MUTANT: Balancing Storage Cost and Performance in LSM-Tree Data Stores

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Why Dave, a Database Engineer, Quit

Hey Dave, our DB costs $30 M/year. Can you make it less expensive?

No problem, Carol!

- Find a new storage type
- Live data migration: backup, replicate new data, validate data, migrate applications. Could take months [Netflix].

(After 2 months)

Here is a new database. It's a bit slower, but costs only $20 M! 😎

Dave, the budget is getting tighter. Can you make it $10 M?

(After 2 months)

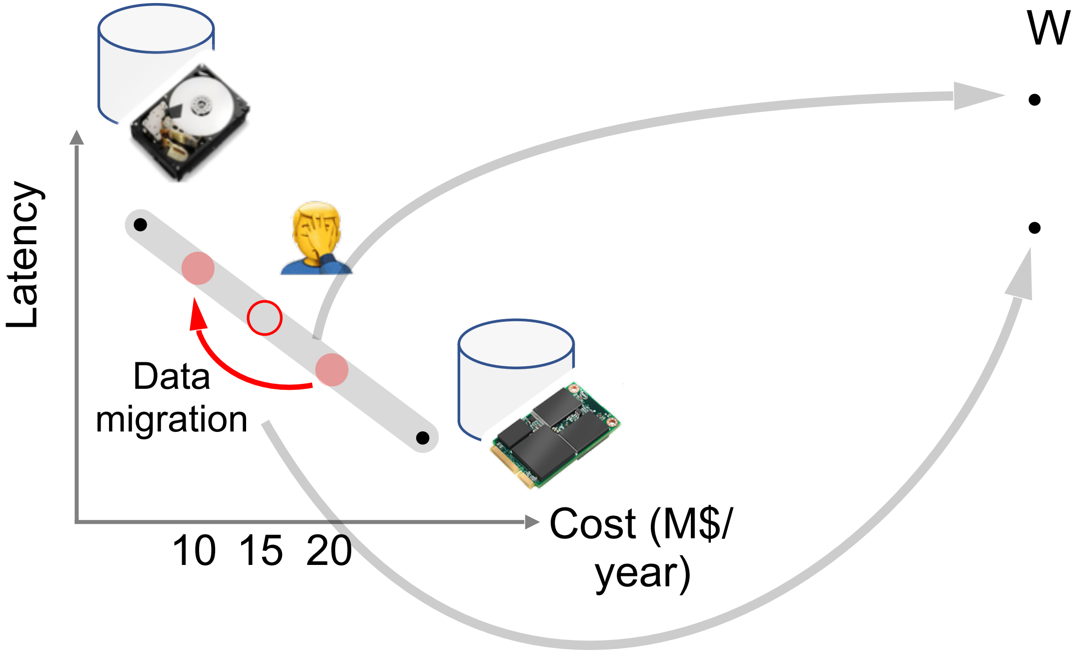
Here is a $10 M database. I was lucky to find a right storage device for the budget. 😅

Actually, it's too slow now. Can you make it a bit faster? I fired 5 people and we have more budget now.

… 🤦‍♂️

Still there?

Seamless Cost-Performance Trade-offs



Wouldn’t it be nice if

- You can get any cost-performance trade-off?
- DB does migrations by itself?

Mutant, a database storage layer

with seamless cost-performance trade-offs!

Problem Formulation

Organize DB storage blocks into fast, expensive storage, and slow, inexpensive storage.

With **cost** constraint:

“I’d like to pay no more than $0.03 /GB/month, while keeping the latency minimum.”

With **latency** constraint:

“I’d like the latency no higher than 40 ms, while keeping the cost minimum.”

NoSQL DBs

Cloud Bigtable

cassandra

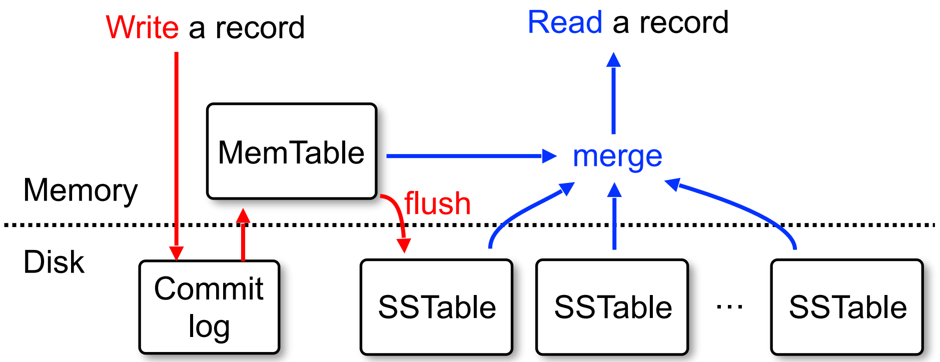
APACHE HBASE

LEVELDB

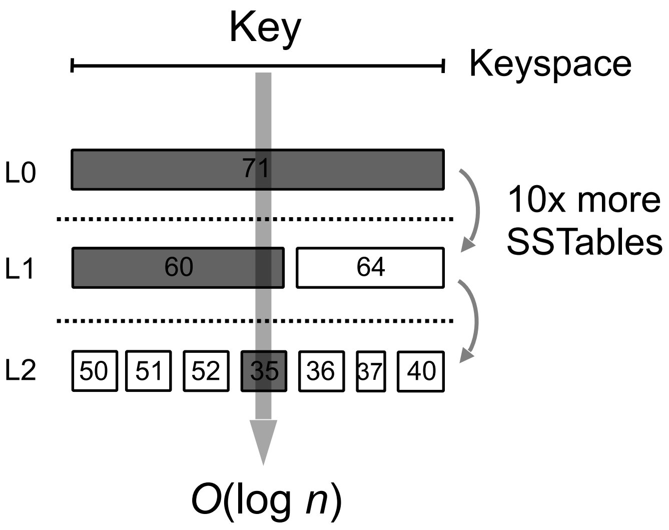
RocksDB

mongoDB

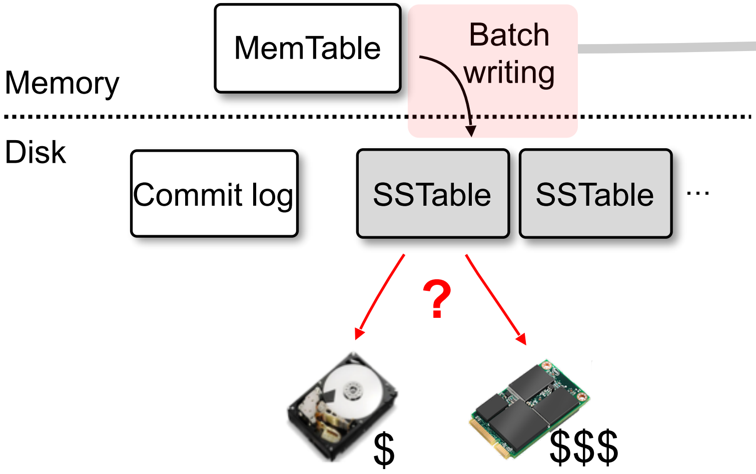
- LSM (Log-Structured Merge) tree



- Read optimization



Organizing SSTables …



MemTable

Batch writing

Memory

Disk

Commit log

SSTable

SSTable

…

?

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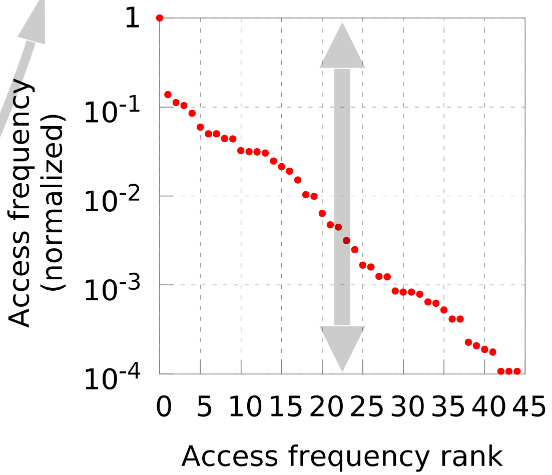
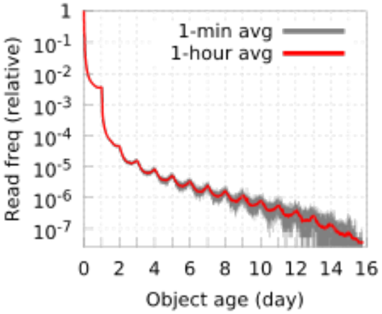
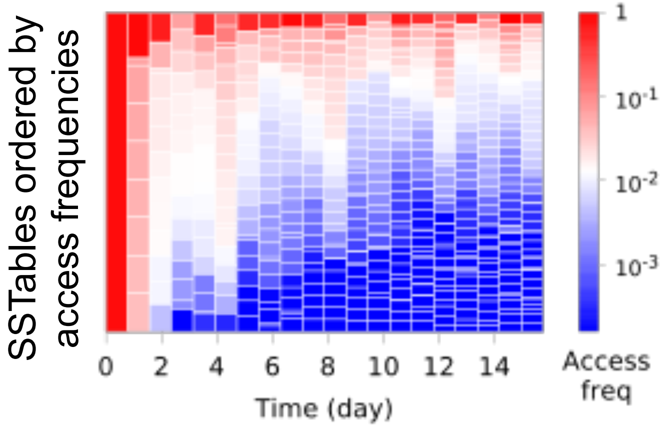
$$$

SSTables have different access frequencies



Web workloads have a strong temporal locality





Problem Formulation

Constraint	I'd like to pay no more than $0.03 / GB/month,	→	I'd like to keep the total SSTable size in the fast storage no more than 50 GB,
Optimization goal	while keeping the latency minimum		while maximizing the SSTable accesses in the fast storage

Hard to formulate:

- No storage latency model
- Parallel accesses

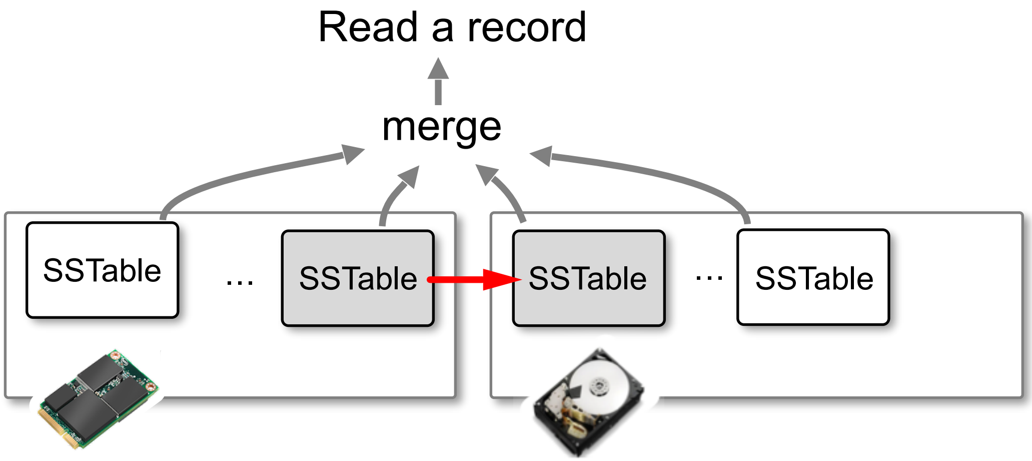
🤦‍♂️

😃

SSTable Organization

- “Store more frequently accessed SSTables into the fast storage of a limited size.”
- **0/1 Knapsack** problem!
  - *O*(*nW*) time and space with dynamic programming 🤔
    - with ***n*** SSTables and a ***W*-byte** storage
- Greedy algorithm!
  - Using SSTable access freq / size
  - Faster: *O*(*n*)
  - Almost optimal! The item sizes are a lot smaller than *W* (64 MB or 160 MB vs. TBs) 😃
- Now, how do you migrate SSTables between storages?

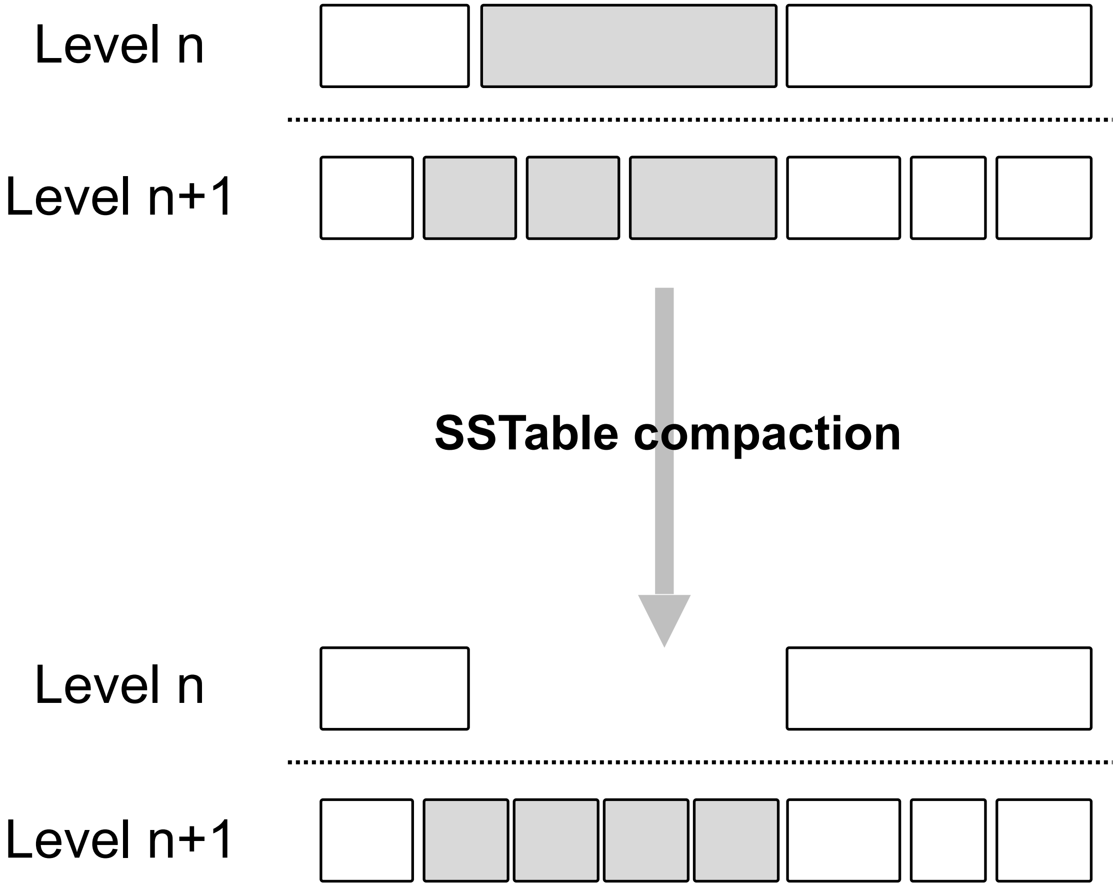
SSTable Migration



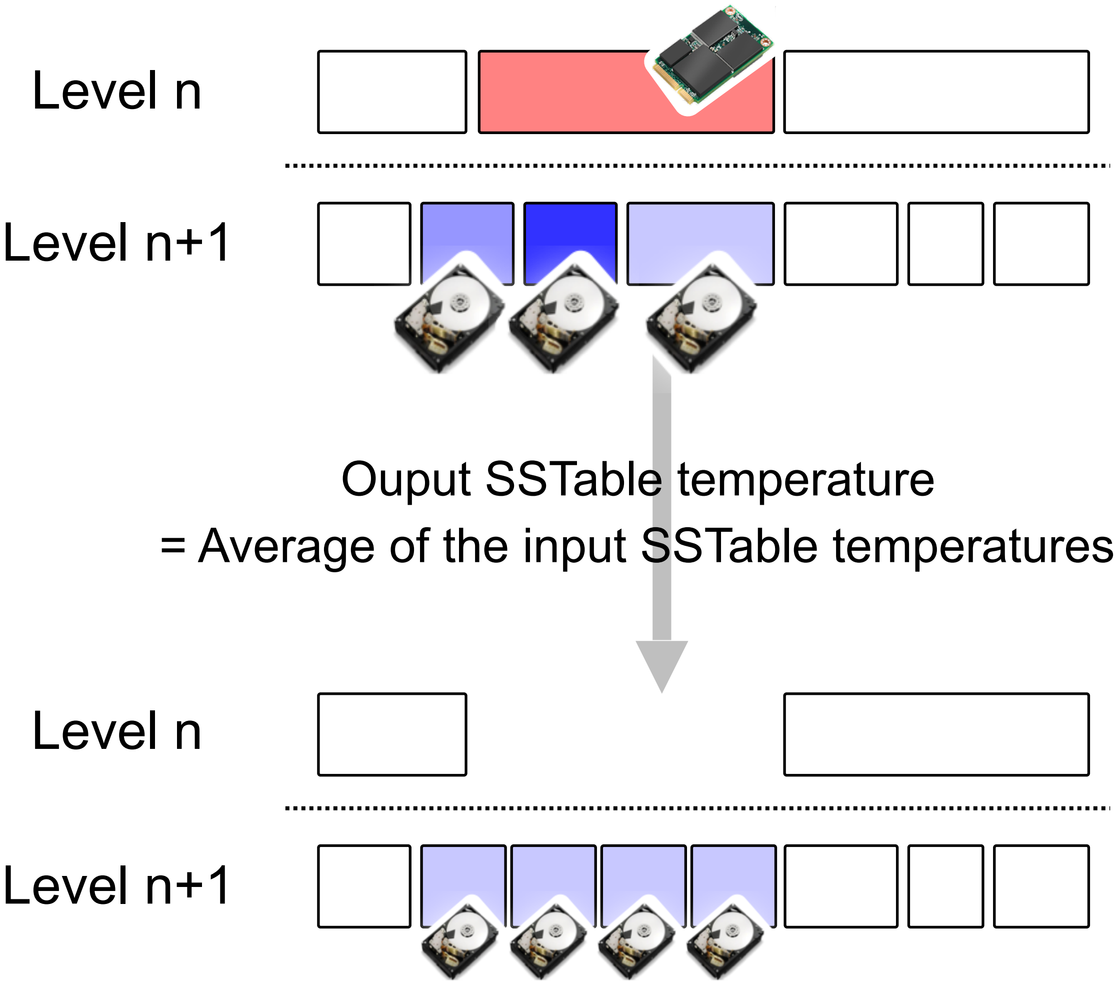
- Copy SSTable → Redirect reads → Delete old SSTable 🤔

- Use SSTable compaction!
- SSTable migration = Single SSTable compaction to a different storage 😃

SSTable Compaction



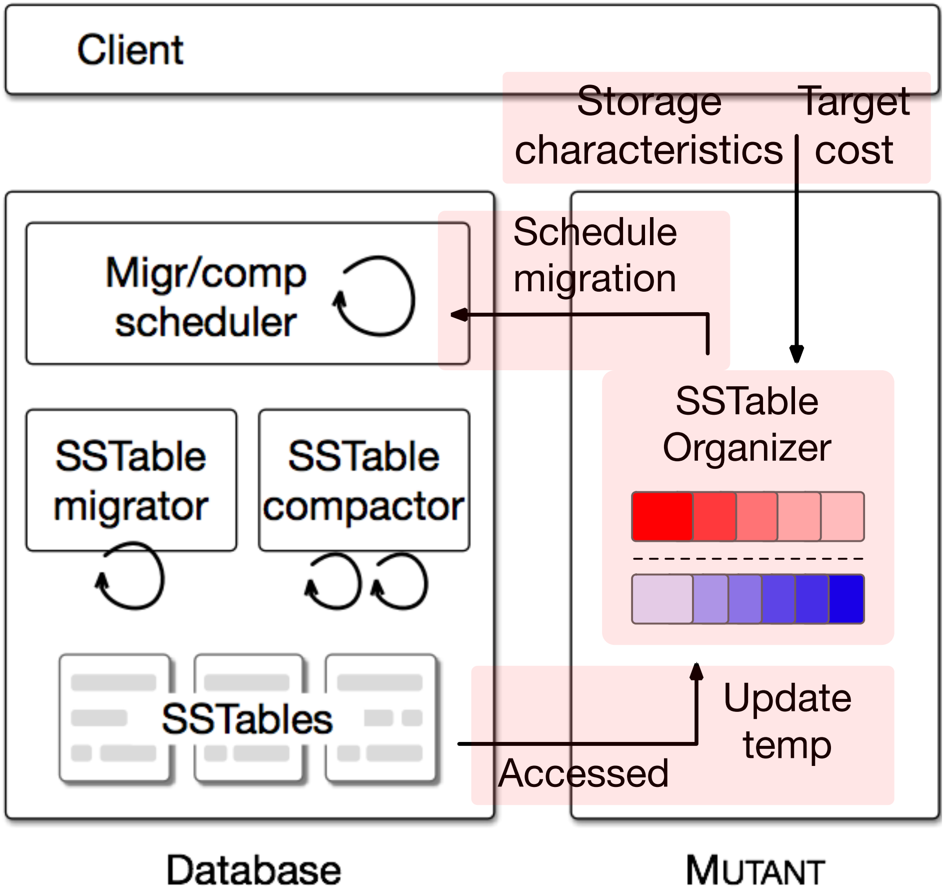
SSTable Compaction



Ouput SSTable temperature

= Average of the input SSTable temperatures

System Architecture

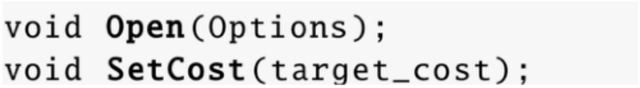


Implementation

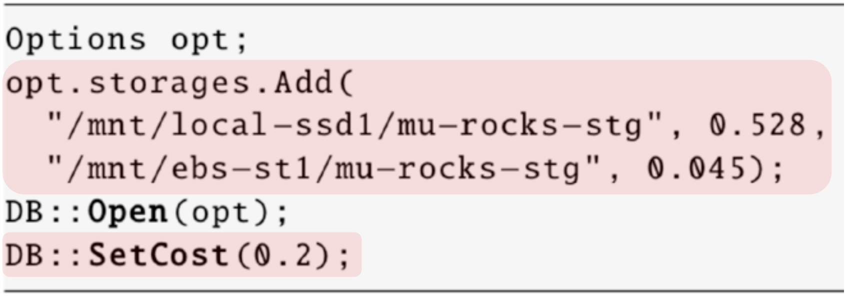
- Mutant in RocksDB with 658 lines of C++ code and 110 lines for the integration.

- Minimal API

Clients:



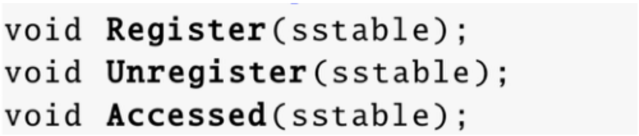
```
void Open(Options);
void SetCost(target_cost);
```



```
Options opt;
opt.storages.Add(
  "/mnt/local-ssd1/mu-rocks-stg", 0.528,
  "/mnt/ebs-st1/mu-rocks-stg", 0.045);
DB::Open(opt);
DB::SetCost(0.2);
```

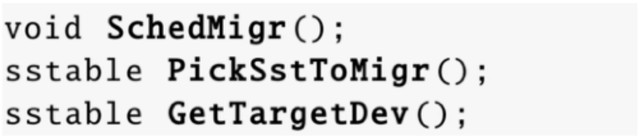
Database:

SSTable temperature monitor



```
void Register(sstable);
void Unregister(sstable);
void Accessed(sstable);
```

SSTable migration



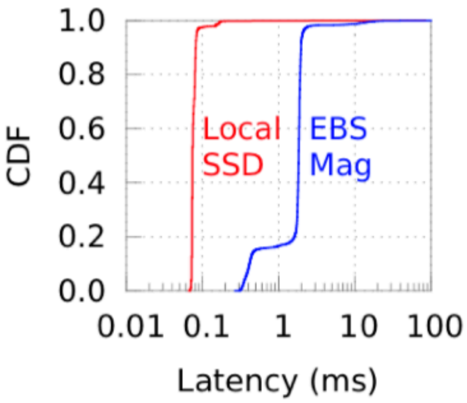
```
void SchedMigr();
sstable PickSstToMigr();
sstable GetTargetDev();
```

Evaluation

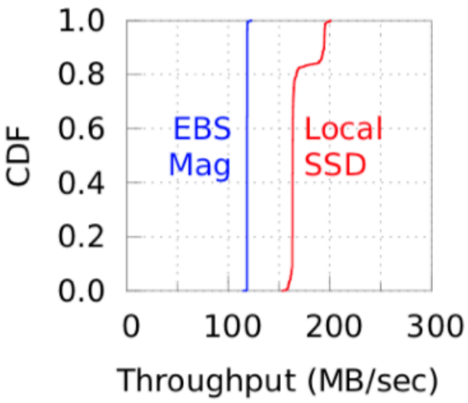
- **Cost Adaptability?**
- **Cost-Performance Spectrum?**
- **System Overhead?**

Evaluation Setup

- Fast storage: Local SSD (EC2 instance store). $0.528/GB/month
- Slow storage: Remote HDD (EBS Magnetic volume). $0.045



4KB random read



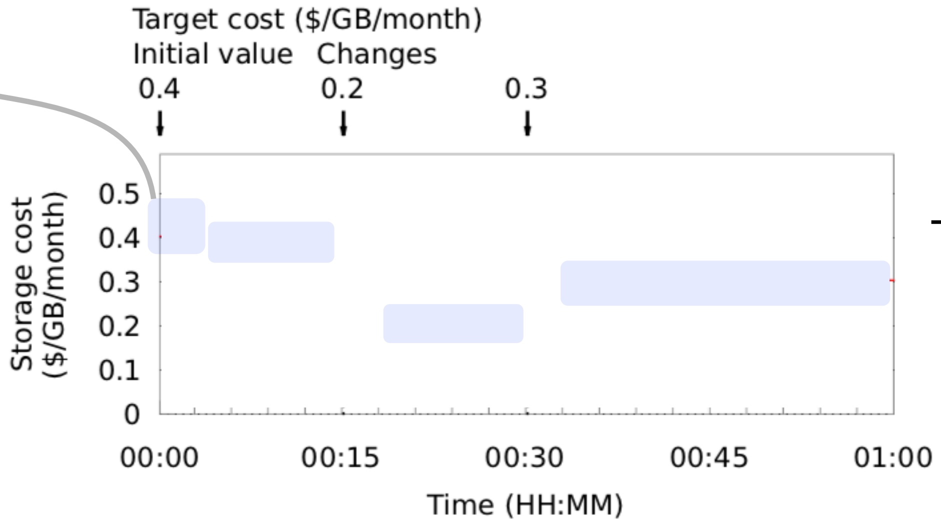
64 MB sequential write

- Workloads: YCSB ”read latest” and QuizUp

Cost Adaptability

Fast: $0.528, Slow: $0.045

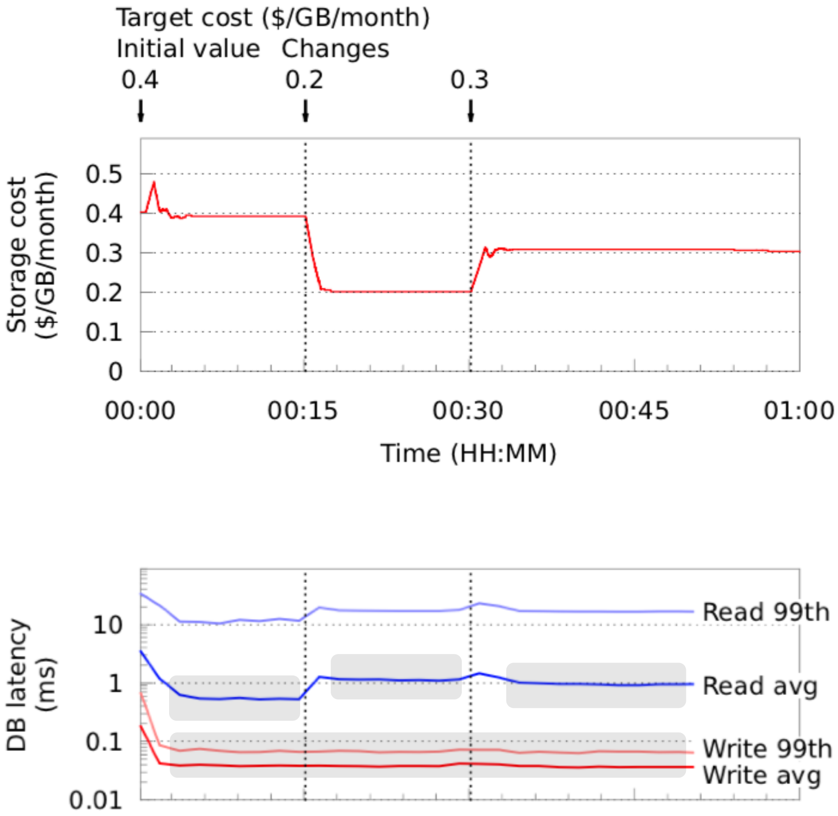
Time for SSTable temperature stabilization



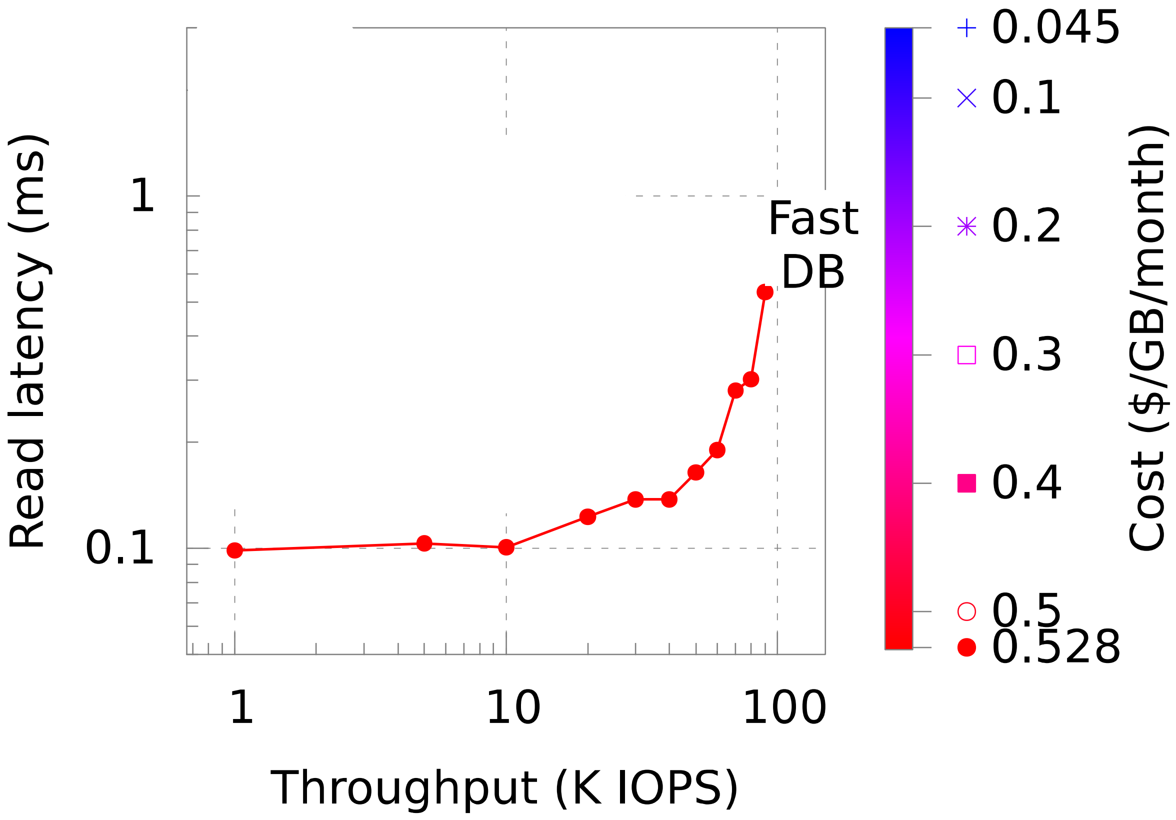
Target cost ± ε

😃

Latency

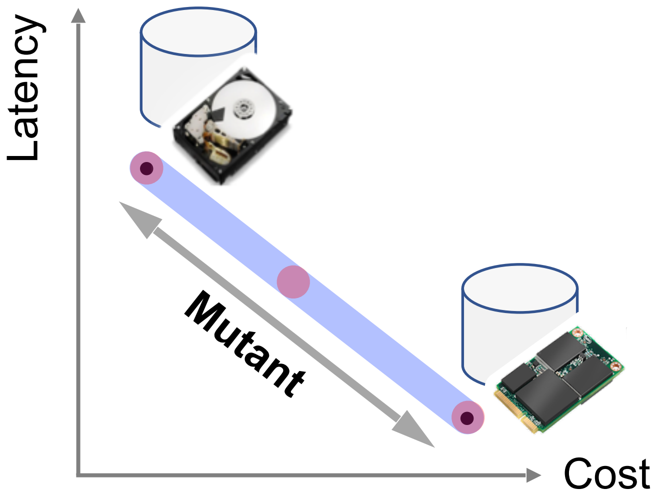

Target cost ($/GB/month)
Initial value
Changes
0.4
0.2
0.3
Storage cost ($/GB/month)
0.5
0.4
0.3
0.2
0.1
0
00:00
00:15
00:30
00:45
01:00
Time (HH:MM)
DB latency (ms)
10
1
0.1
0.01
Read 99th
Read avg
Write 99th
Write avg

Cost-Performance Spectrum



Summary

Cost-performance trade-offs in DBs were manual and limited in options.



Mutant: Automatic, seamless cost-performance trade-offs by

(a) carefully monitoring SSTable temperatures

and (b) organizing them into different storages.

Dave’s life made easy! 😃