy]
Data Layout

number of runs per level

leveling

1-leveling

L-leveling

tiering
Compaction Granularity

data moved per compaction
Compaction Granularity

data moved per compaction

levels
Compaction Granularity

data moved per compaction

levels

files
Compaction Granularity

data moved per compaction

levels

files

sorted runs in a level
Data Movement Policy

which data to compact

files
Data Movement Policy

*which data to compact*

- **round-robin**
- minimum *overlap with parent* level
- file with most *tombstones*
- *coldest* file
Compaction Trigger

invoking the compaction routine

level **satu**ration
Compaction Trigger

*invoking the compaction routine*

level *saturation*
Compaction Trigger

*invoking the compaction routine*

- level *saturation*
- number of *sorted runs*
- *age* of a file
- space amplification
Any Compaction Algorithm
| Database | Data layout | Compaction Trigger | Compaction Granularity | Data Movement Policy |
|----------|-------------|---------------------|------------------------|---------------------|
|          |             | Level saturation    | Sorted runs            |                      |
|          |             | #Sorted runs        | File staleness         |                      |
|          |             |                     | Space amp.             |                      |
|          |             |                     | Tombstone-TTL          |                      |
|          |             |                     | Level                  |                      |
|          |             |                     | Sorted run File        |                      |
|          |             |                     | (single)               |                      |
|          |             |                     | File (multiple)        |                      |
|          |             |                     | Round-robin            |                      |
|          |             |                     | Least overlap (+1)     |                      |
|          |             |                     | Least overlap (+2)     |                      |
|          |             |                     | Coldest file           |                      |
|          |             |                     | Oldest file            |                      |
|          |             |                     | Tombstone density      |                      |
|          |             |                     | Expired TS-TTL         |                      |
|          |             |                     | N/A (entire level)     |                      |
| RocksDB [30], Monkey [22] | Leveling / 1-Leveling | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| LevelDB [32], Monkey (J.) [21] | Leveling | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| SlimDB [47] | Tiering | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Dostoevsky [23] | L-leveling | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| LSM-Bush [24] | Hybrid leveling | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Lethe [51] | Leveling | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Silk [11], Silk+ [12] | Leveling | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| HyperLevelDB [35] | Leveling | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| PebblesDB [46] | Hybrid leveling | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Cassandra [8] | Tiering | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| WiredTiger [62] | Leveling | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| X-Engine [34], Leaper [63] | Hybrid leveling | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| HBase [7] | Tiering | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| AsterixDB [3] | Tiering | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
Blueprint for **Experiments**

10 compaction strategies

- primitives
- workloads [distribution + composition]
- LSM tuning

612 metrics
Compacting data at smaller granularity reduces data movement.
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![Graph showing compaction strategies and data moved (GB)]
Compacting data at smaller granularity reduces data movement.

Tiered data layout has the highest write throughput but also the highest tail write latency.

![Graph showing tail write latency for different compaction strategies.](image)
Compacting data at smaller granularity reduces data movement.

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Hybrid data layouts dominate point lookup performance.
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For update-intensive workloads, tiering dominates the performance space.
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For update-intensive workloads, tiering dominates the performance space.

The relative benefits of compaction strategies are marginally affected by LSM-tuning.
Summary

Compaction is **key to LSM-performance**.

Compaction as first-order **design primitives**.

**Guidelines to design and tuning** through experiments.

Thank You!