NTNU
Kunnskap for en bedre verden

SSDs, LSM-trees and RocksDB
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Contents

- HDDs
- SSDs
- Sequential writes
- B+-trees
- LSM-trees
- RocksDB
- MyRocks
- Write amplification
- Write stalls and write stops

HDDs

- Rotating, magnetic disks
- Have been developed since 1956
- Storing vast amounts of data at low costs
- Access time does not improve much with new disks
- 5-10 millisecs today, the first (1956) had 600 millisecs.
- Throughput (typical every day, desktop disk):
  160 MB/s (write)
  180 MB/s (read)
- Needs to be careful with layout of file system

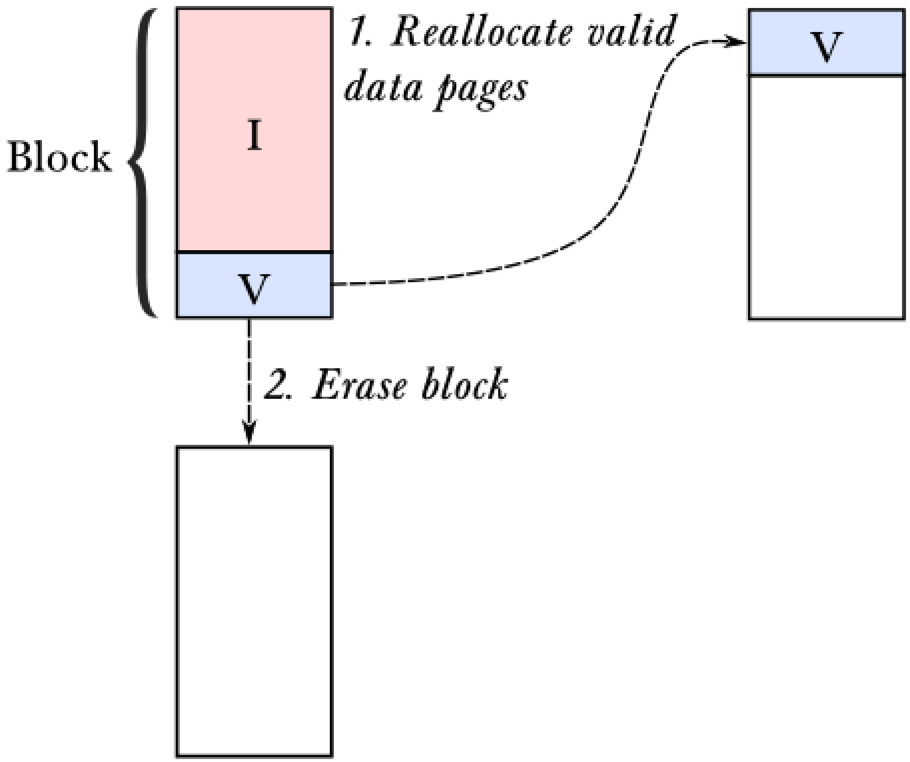
SSDs (1)

- Solid state drives – purely electronic devices
- Faster access times, lower latency, lower power consumption, completely silent operation, uniform random access speed
- NAND: Block: 64 or 128 *pages* of 2 Kbyte or 4 Kbyte Block: 128 KB to 512 KB
- Reads and writes of *pages*
- Erase *complete blocks*
- Erase-before-write
- Throughput: Four times of HDD (at least), 550 MB/s (SATA SSD) and (**NVMe SSD) 1000 MB/s – 7000 MB/s**

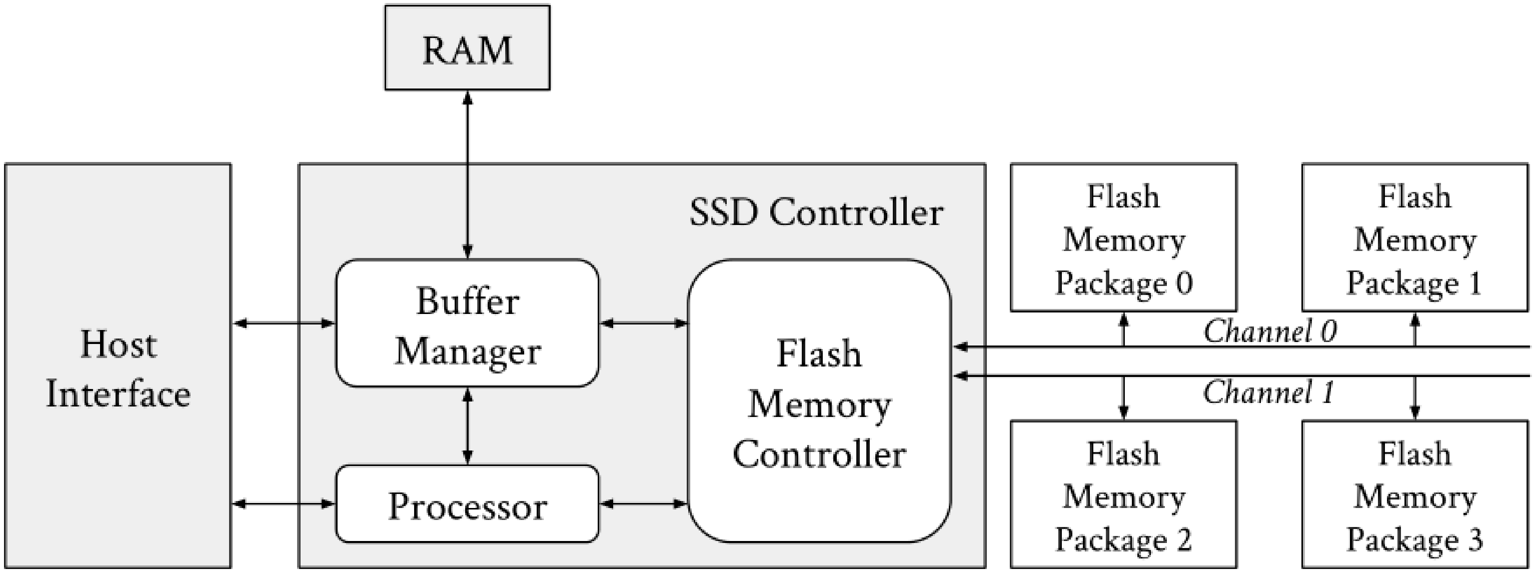
SSDs – wear leveling

- Limited number of writes possible (wearing)
- Flash Translation Layer – firmware layer implementing wear leveling: Standardized by Intel.
  - *No wear leveling*: Fixed mapping from logical addresses to physical addresses
  - *Dynamic wear leveling*: At updates, the old block is marked as invalid and the block is relocated.
  - *Static wear leveling*: Also moves static blocks periodically. All parts of the disk will be worn out eventually.
- Garbage collection is important in SSDs. Done in units of blocks.
- Host based FTL (computer) and array-based FTL (disk)

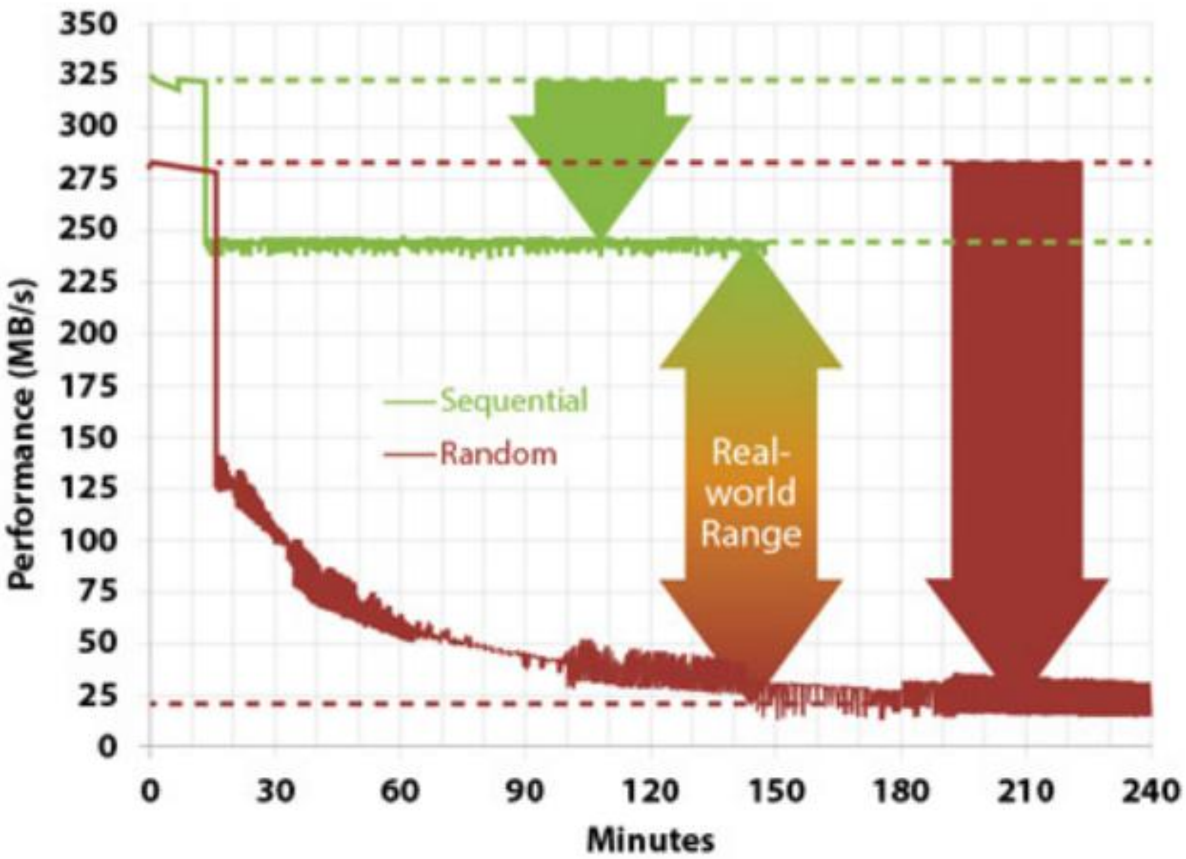
SSDs – garbage collection



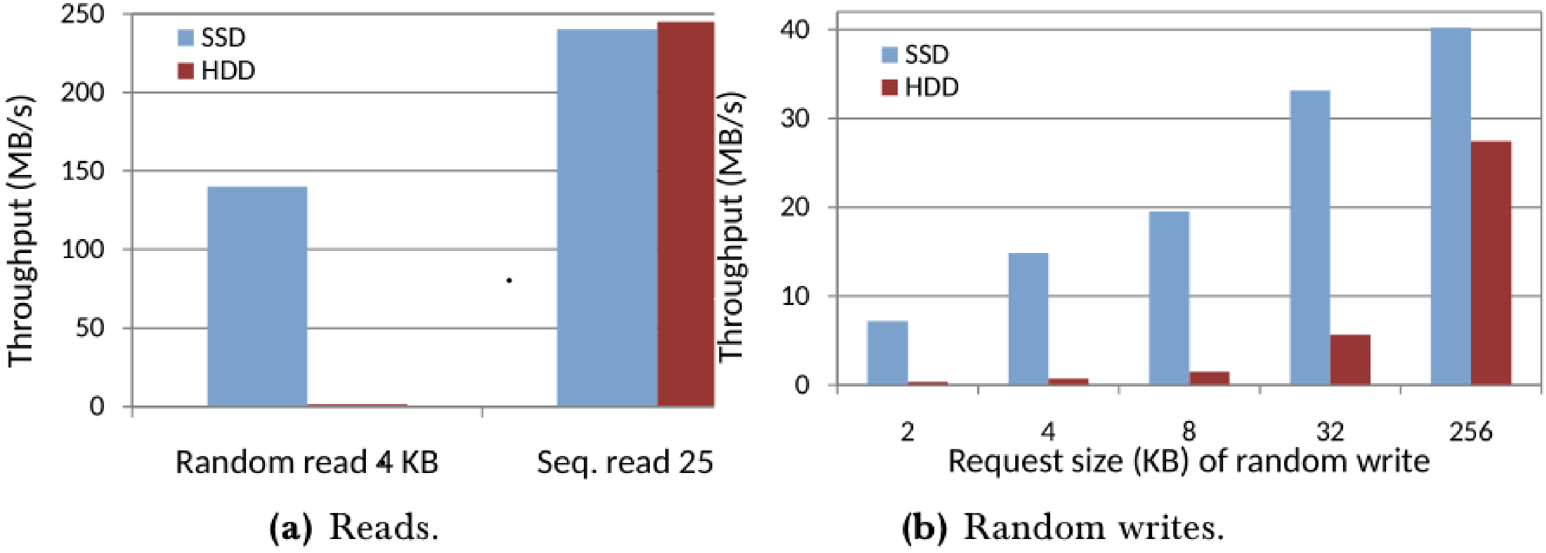
SSDs – parallel I/O



Sequential writes (1)



Random writes, use big chunks when writing



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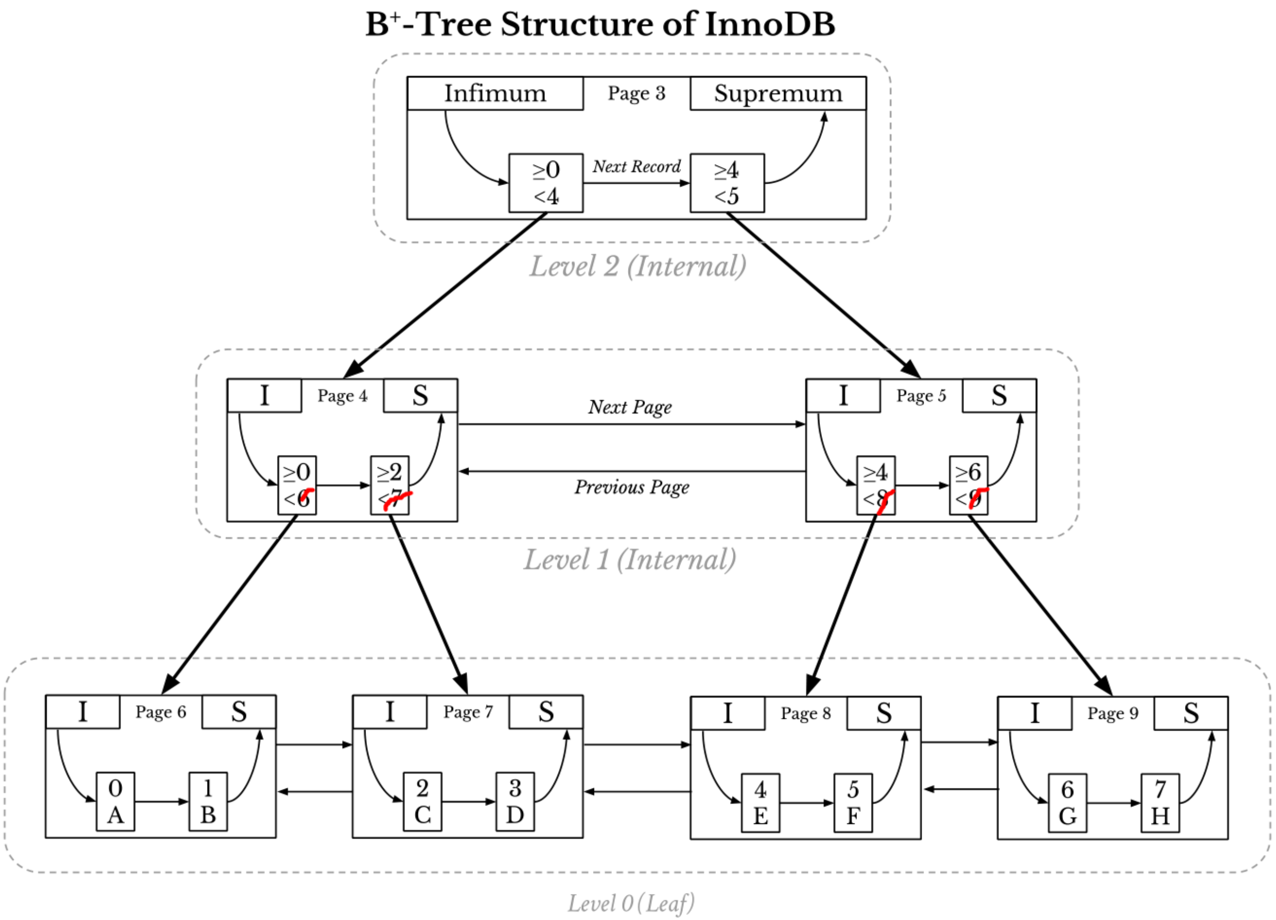
Sequential writes (3)

- One of the essential keys to great write performance is to organize data in such a way that each write request distributes the overhead of the write over multiple inserts batched together – large blocks are also good
- *Over-provisioning*: When the GC has too much to do, writes happen more often than erase operations -- The SSD has a reserved area where the garbage collector could put writes at high peaks periods. 7 – 28 % of disk.

Writes/reads measured (old exercise)

	HDD/w	HDD/r	SSD/w	SSD/r
1GB	1976 MB/s	3835 MB/s		
2GB	2101 MB/s	3954 MB/s		
4GB	1766 MB/s	202 MB/s		
8GB	386 MB/s	157 MB/s		
16GB	221 MB/s	162 MB/s		
32GB	184 MB/s	163 MB/s	354 MB/s	463 MB/s

B+-trees (1)

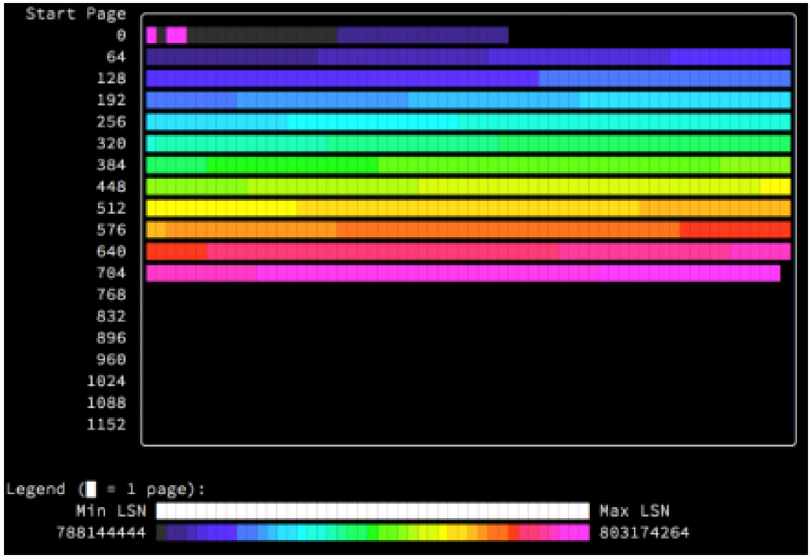


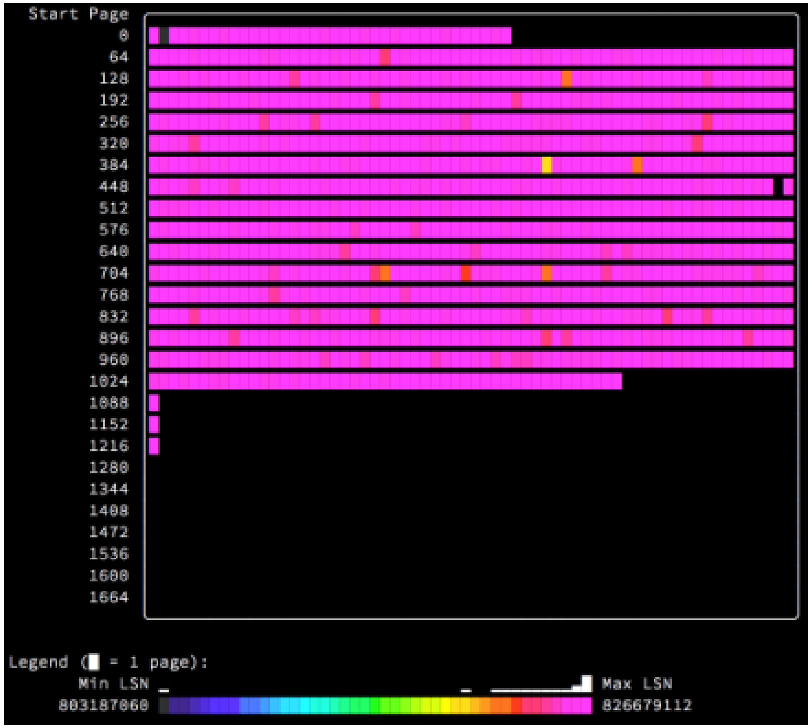
B+-Tree Structure of InnoDB
Infimum
Page 3
Supremum
≥0
<4
Next Record
≥4
<5
Level 2 (Internal)
I
Page 4
S
Next Page
Previous Page
I
Page 5
S
≥0
<6
≥2
<7
≥4
<8
≥6
<9
Level 1 (Internal)
I
Page 6
S
0
A
1
B
I
Page 7
S
2
C
3
D
I
Page 8
S
4
E
5
F
I
Page 9
S
6
G
7
H
Level 0 (Leaf)

B+-trees (2) Freshness of PageLSNs

Sequential

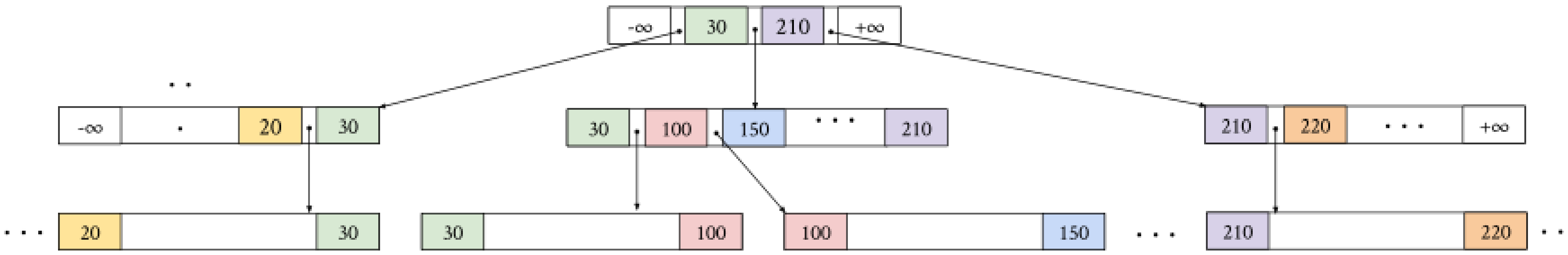
Random



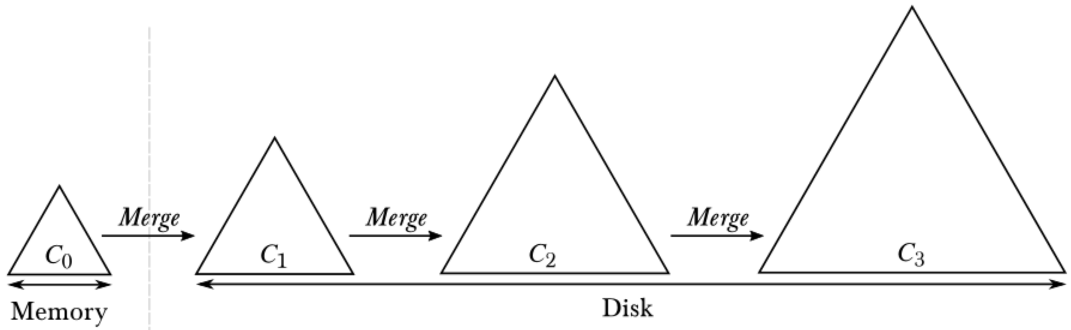


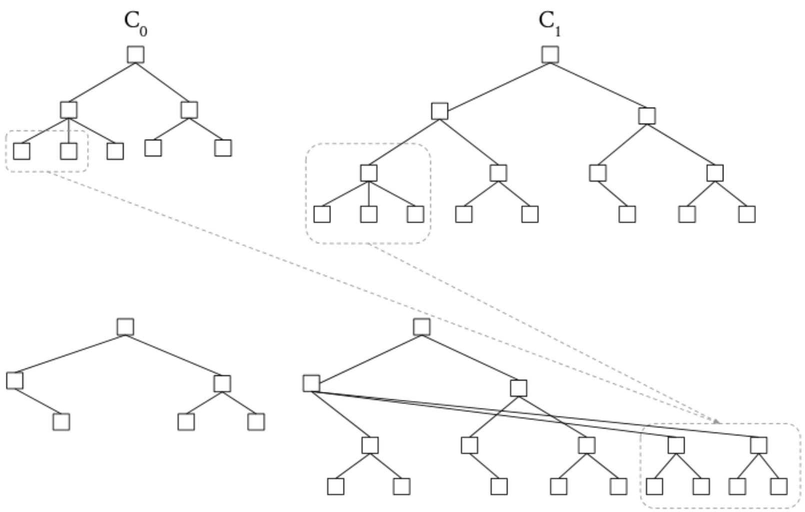
Variants of B+-trees

- *FB-tree*: Variable sized blocks simulating FTL's GC algorithm. (disk-aware algorithm)
- *Copy-on-write B-tree*: Copy a block to a new location at updates. E.g. LMDB. BTRFS (file system on Linux).
- *Write-optimized B-tree*: No sideway pointers, index records contain lowKey and highKey of the leaf blocks. Prevents multiple writes due to pointers when moving a block.



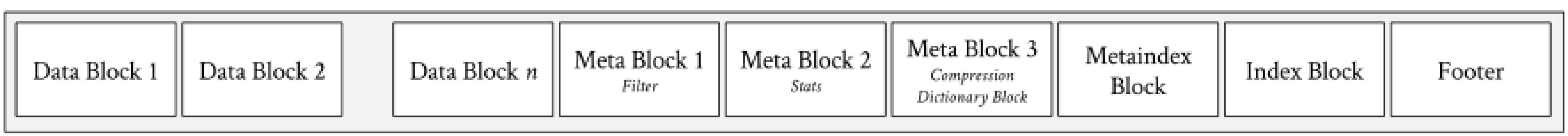
LSM-trees (O'Neil & O'Neil, 1996)





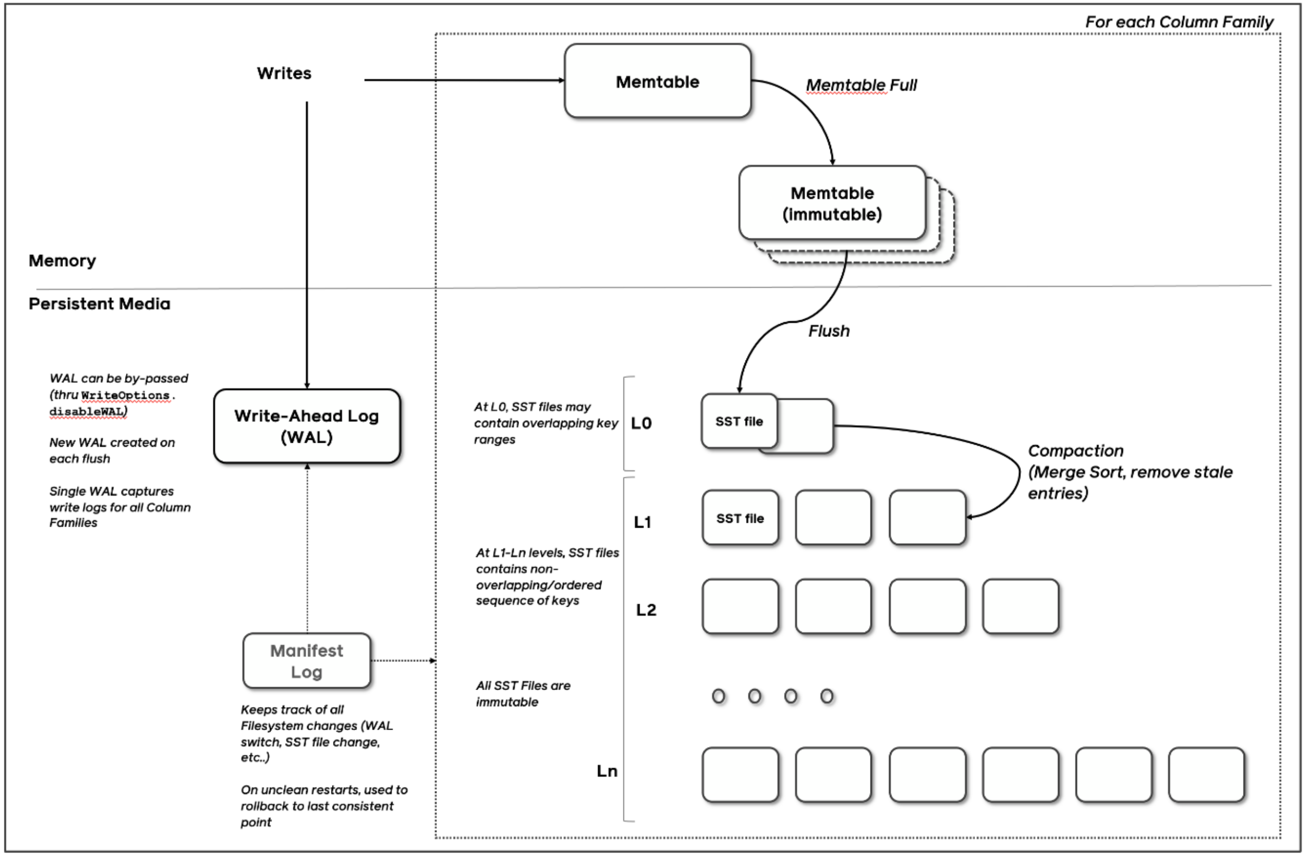
RocksDB

- Builds on Google's LevelDB and Apache HBase
- Multi-threaded compaction
- Multi-threaded insertion into MemTable
- Extensive control over Bloom filters
- Multicore and SSD support
- 10 x improved write performance compared to LevelDB due to multi-threaded compactions



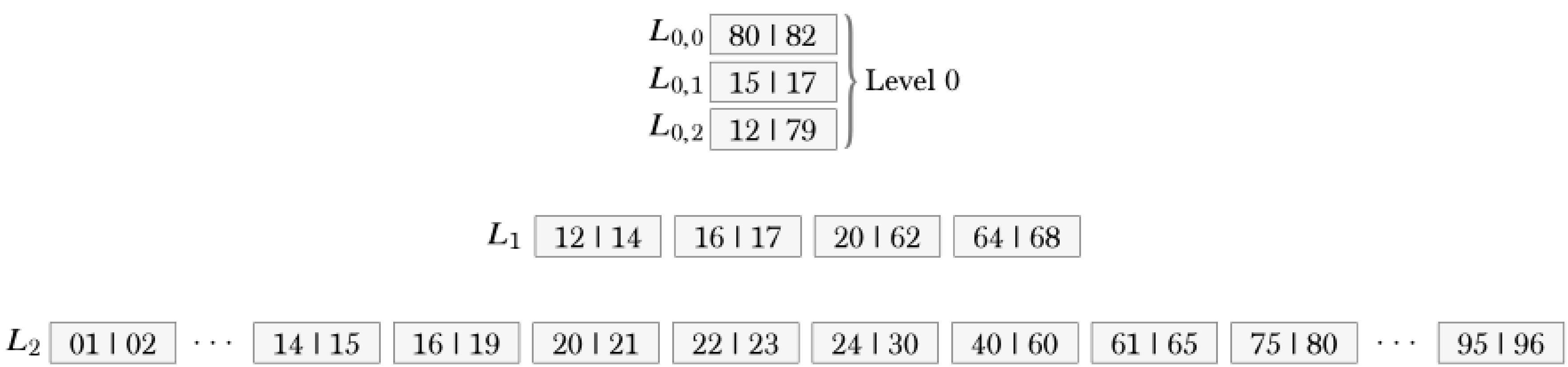
RocksDB (2)

- SST File (sorted key ranges)
- Memtable
- Write Ahead Log



Leveled Compaction

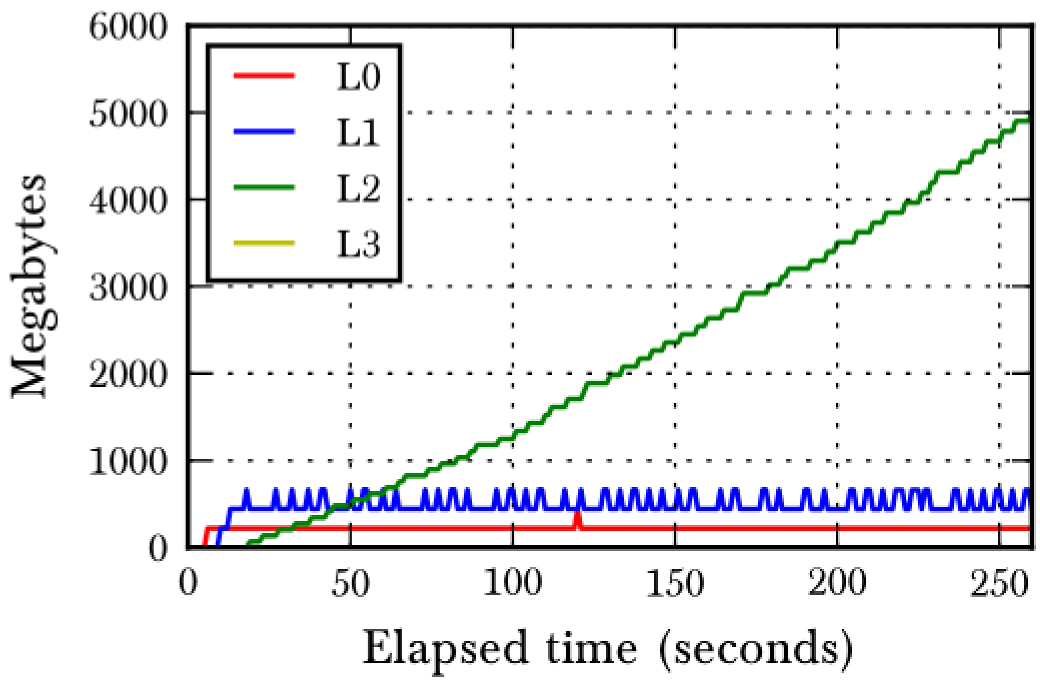
- Original compaction style in LevelDB
- SSTable files stored in multiple levels
- Multiple overlapping SSTables at level 0 to get fast write of MemTables



LSM strength and weakness

- Superior write speed mainly due to large segments written to disk. The data structure of big data.
- Good read performance on recent data (social media data, e.g.)
- Not so good read performance on old data, need to search through multiple SSTables.
- Some trouble on performance when having peaks in write load as well
- Searching for a non-existing key?

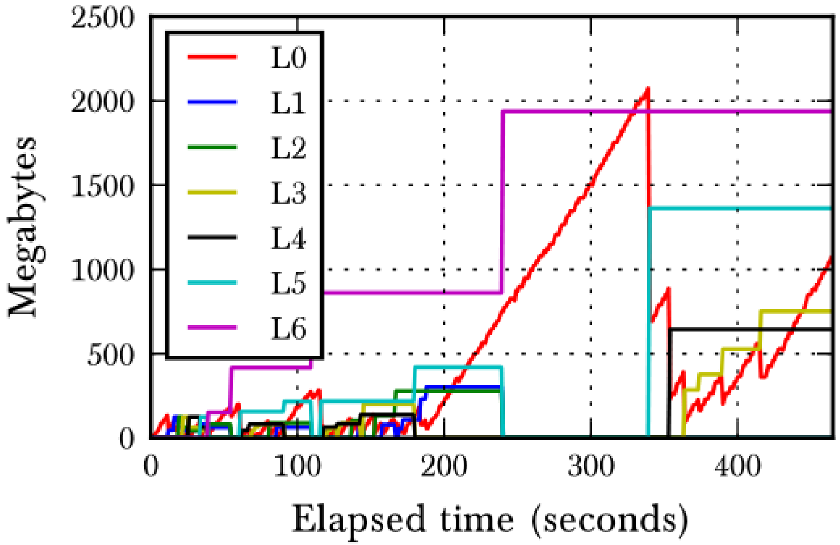
Leveled Compaction (2)



(a) Leveled compaction.

Universal Compaction

- SSTables overlap in key range, but not in time
- Merging SSTables to cover bigger time ranges
- Universal typically results in lower write-amplification but higher space- and read-amplification than Level Style Compaction.



(b) Universal compaction.

Bloom filter

- Simple data structure to quickly check if a key *may* exist in a dataset
- Bitmap of m bits and k unique hash functions
- Either used on each block or the complete SSTables

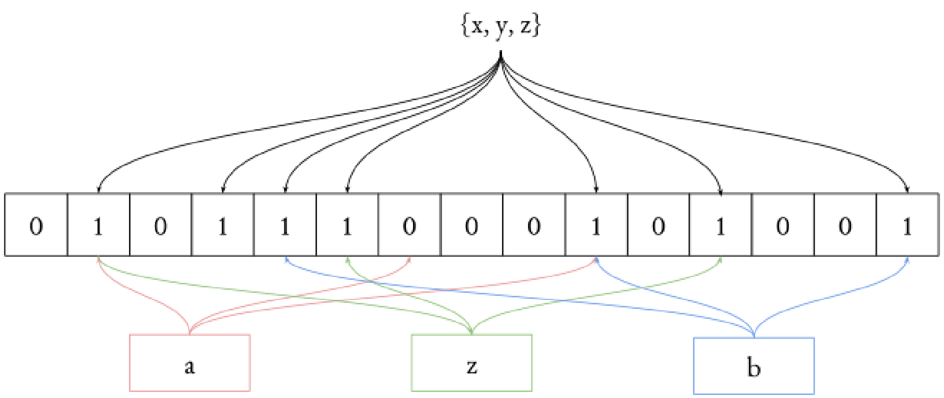


Figure 2.25: Example of a Bloom filter with the dataset x, y, z and $m = 15$ bits. There are $k = 3$ different hash functions.

MyRocks

- Facebook’s integration of RocksDB as a storage engine with MySQL
- Created due to serious space and write amplification of MySQL’s InnoDB
- MariaDB (MySQL competitor) has also integrated RocksDB as a storage engine

Write amplification

- #bytes written to database / #bytes written to api
- B-trees: write amp less with big records
- LSM-trees: less write amp due to big write chunks, but compaction require more writes
- LSM-trees: write amp independent on record size
- May be measured by insert throughput. RocksDB performs very well

Write stalls and write stops

- Write stalls: Slow the speed of inserts to cope with compaction
- Write stops: Stop inserts.
- RocksDB can configure parameters to control this:
  - Number of MemTables
  - Number of SST files at level 0
  - Number of bytes awaiting compactions
- Hans-Wilhelm Kirsch Warlo developed an auto-tuner for compactions in RocksDB during his master thesis: Turns off compactions during high insert loads (spring 2018).

Warlo’s auto-tuner