Constructing and *Analyzing* the **LSM Compaction Design Space**

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Zichen Zhu   Manos Athanassoulis

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DiSC lab

Log-**S**tructured **M**erge-tree

LSM-tree

LSM-tree

WT

levelDB

SCYLLA

APACHE HBASE

cassandra

tarantool

RocksDB

Bigtable

DynamoDB

accumulo™

SQLite

influxdb

riak

QuasarDB

2021

LSM-tree

Why **LSM** ?

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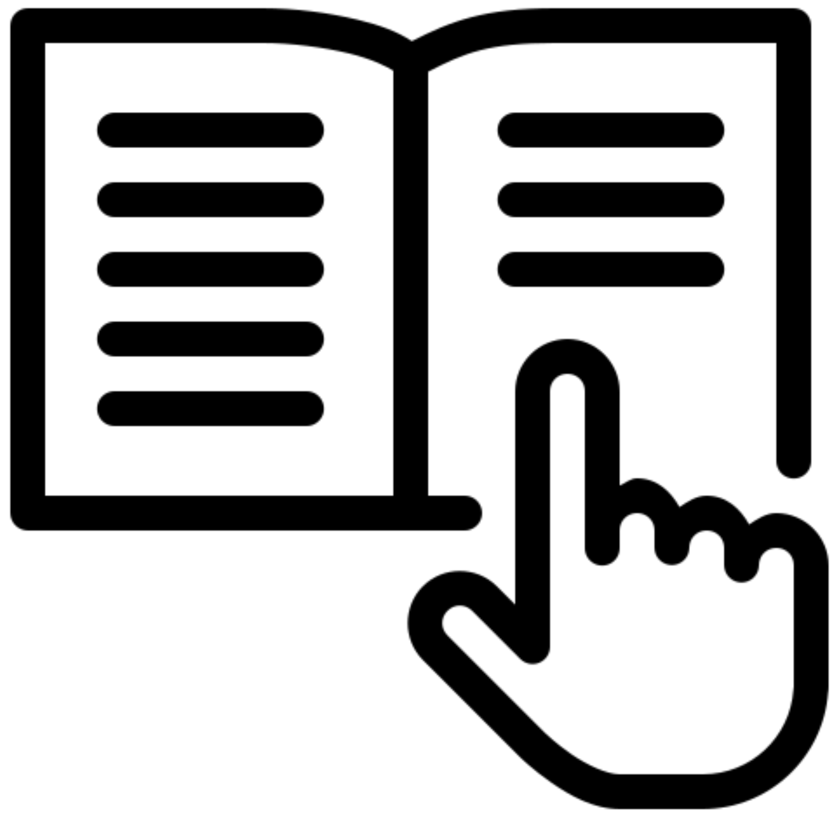
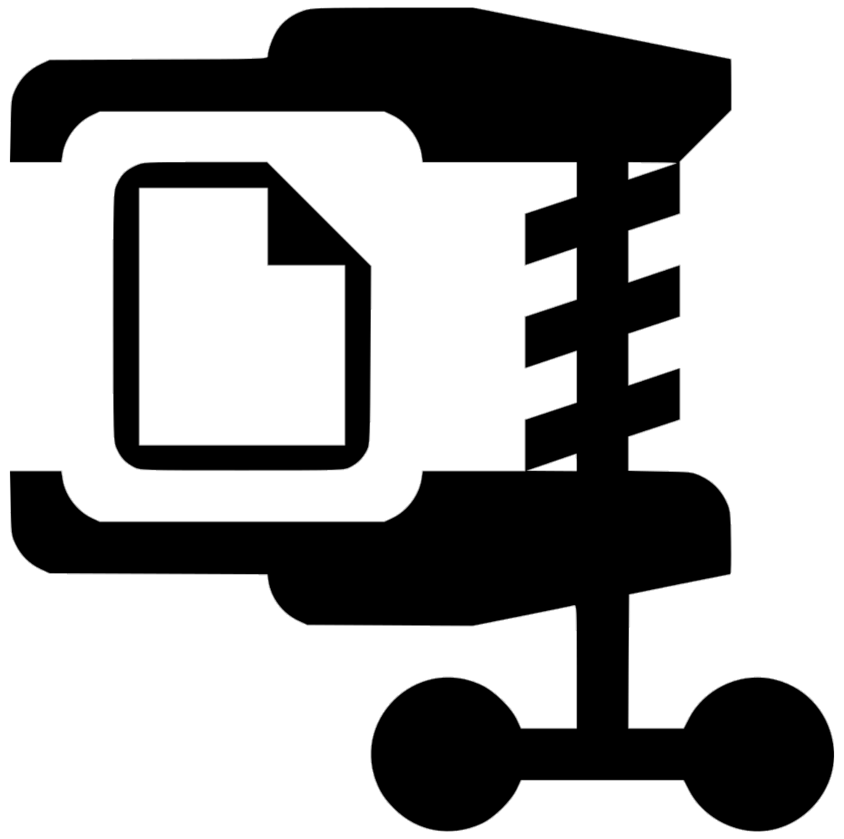
Why **LSM** ?

fast writes



competitive reads



good space utilization

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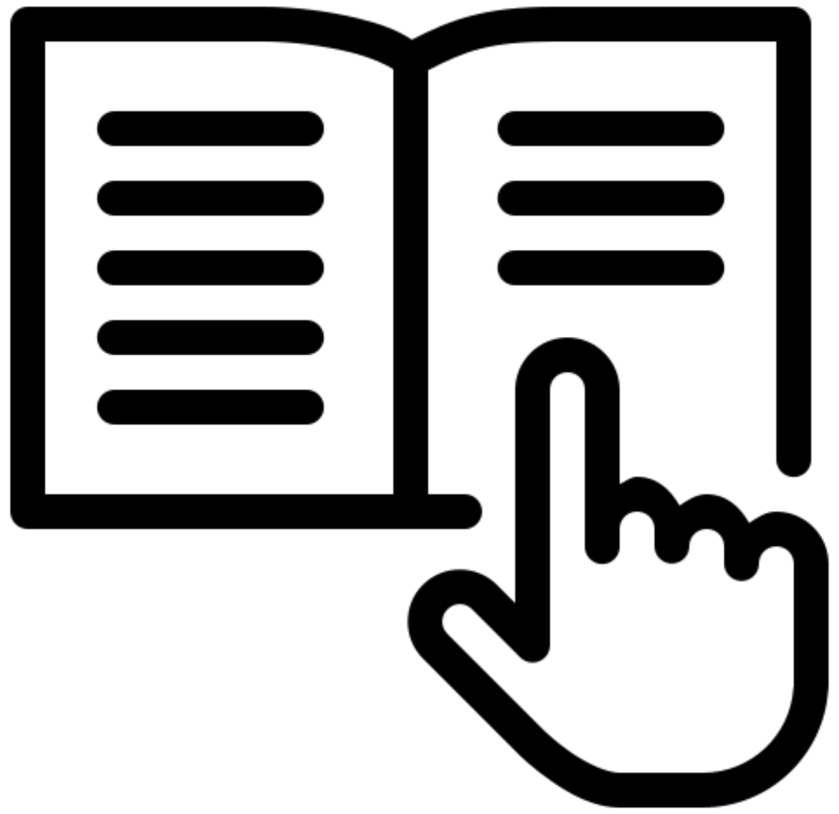
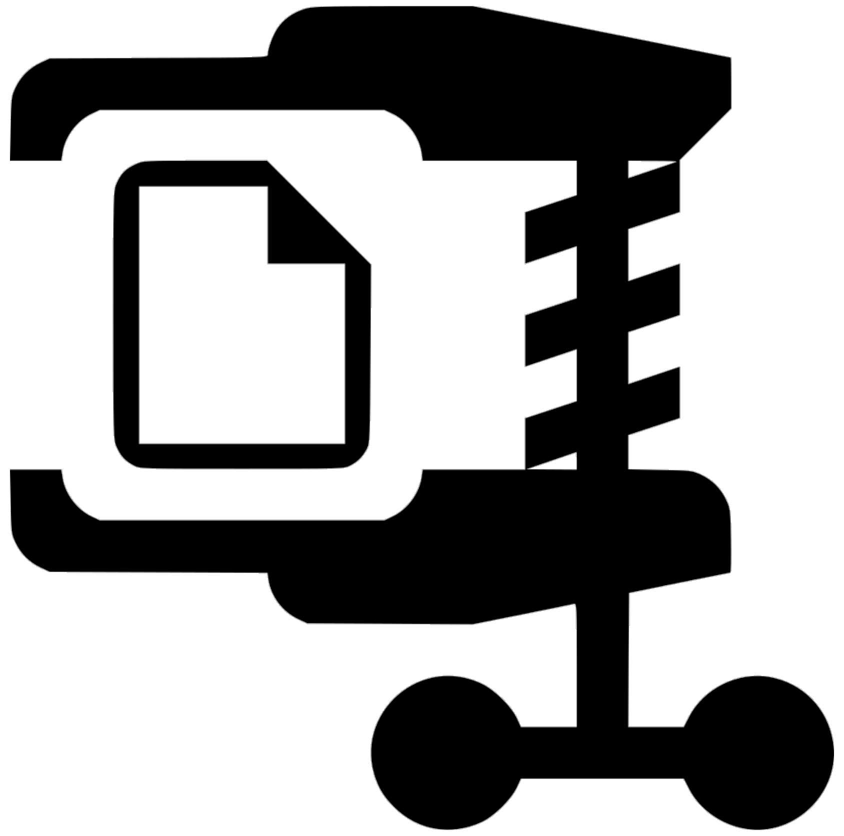
fast writes

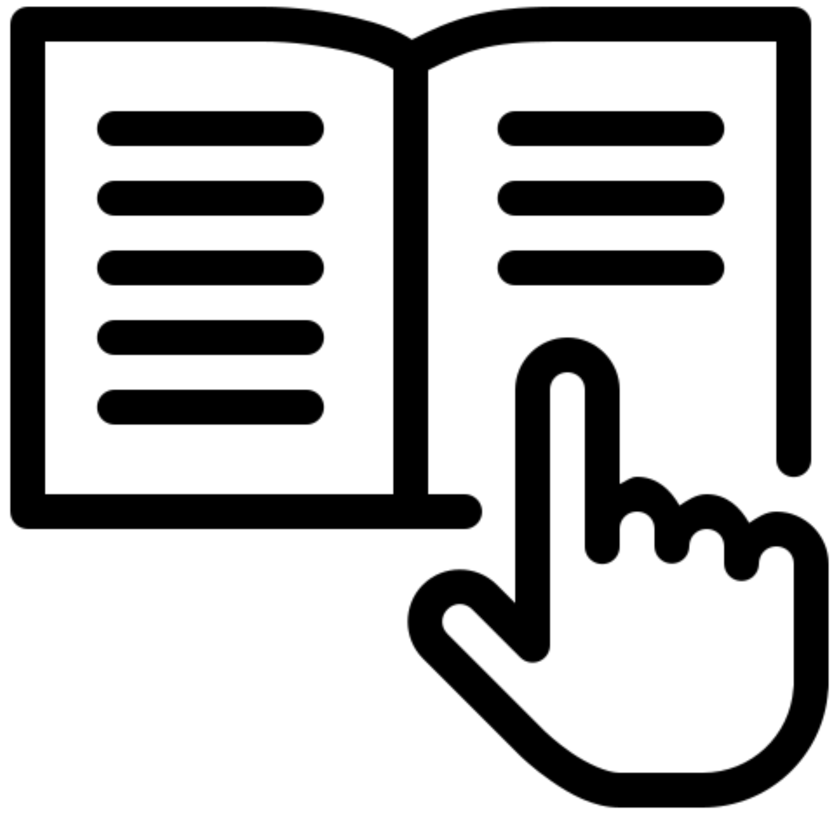


competitive reads

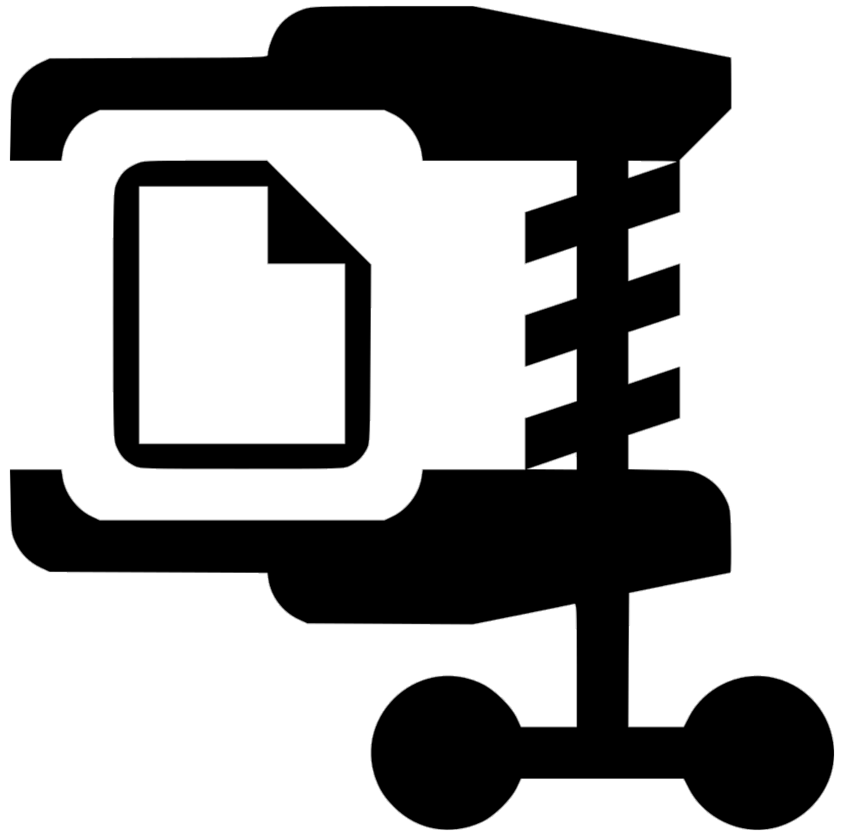


good space utilization

fast writes



competitive reads



good space utilization

COMPACTION

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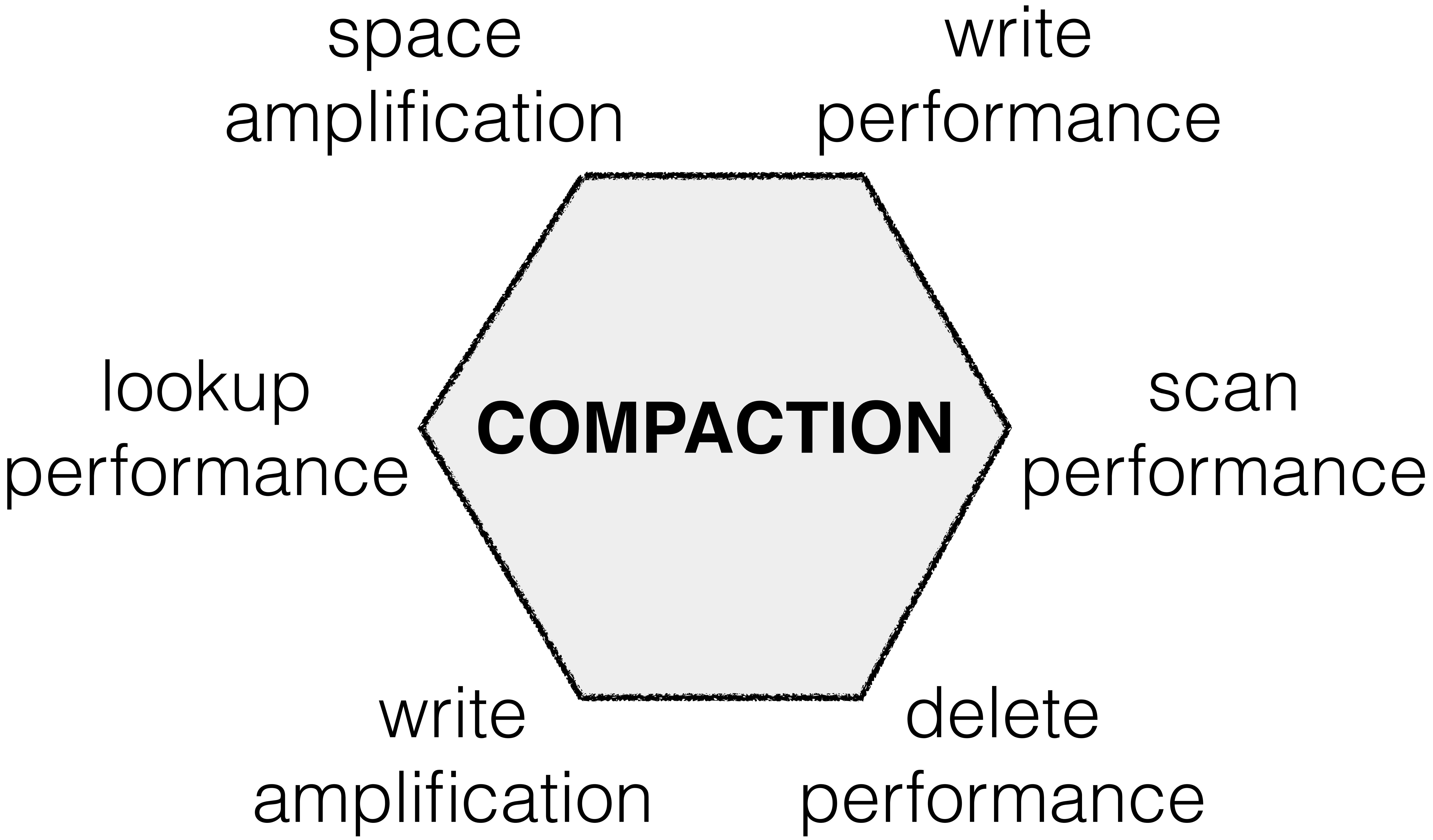
COMPACTION



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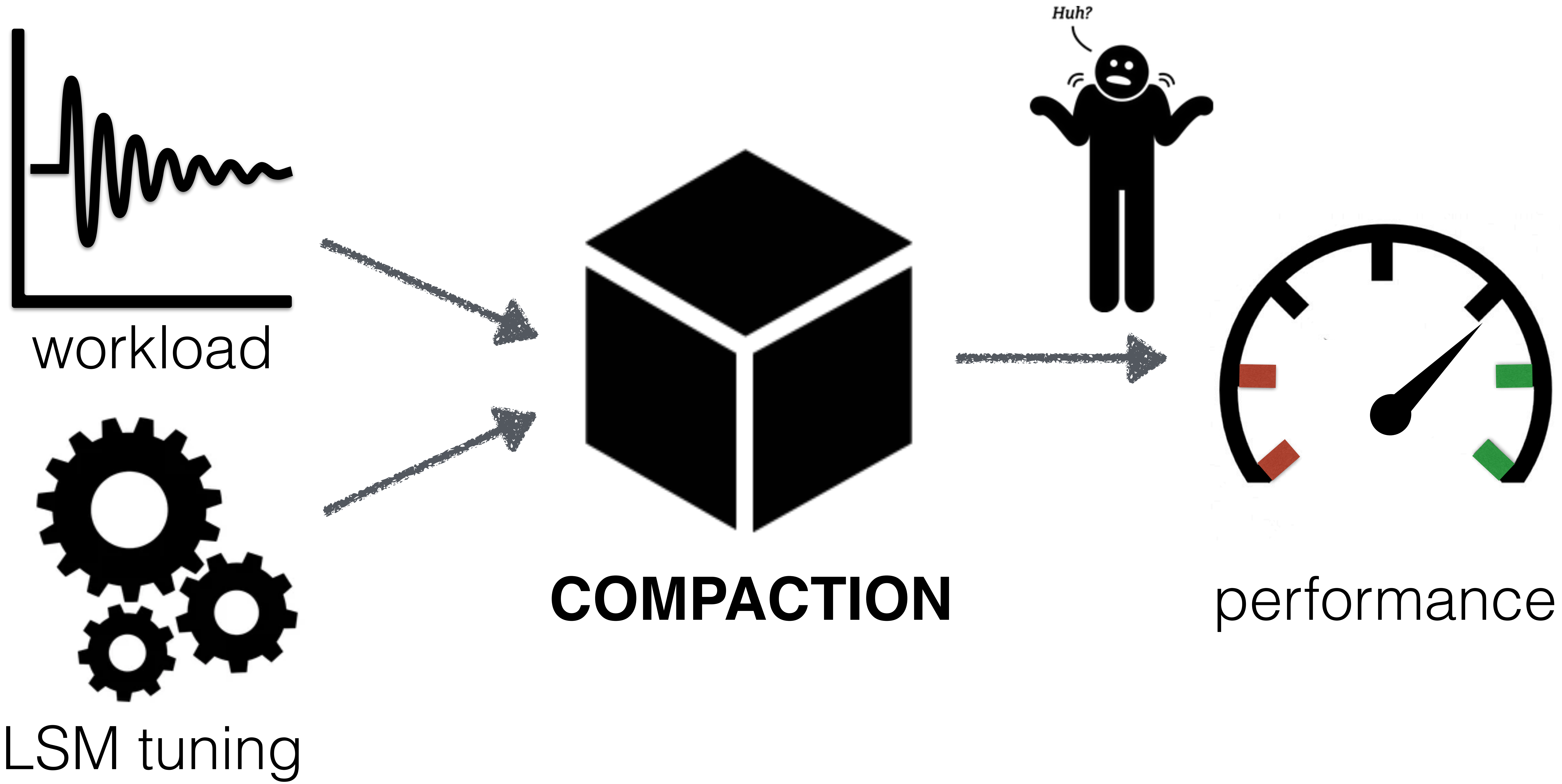
COMPACTION

COMPACTION


workload
LSM tuning
COMPACTION
Huh?
performance

Our **Goal**

Our **Goal**

1

Roadmap to pick compactions

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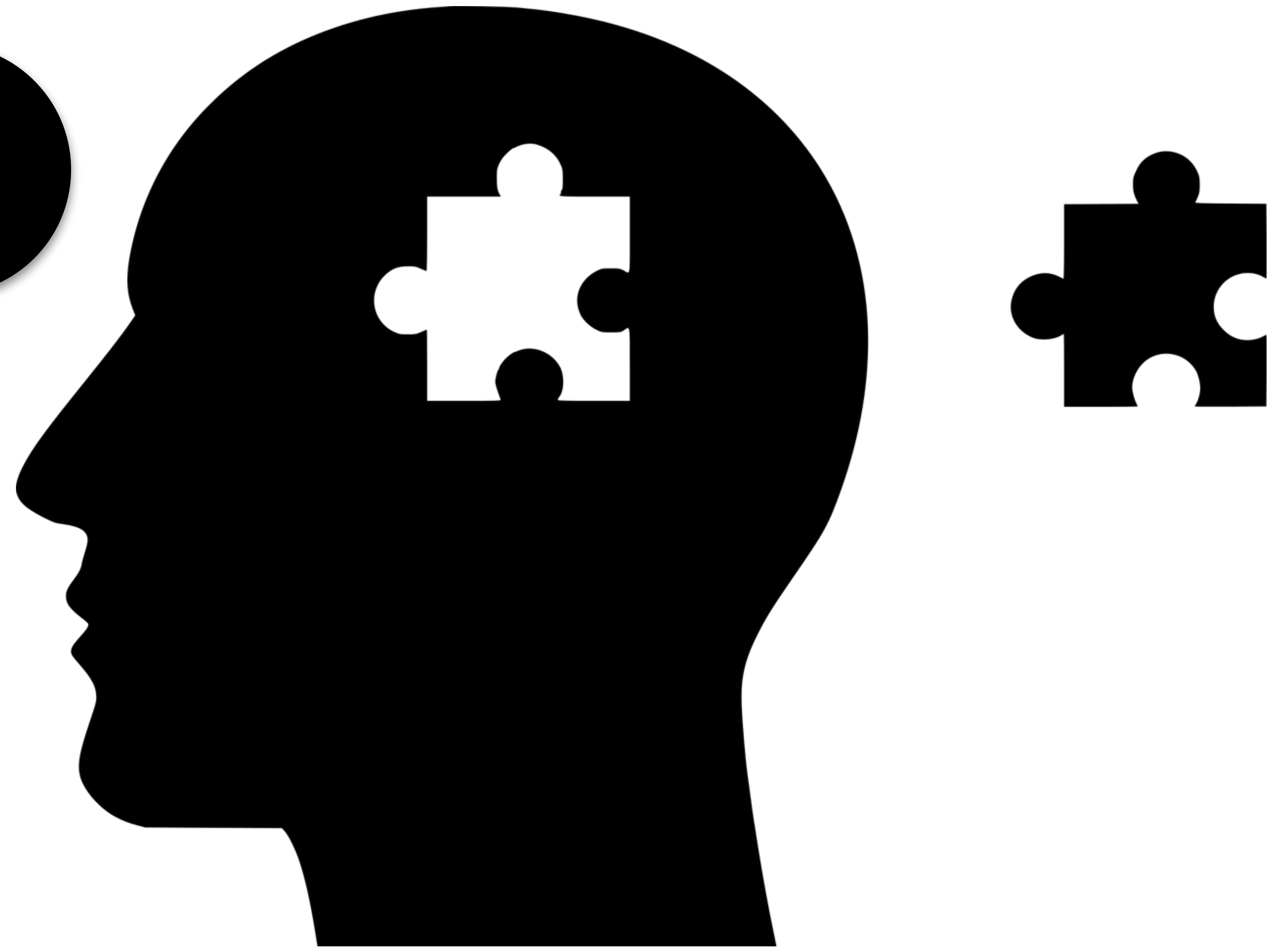
Our **Goal**

1

Roadmap to pick compactions

2



Answer to complex design questions

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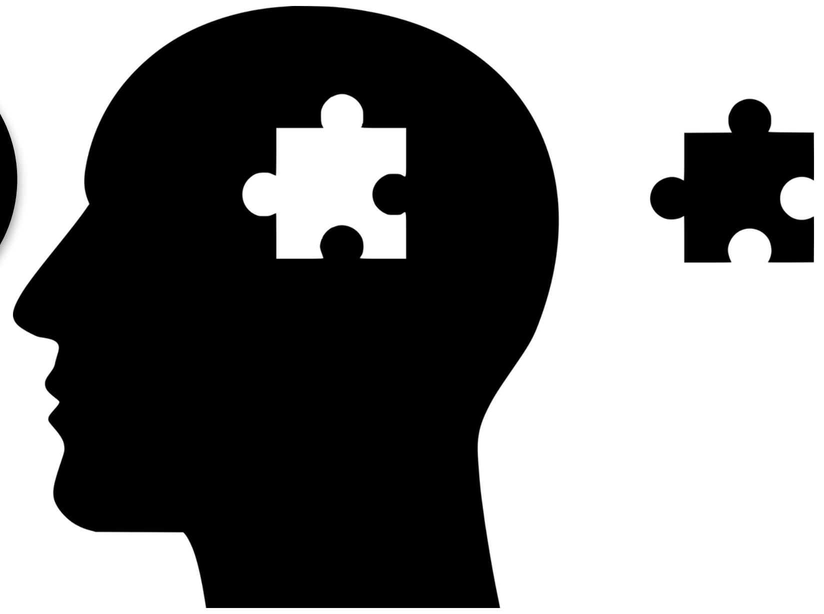
Our **Goal**

1 

2 

break the black box

learn from 2000+ experiments

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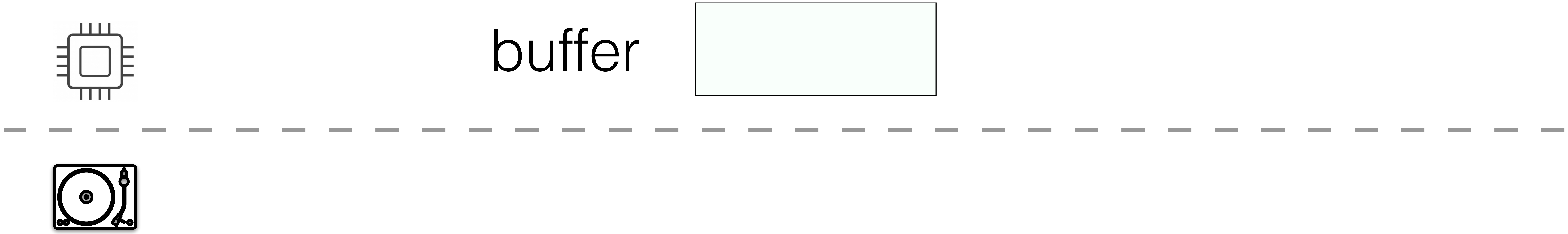
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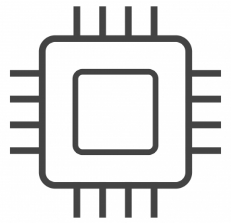
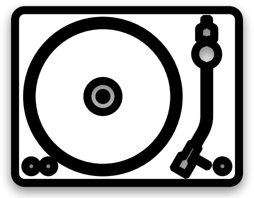
buffer

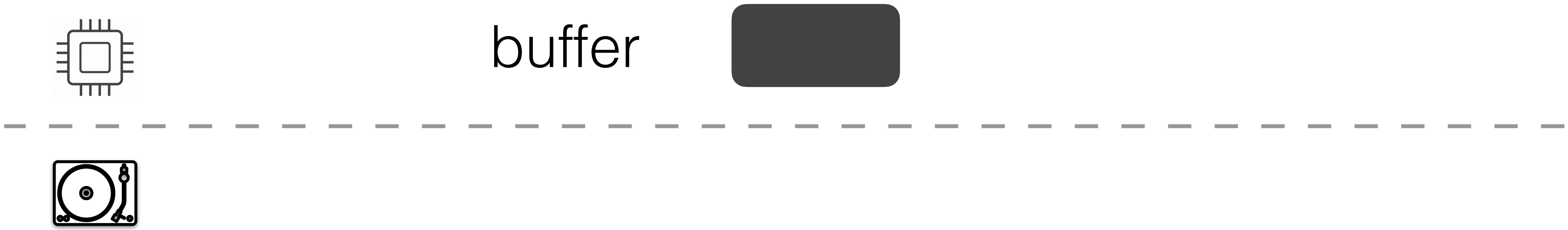
2	6	1	4



buffer

1	2	4	6

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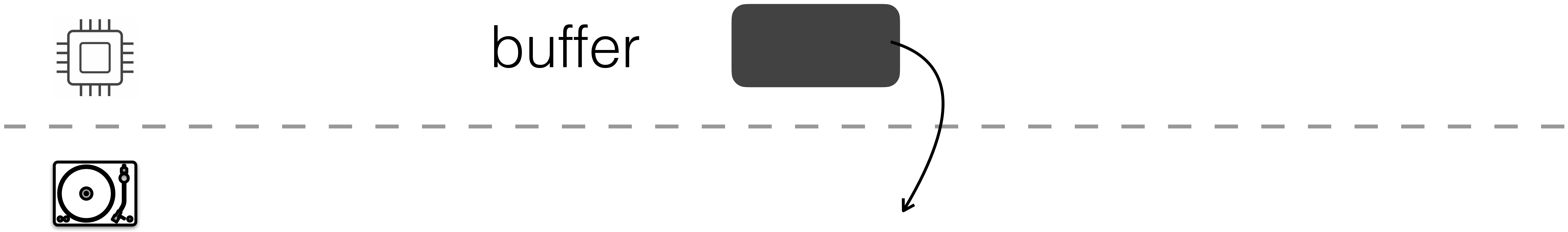
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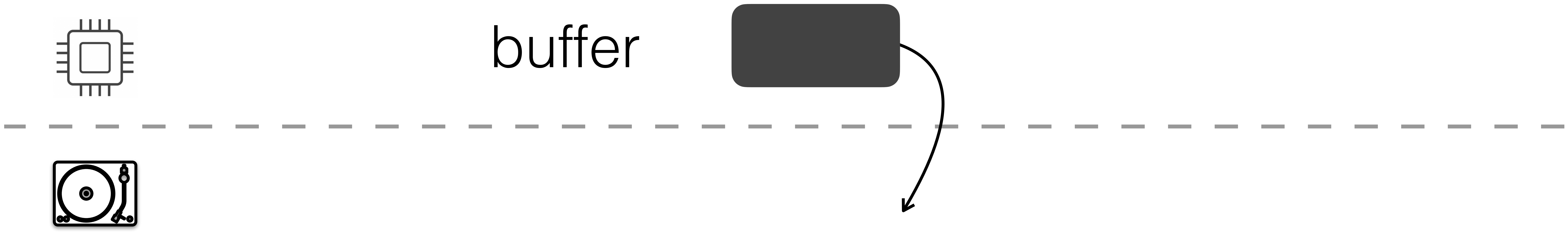
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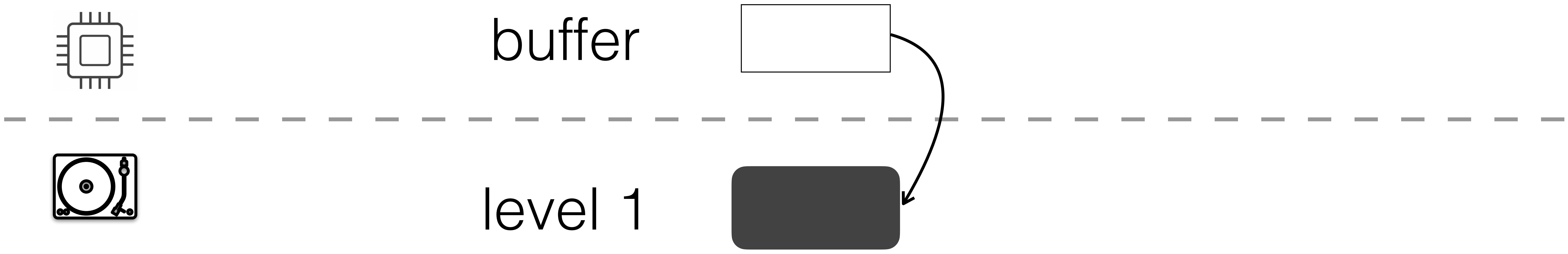
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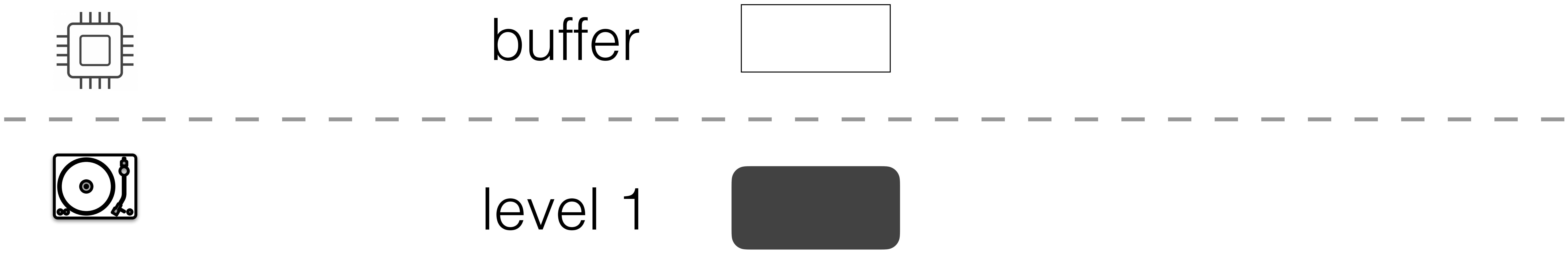
level 1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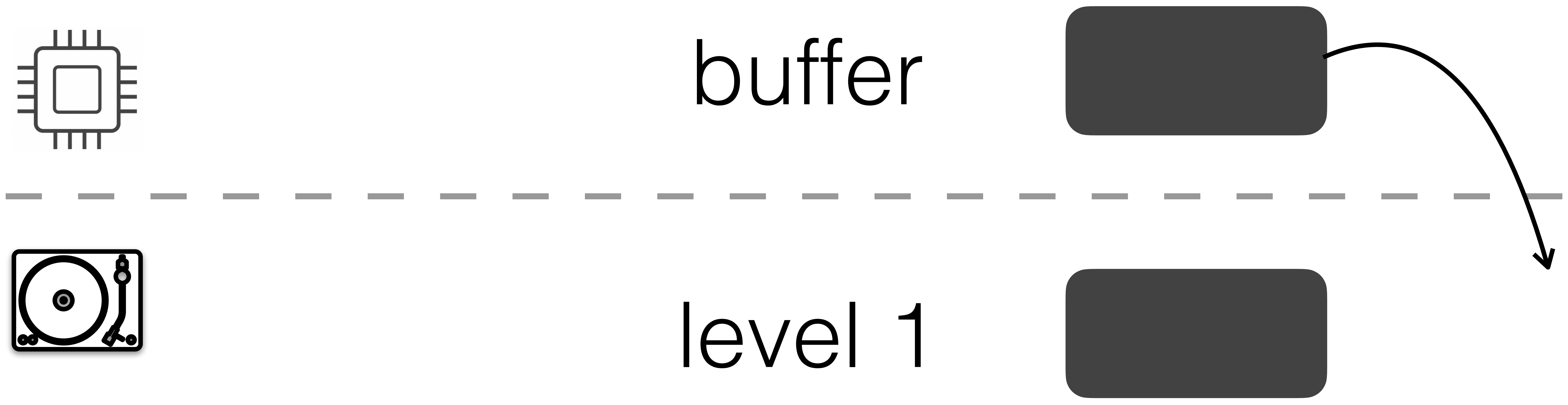
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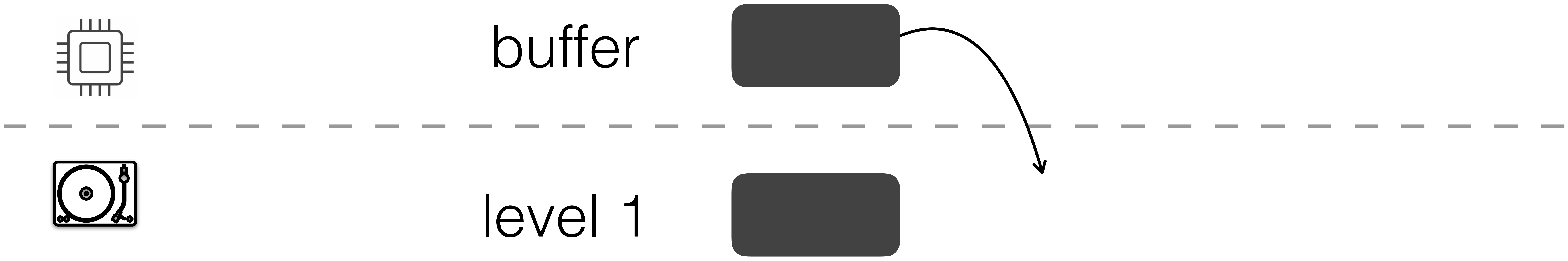
level 1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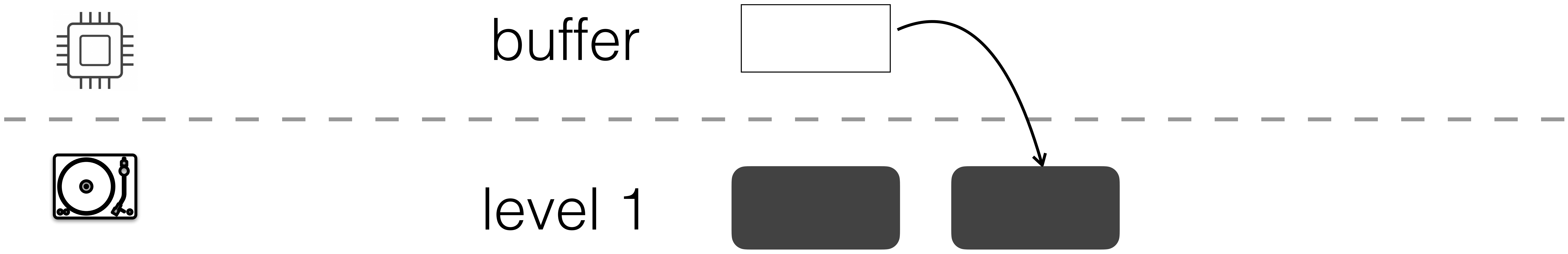
level 1



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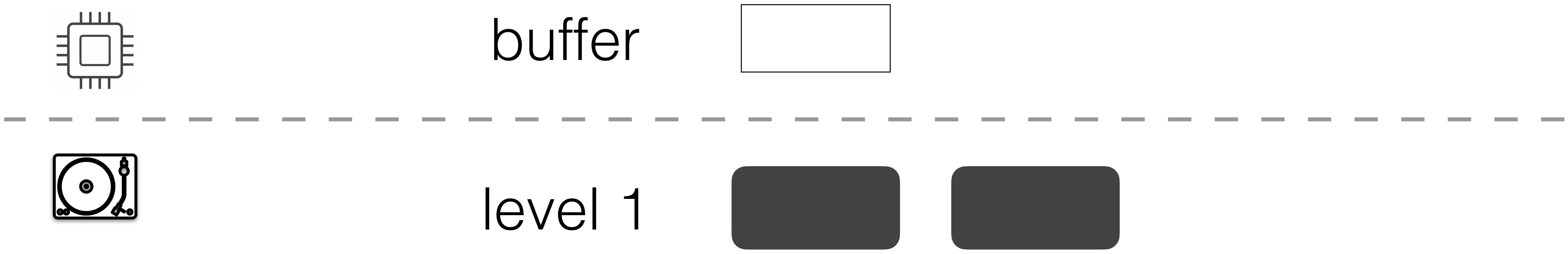
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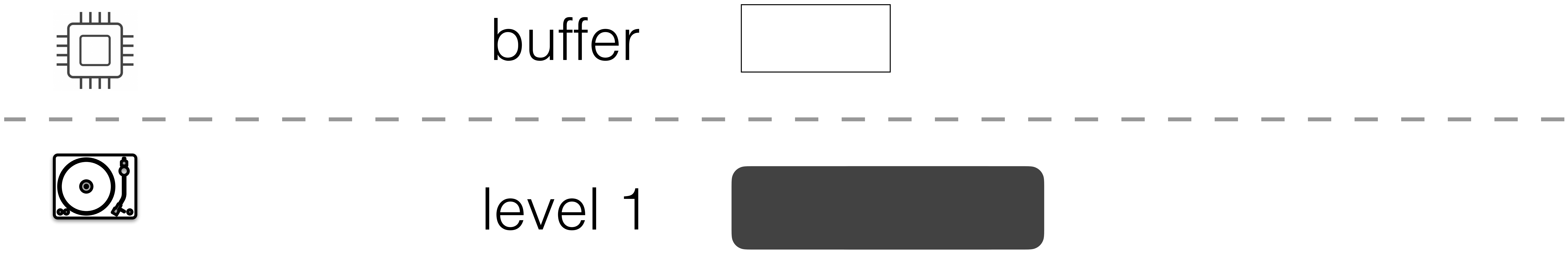
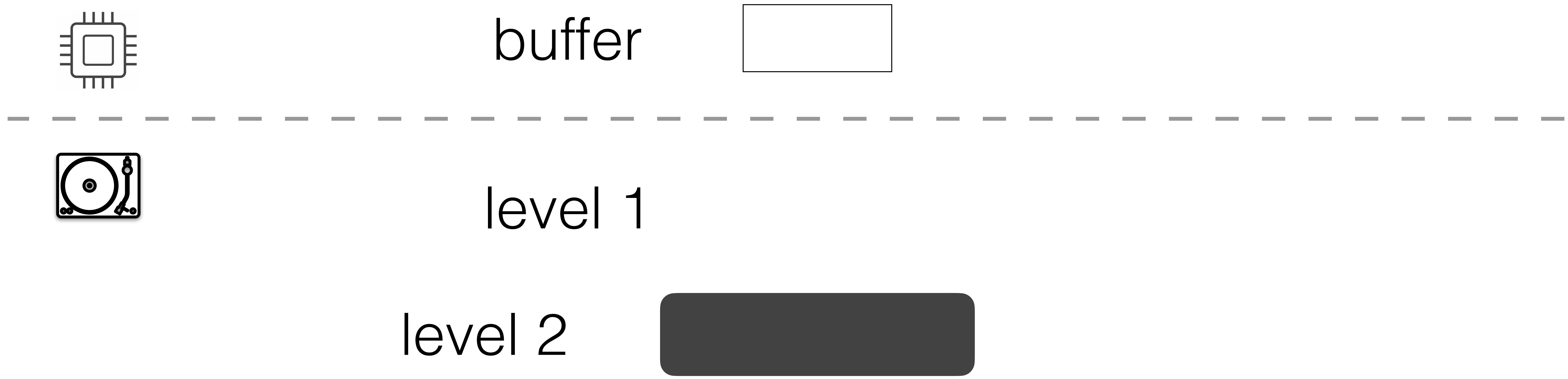
level 1


buffer
level 1



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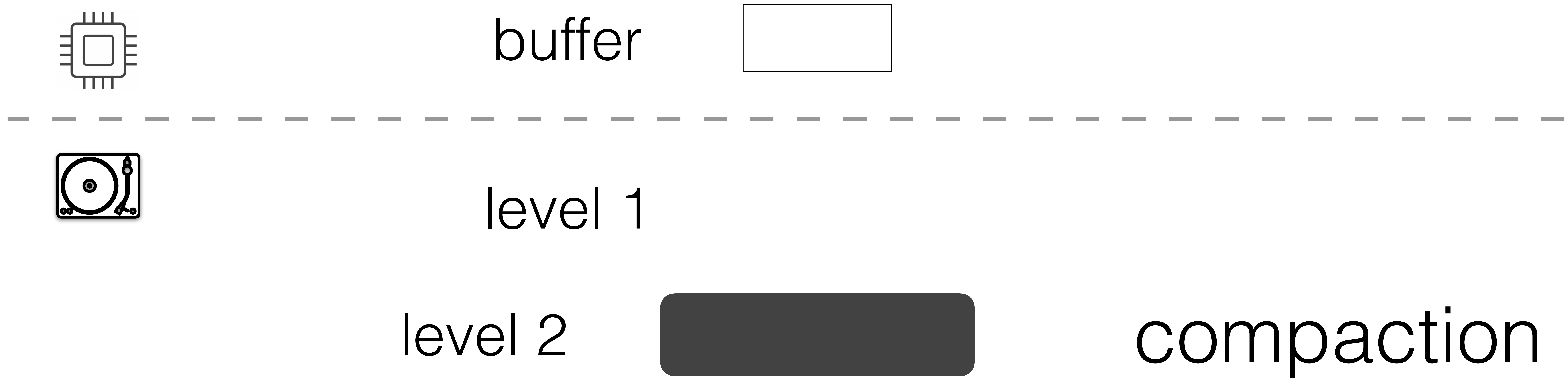

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compaction?

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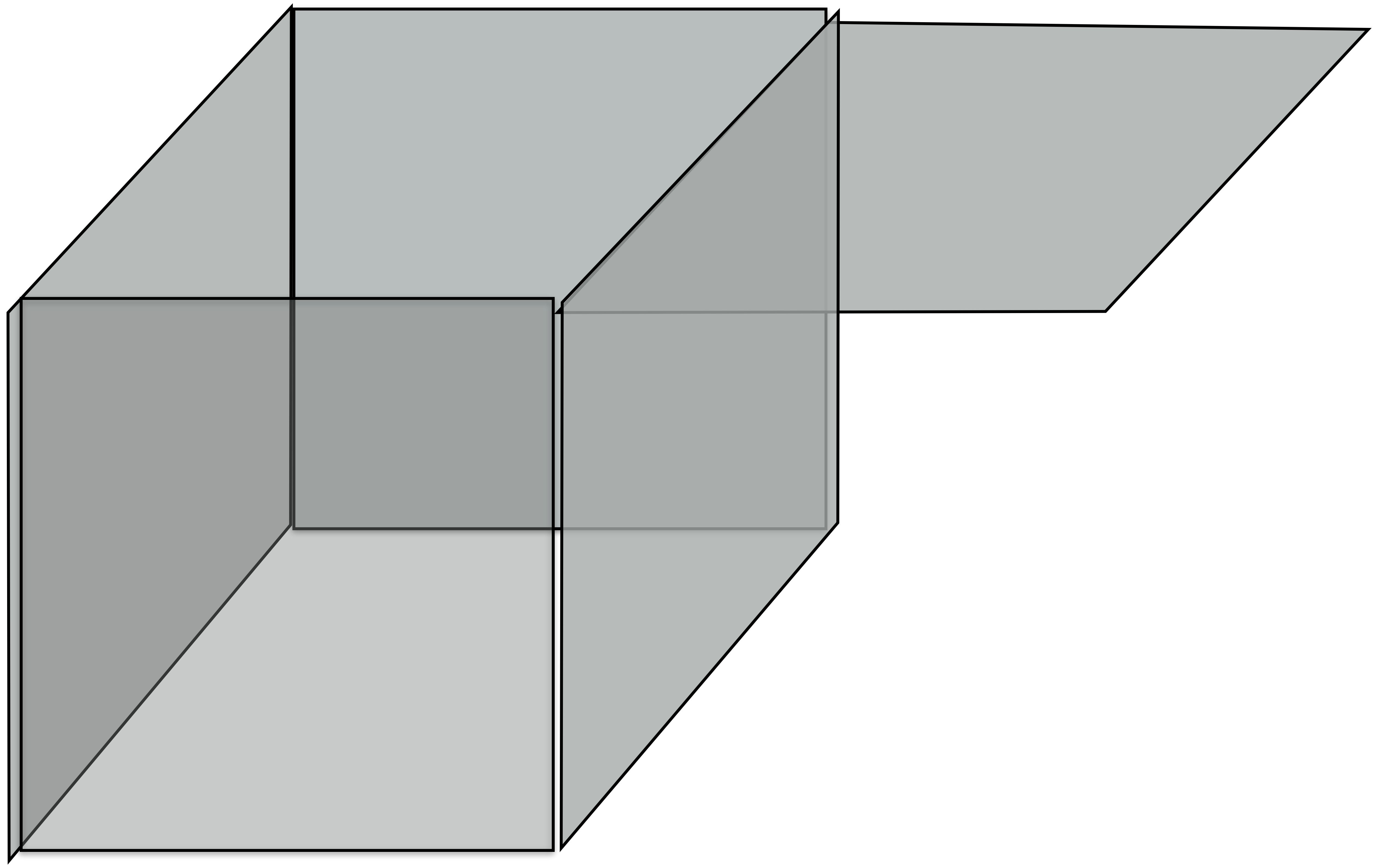
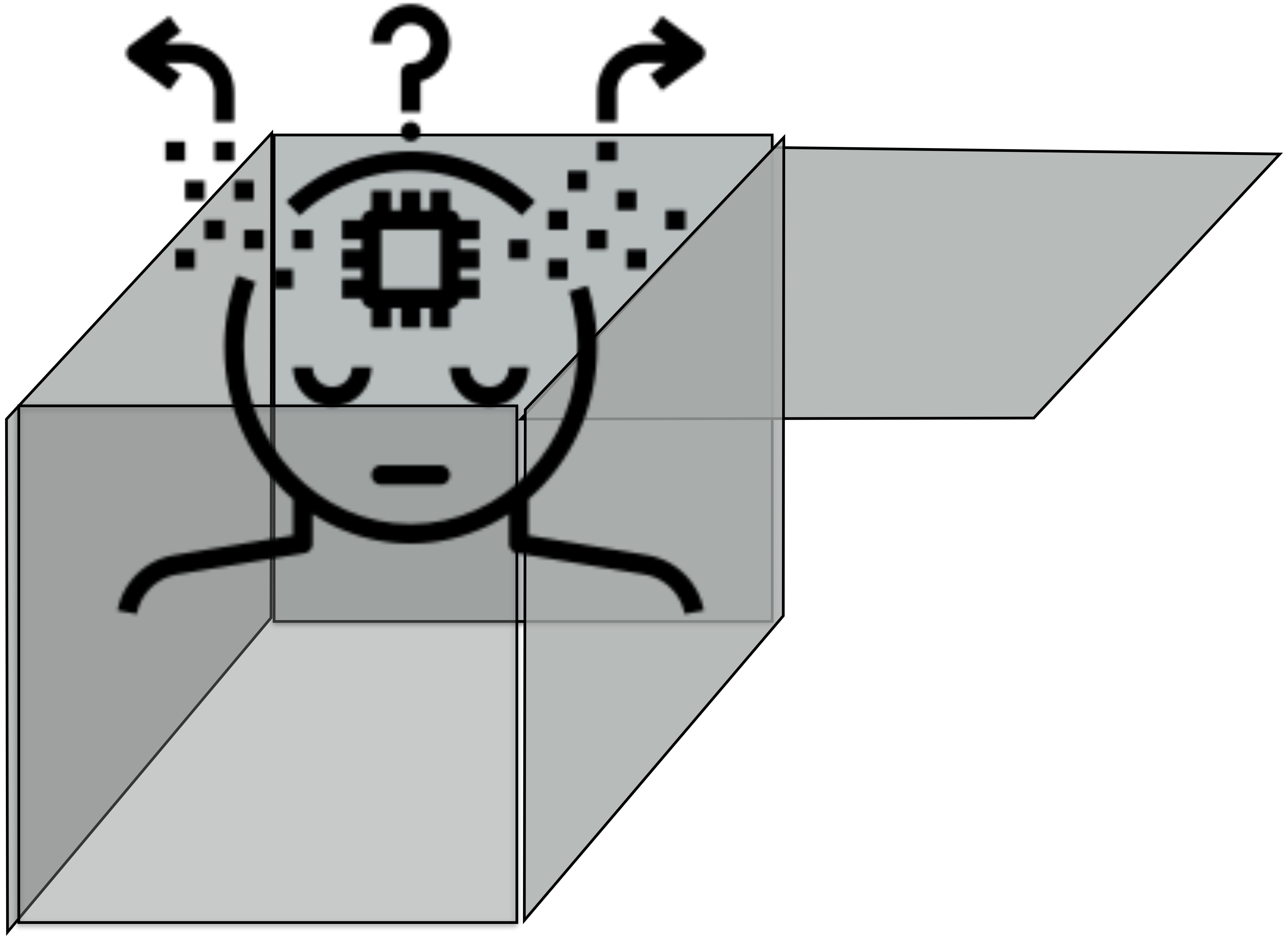
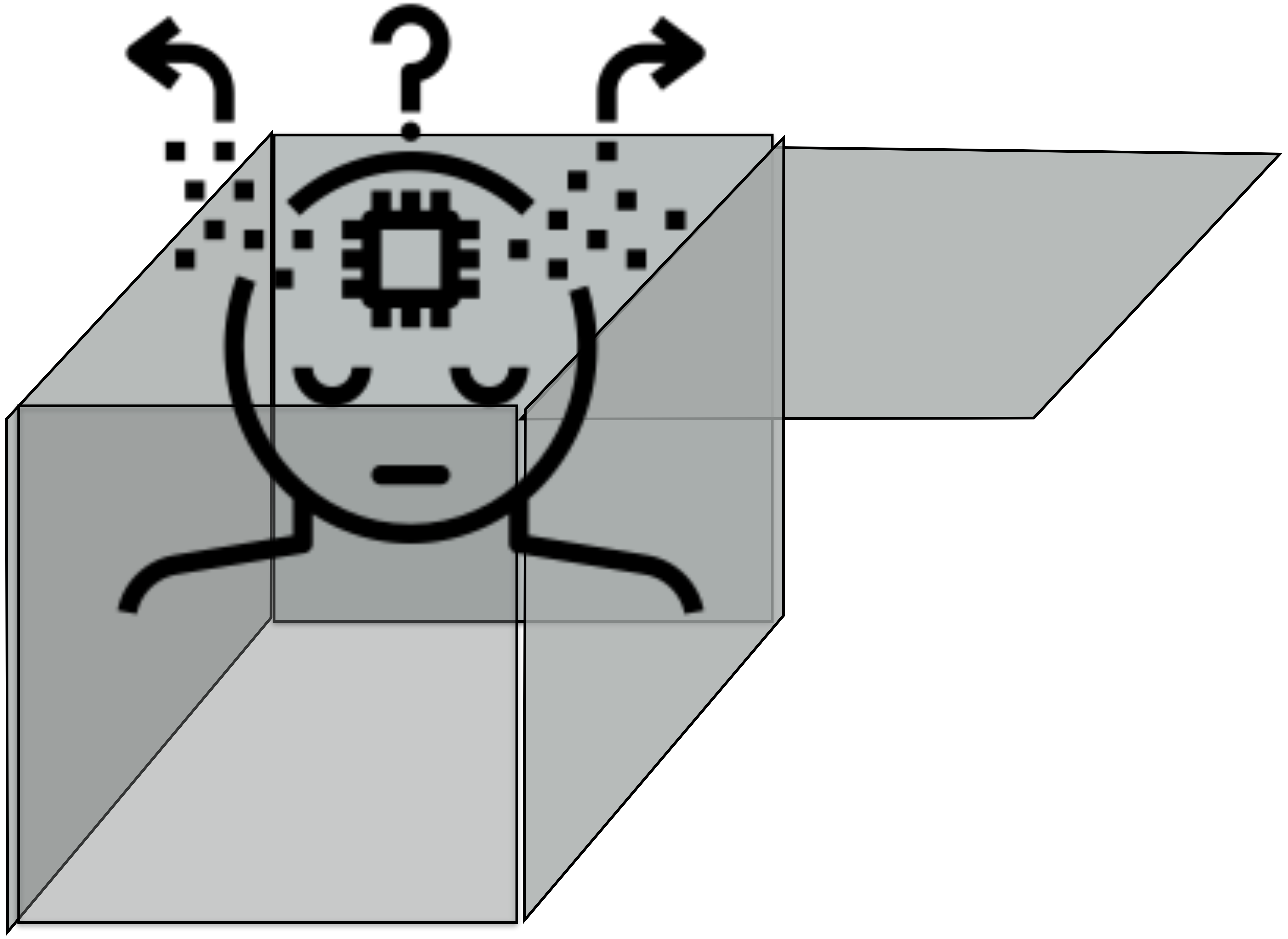




How many runs per level?



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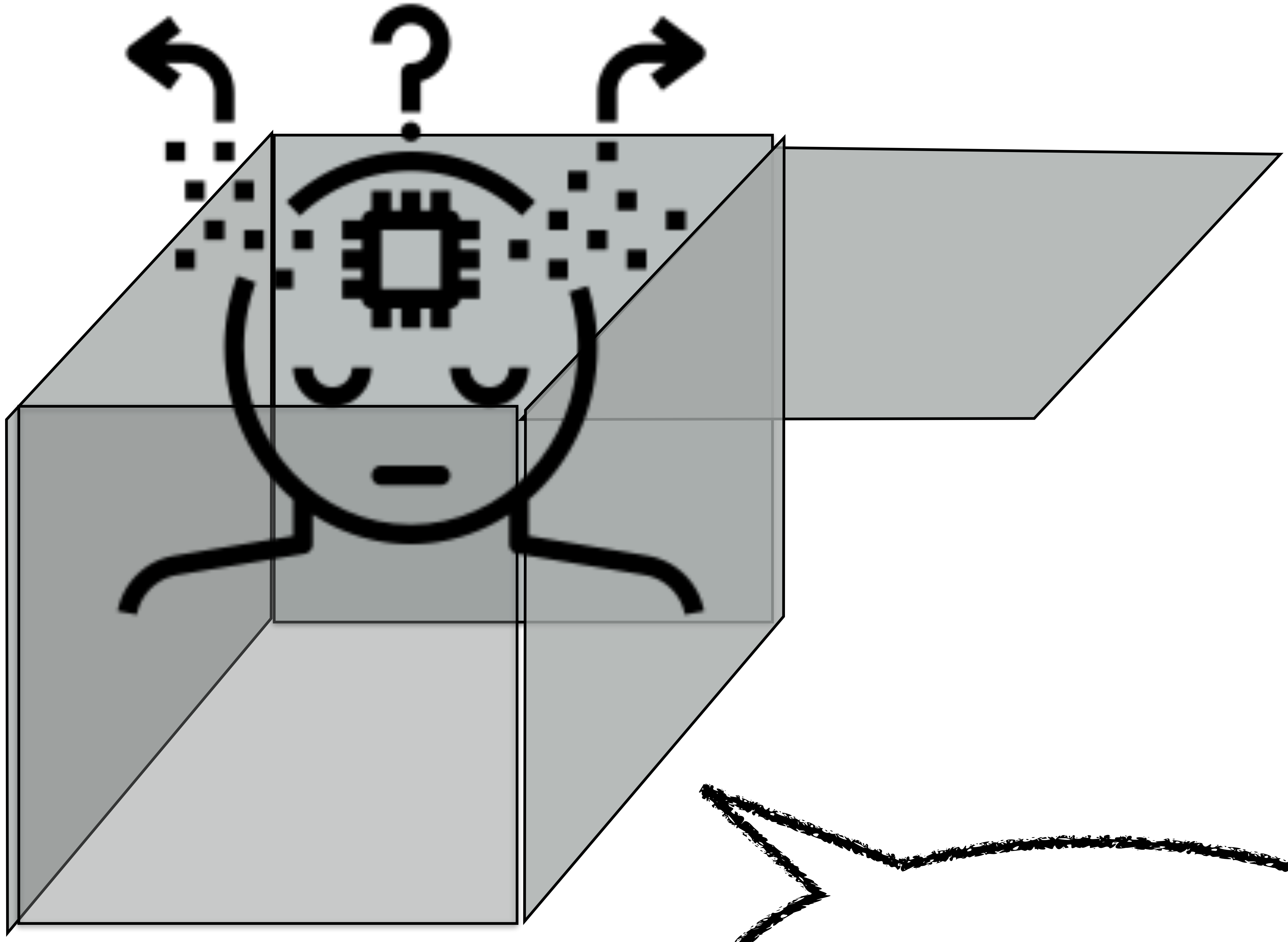

How much data to compact at once?

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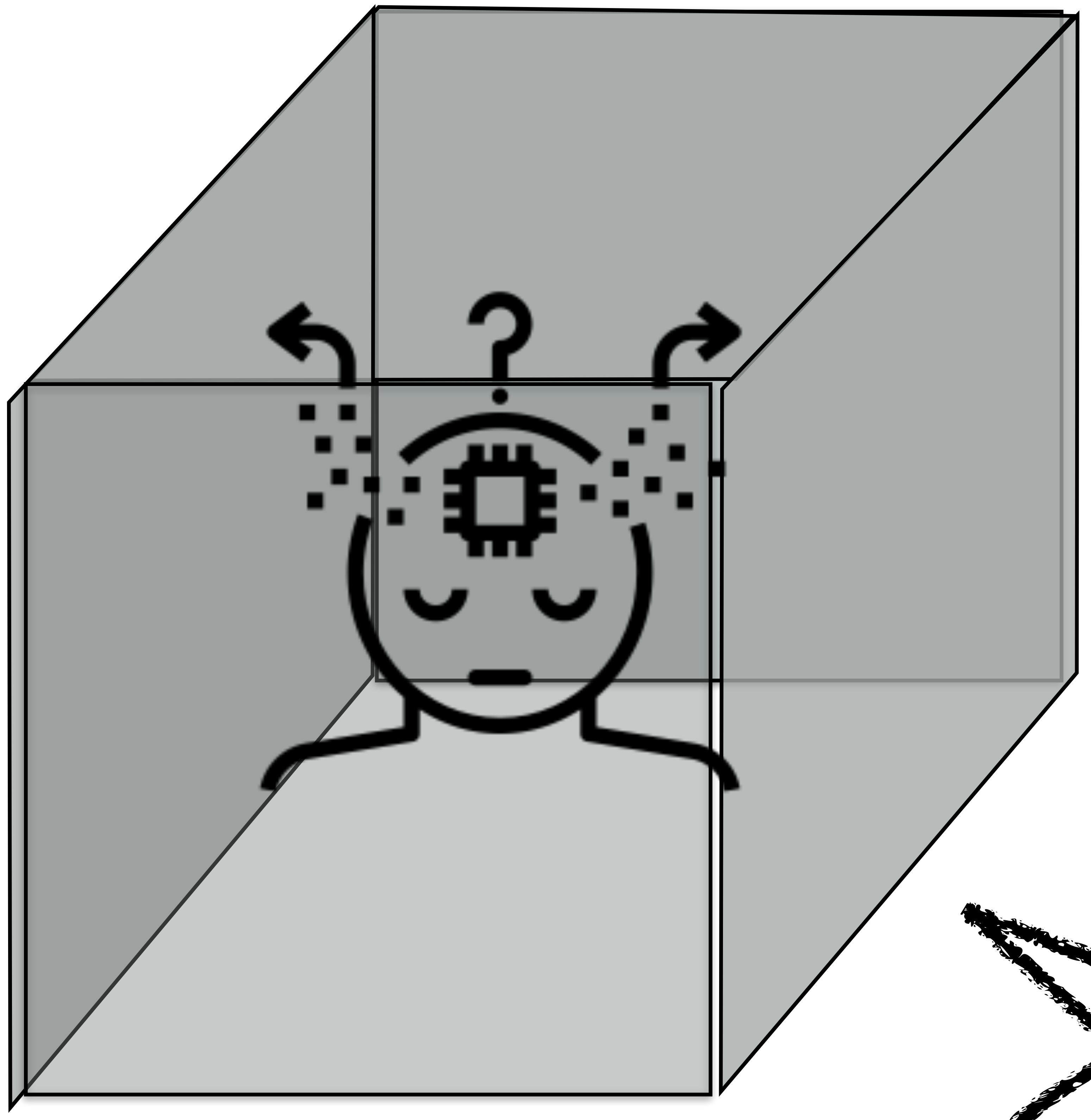
How many runs per level?



How much data to compact at once?

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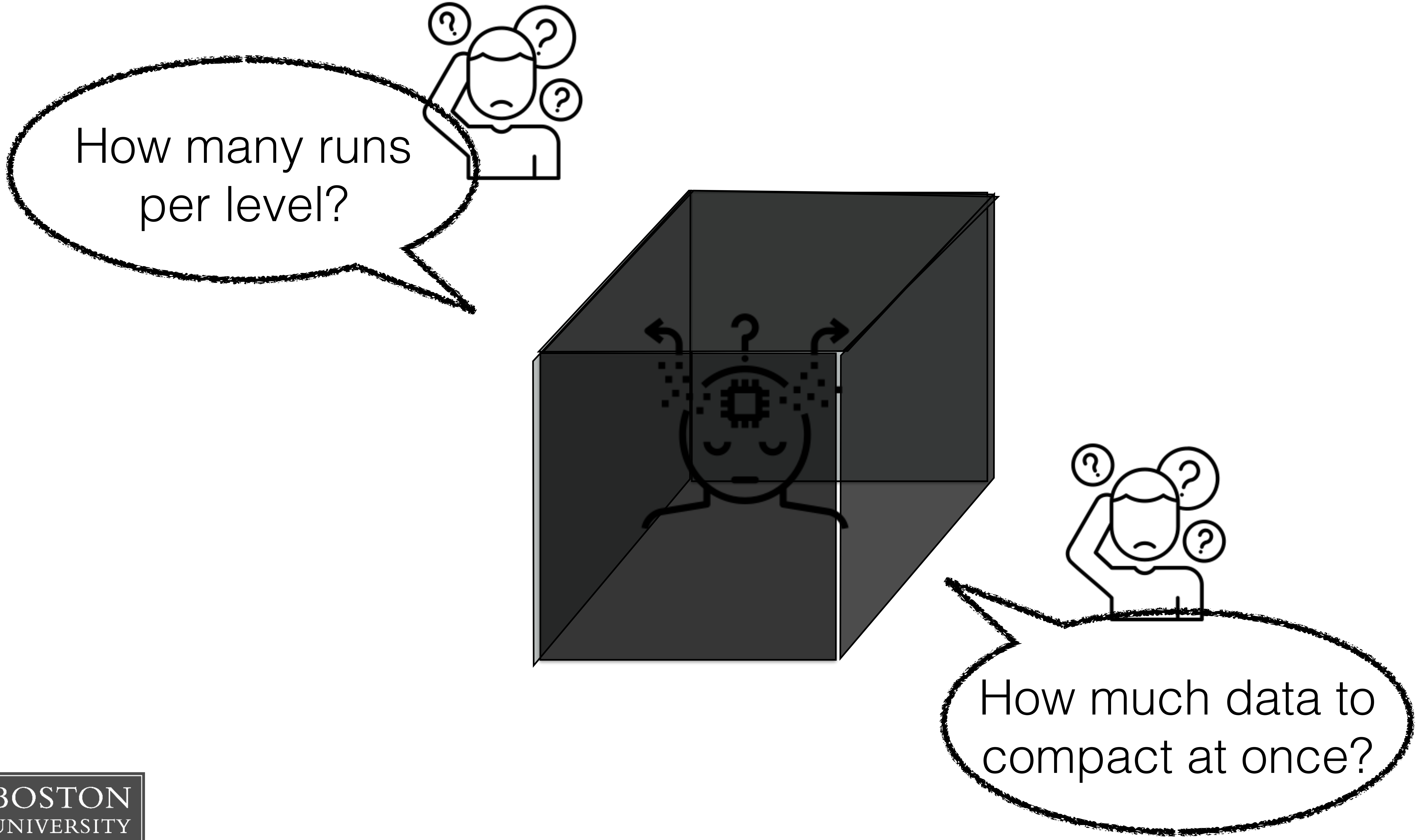
How many runs per level?
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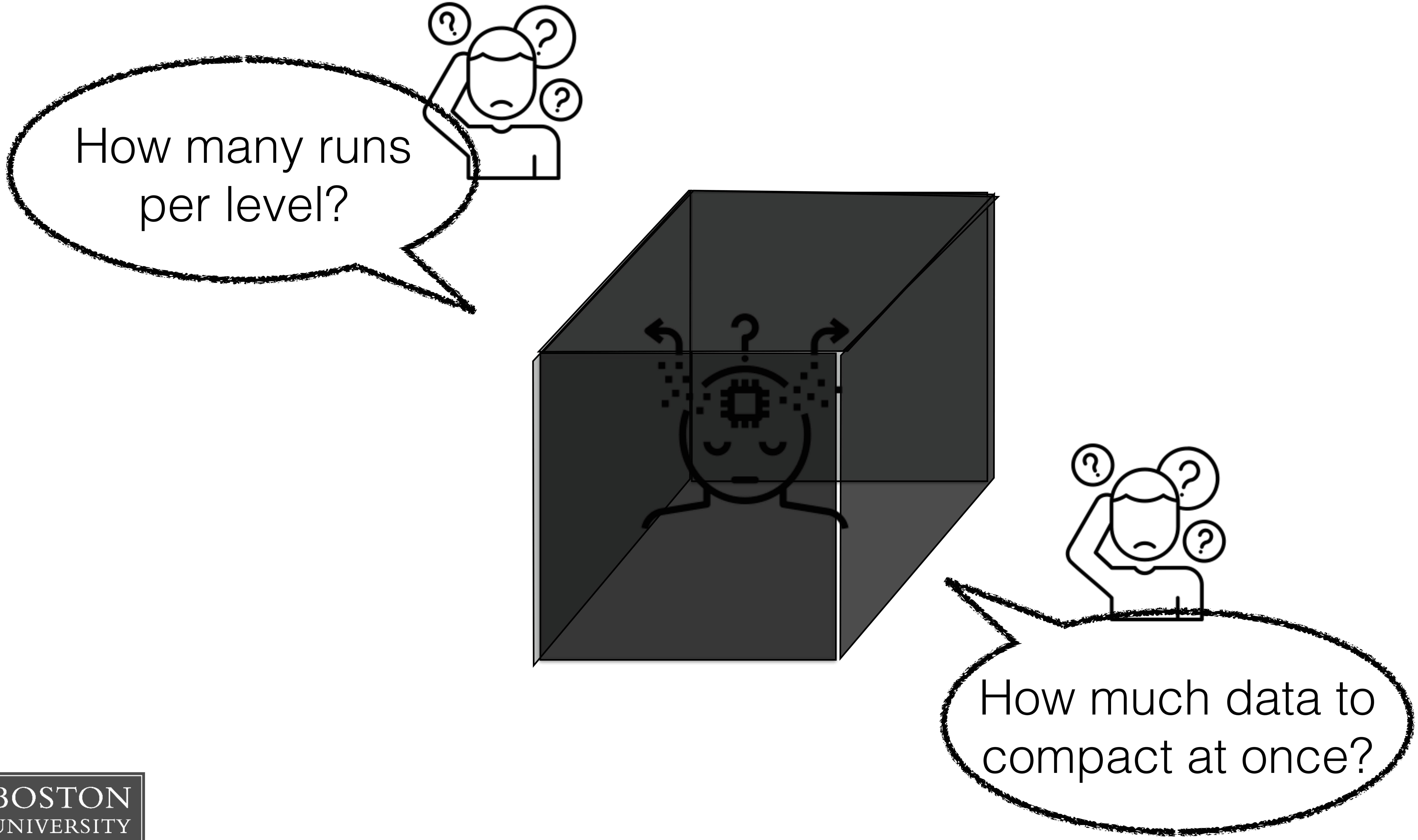

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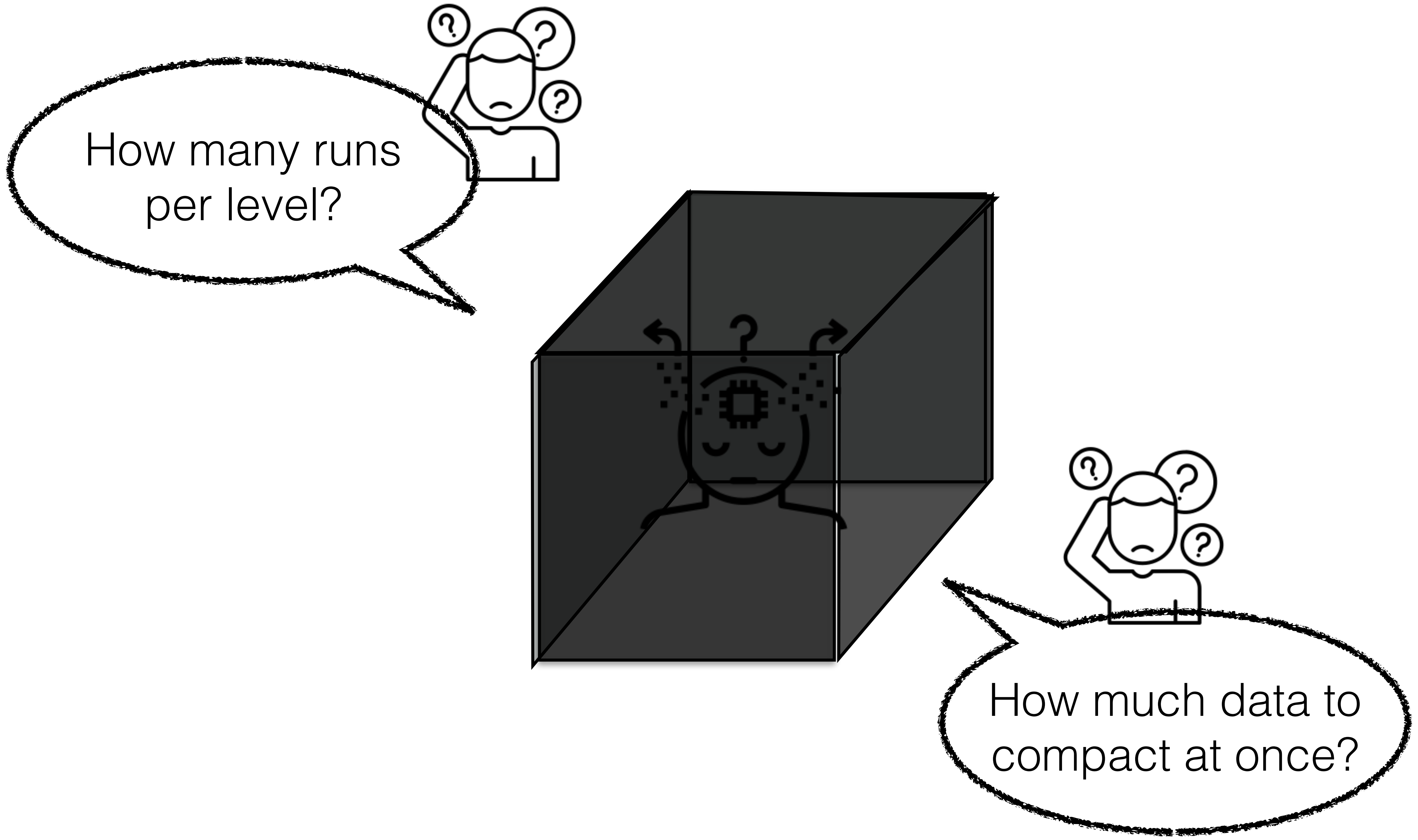

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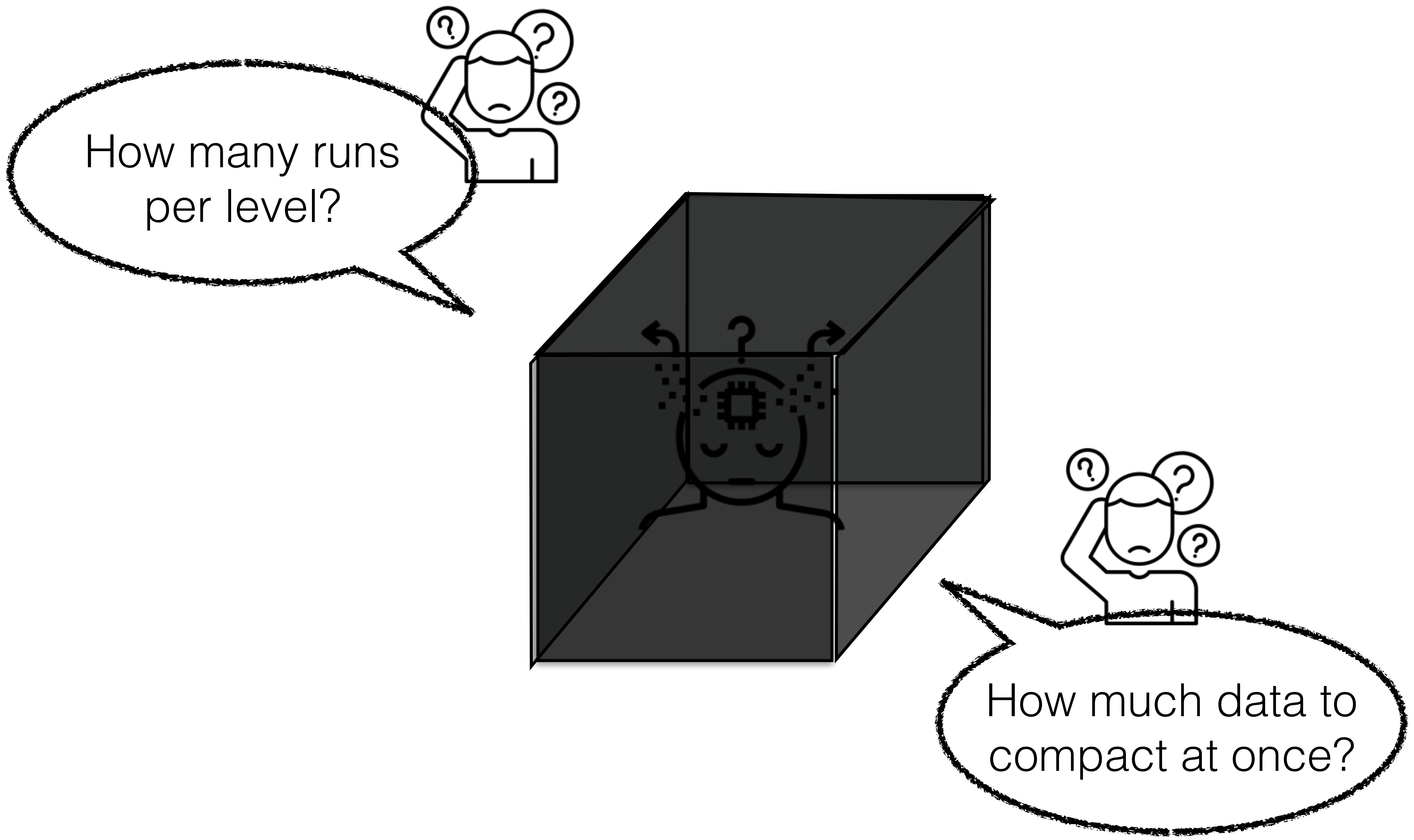
What are the **design choices**?

How does a choice **affect performance**?



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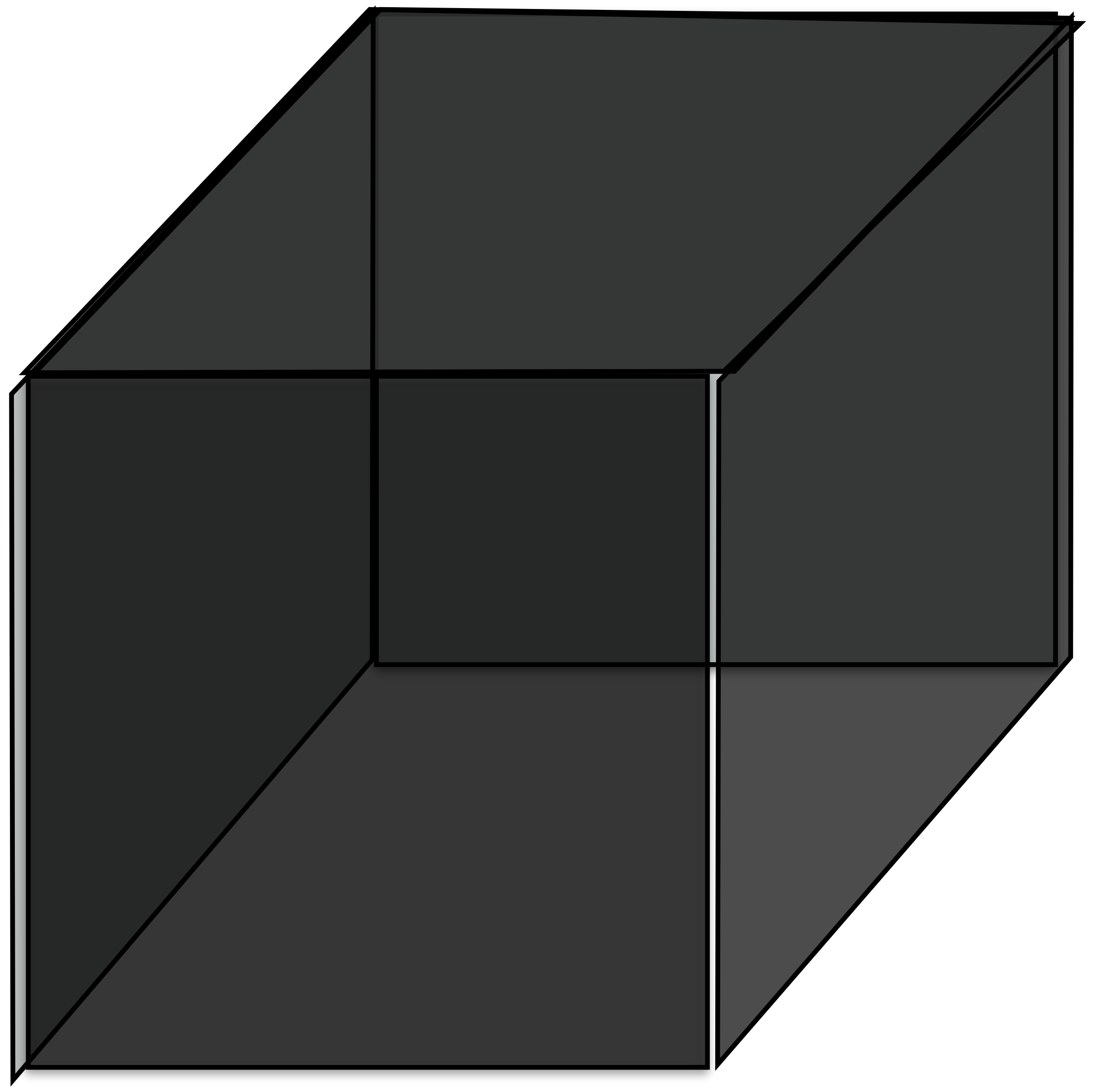
affect performance?



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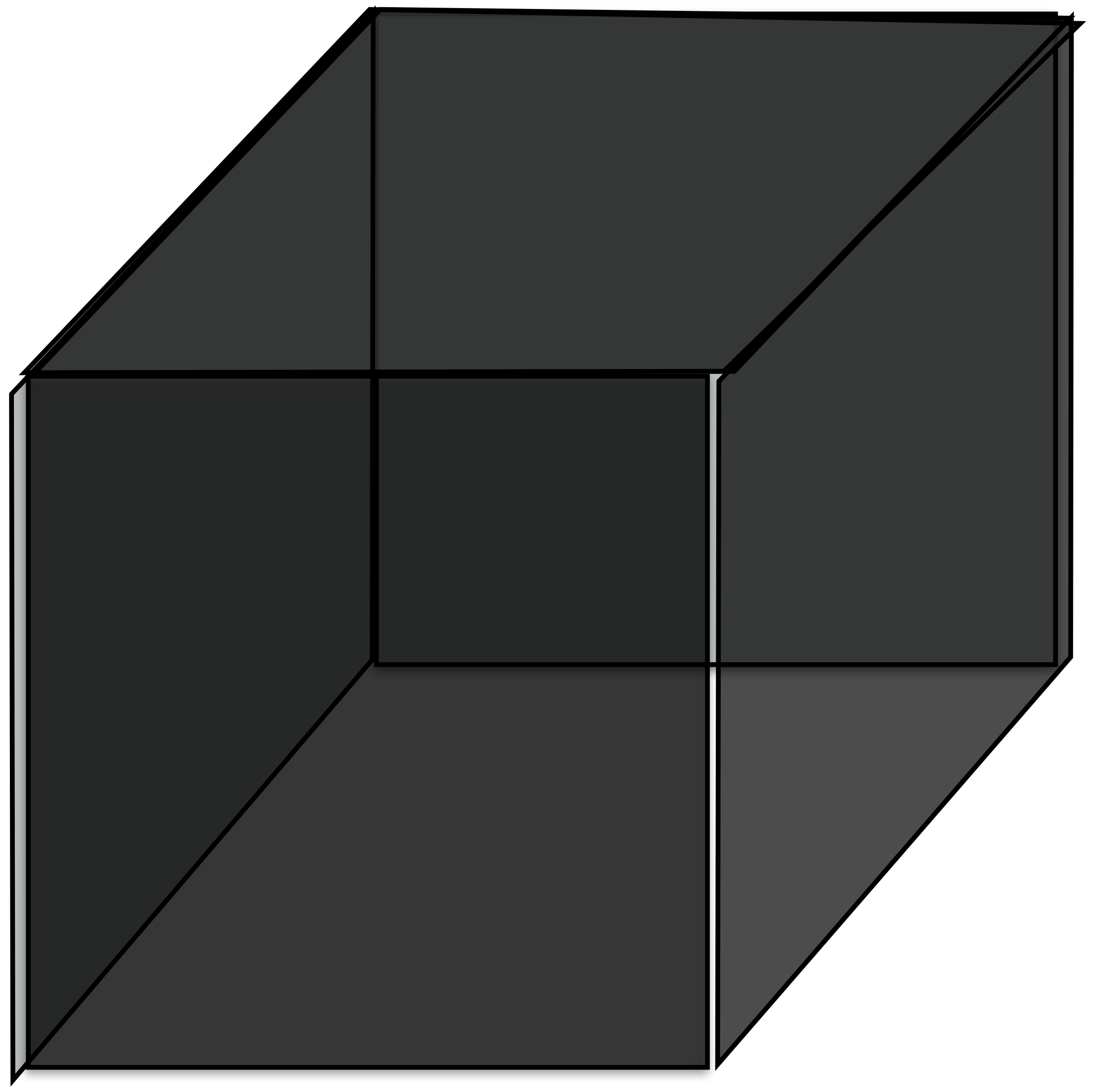

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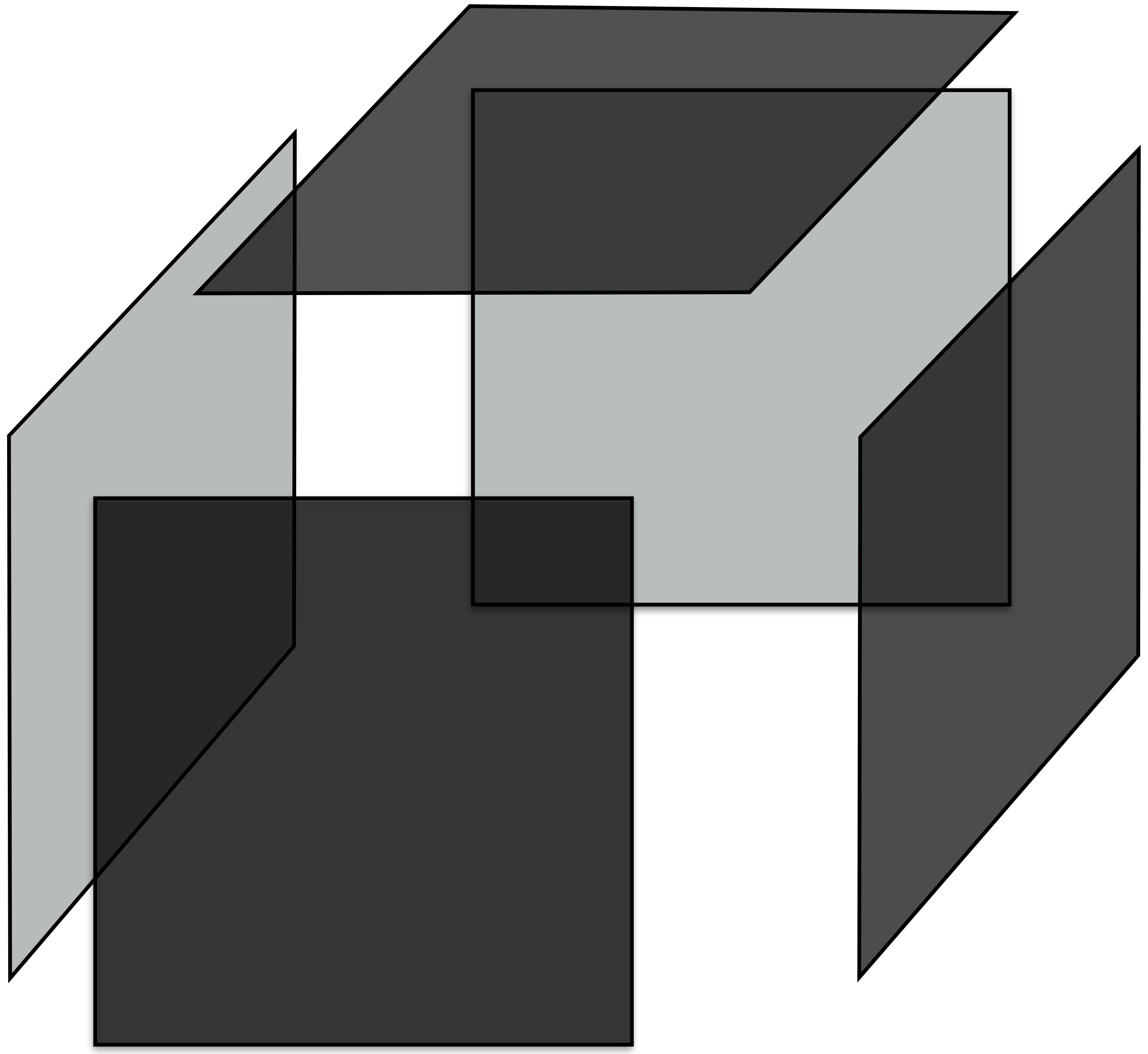

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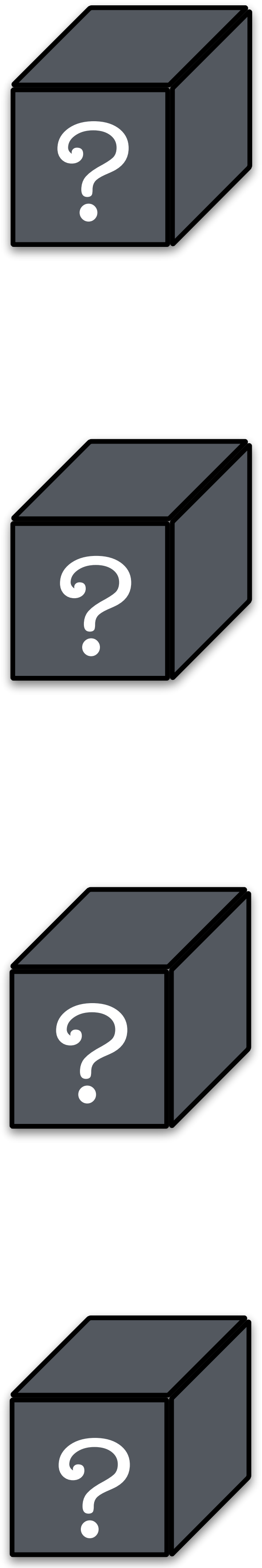

1. **How** to organize the data on device?
2. **How much** data to move at-a-time?
3. **Which** block of data to be moved?
4. **When** to re-organize the data layout?

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?

1 Data Layout

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1 Data Layout

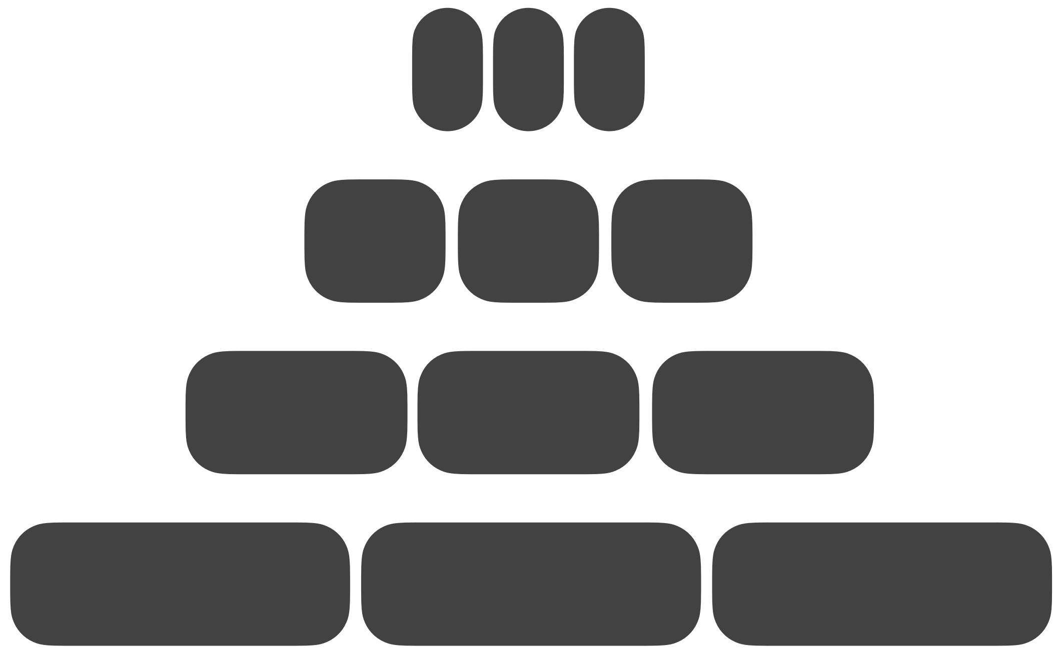
number of runs per level

Data Layout

number of runs per level

leveling

[eager]

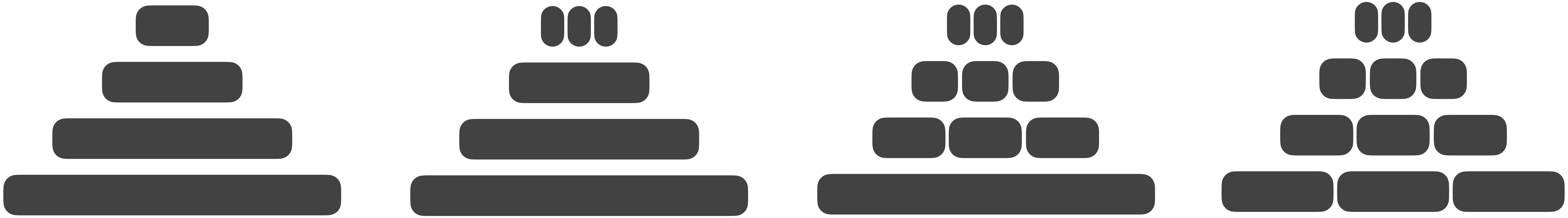


tiering

[lazy]

Data Layout

number of runs per level



leveling | **1-leveling** | **L-leveling** | tiering

2 Compaction Granularity

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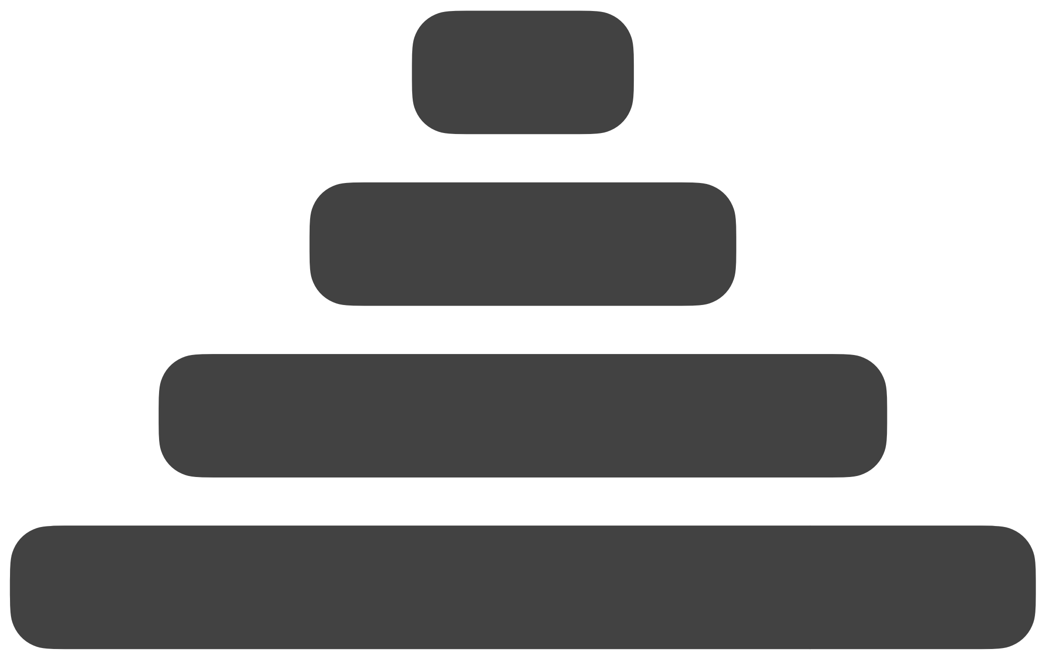
2 Compaction Granularity

data moved per compaction

2 Compaction Granularity

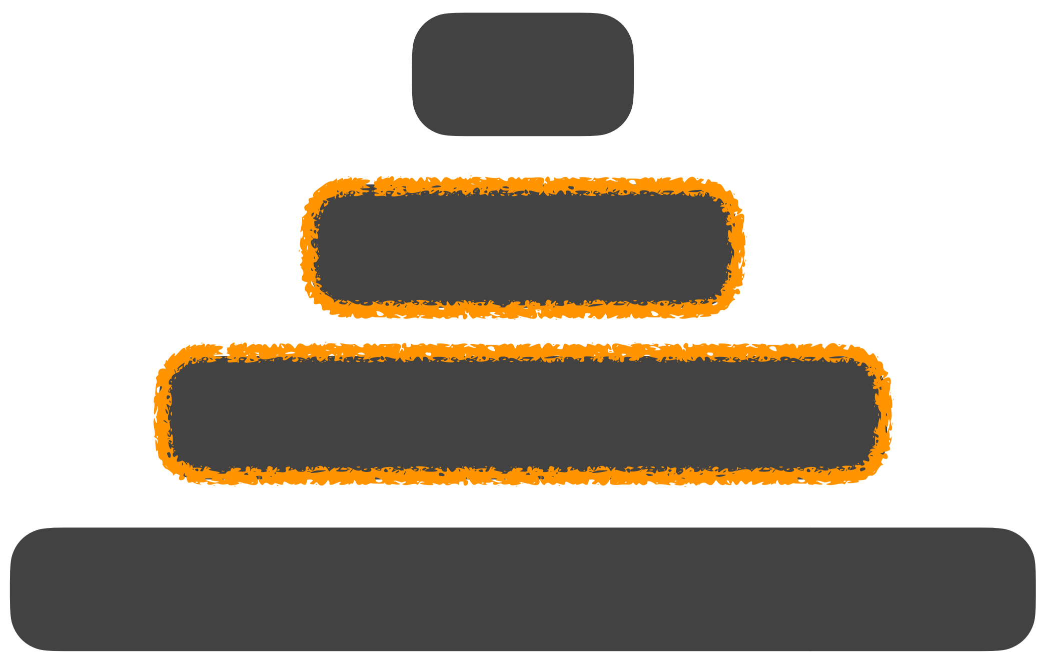
data moved per compaction



levels

2 Compaction Granularity

data moved per compaction



levels

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2 Compaction Granularity

data moved per compaction

levels **files**

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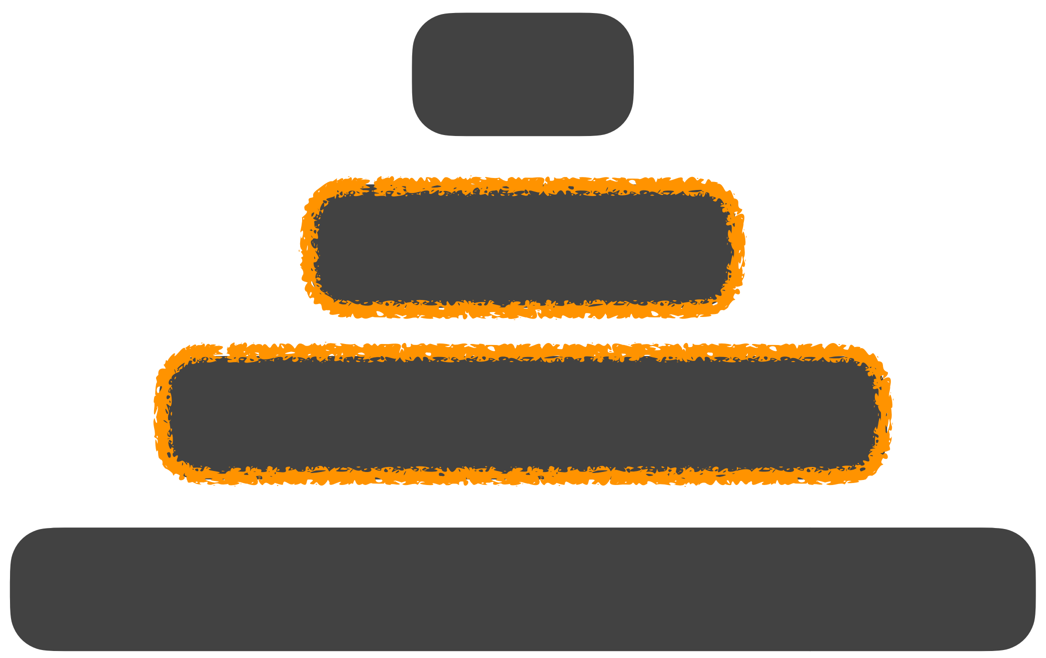
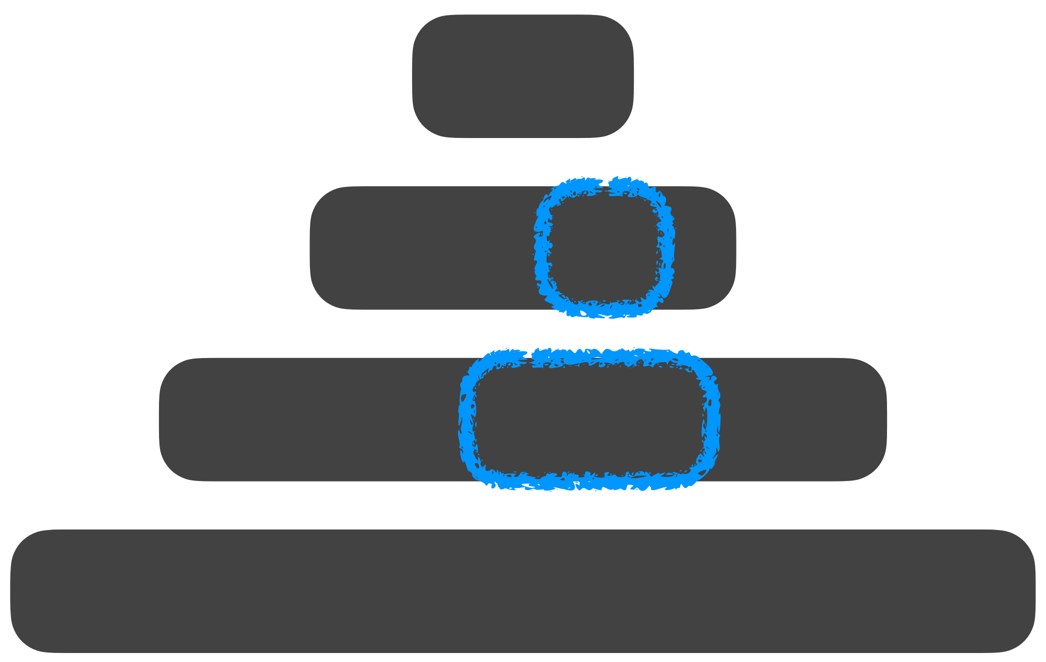
Compaction Granularity

data moved per compaction



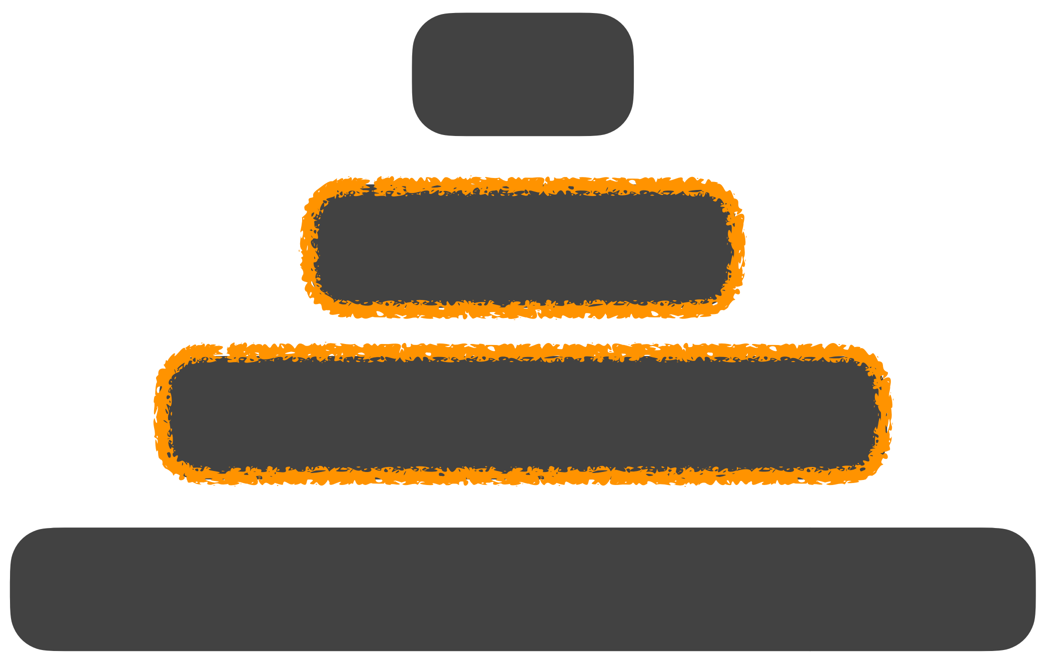
levels



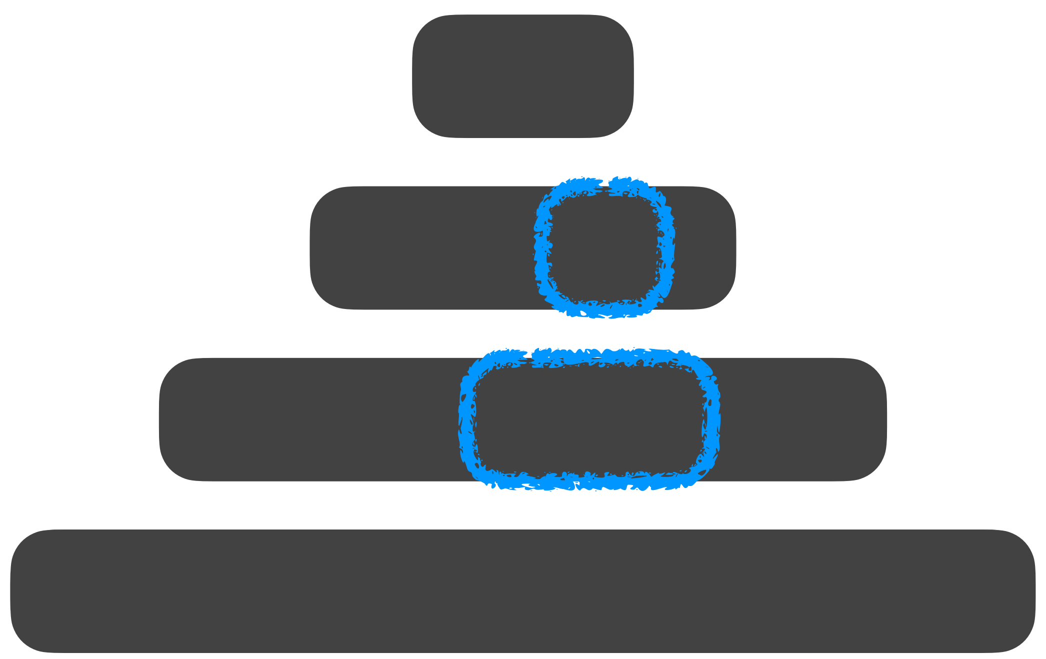
files

Compaction Granularity

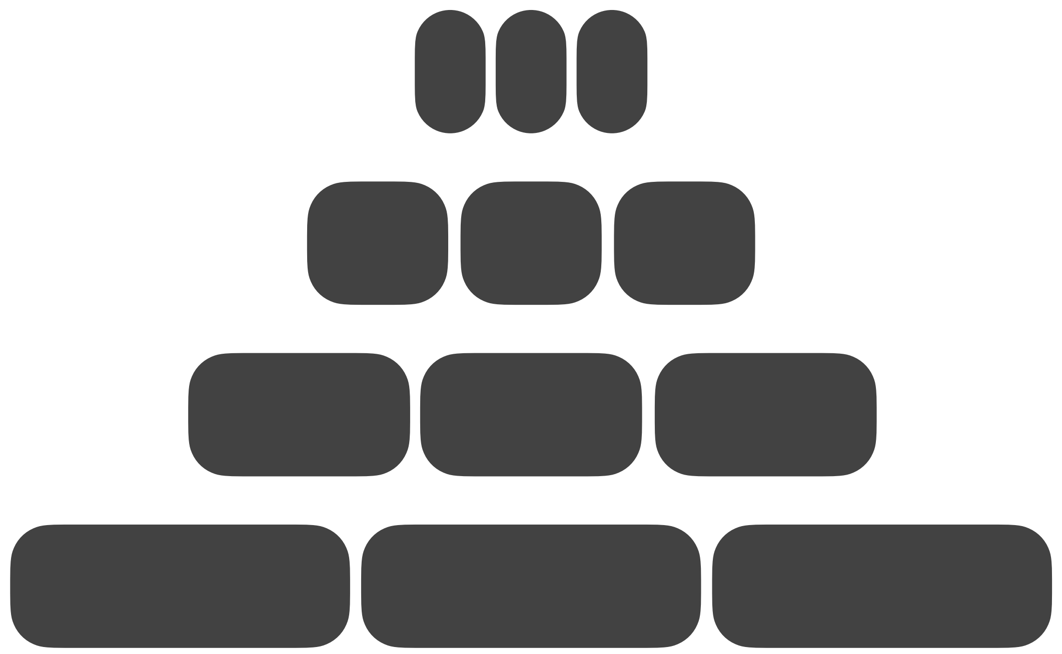
data moved per compaction



levels



files



sorted runs in a level

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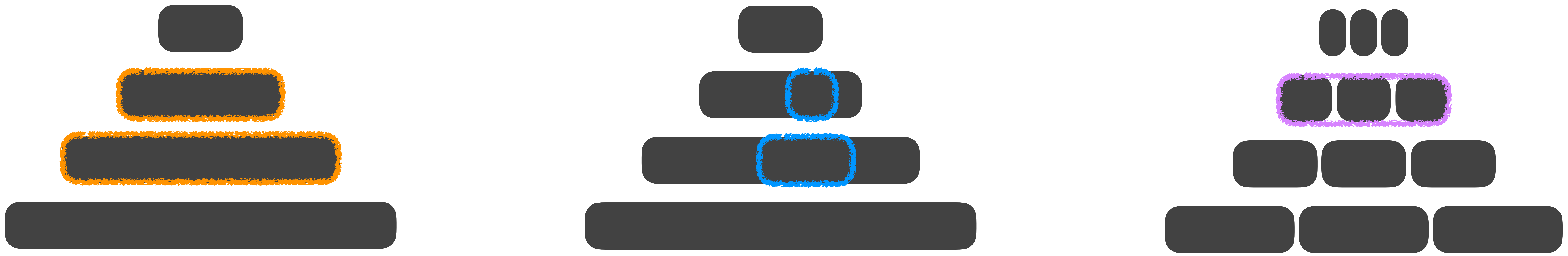
2 Compaction Granularity

data moved per compaction



levels

files

sorted runs in a level

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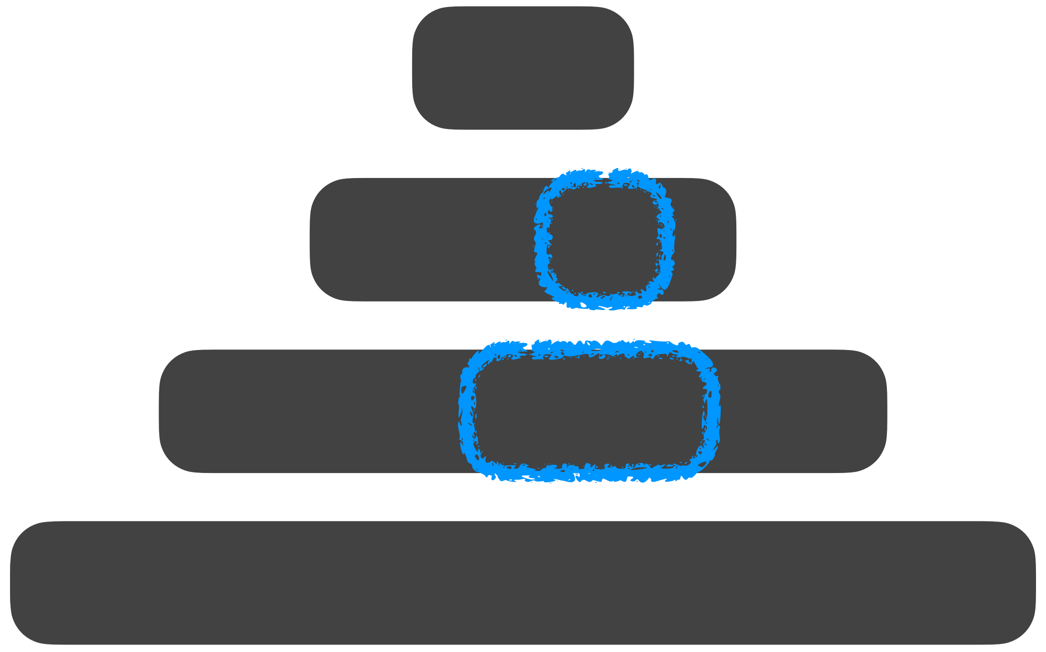
3 Data Movement Policy

files

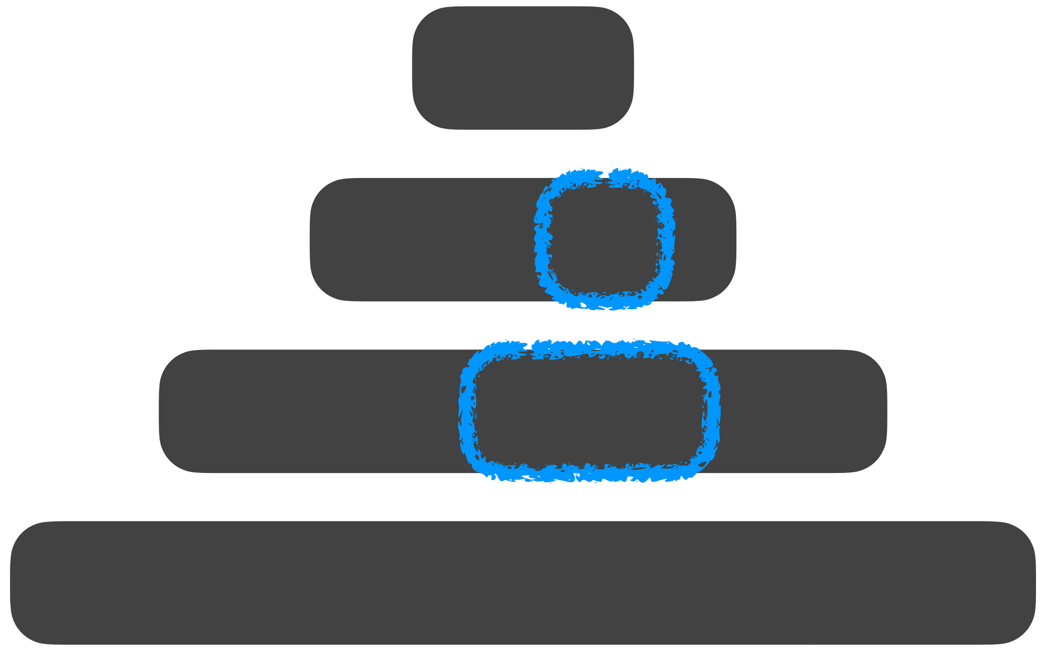
3 Data Movement Policy

which data to compact



Data Movement Policy

which data to compact



round-robin

minimum **overlap with parent** level

file with most **tombstones**

coldest file

4 Compaction Trigger

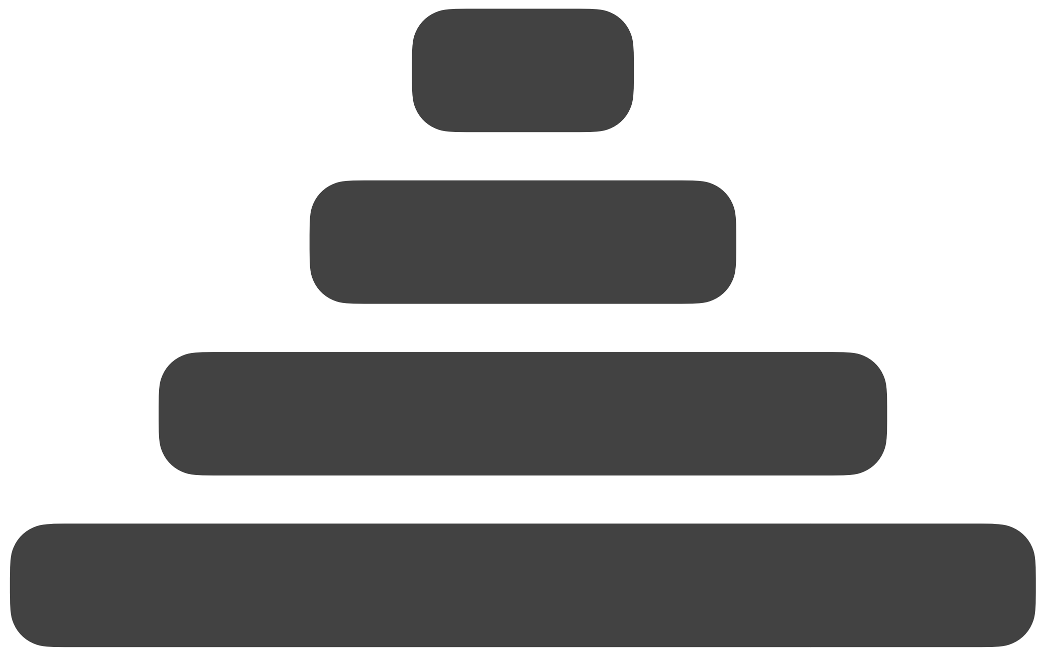
4 Compaction Trigger

invoking the compaction routine

Compaction Trigger

invoking the compaction routine

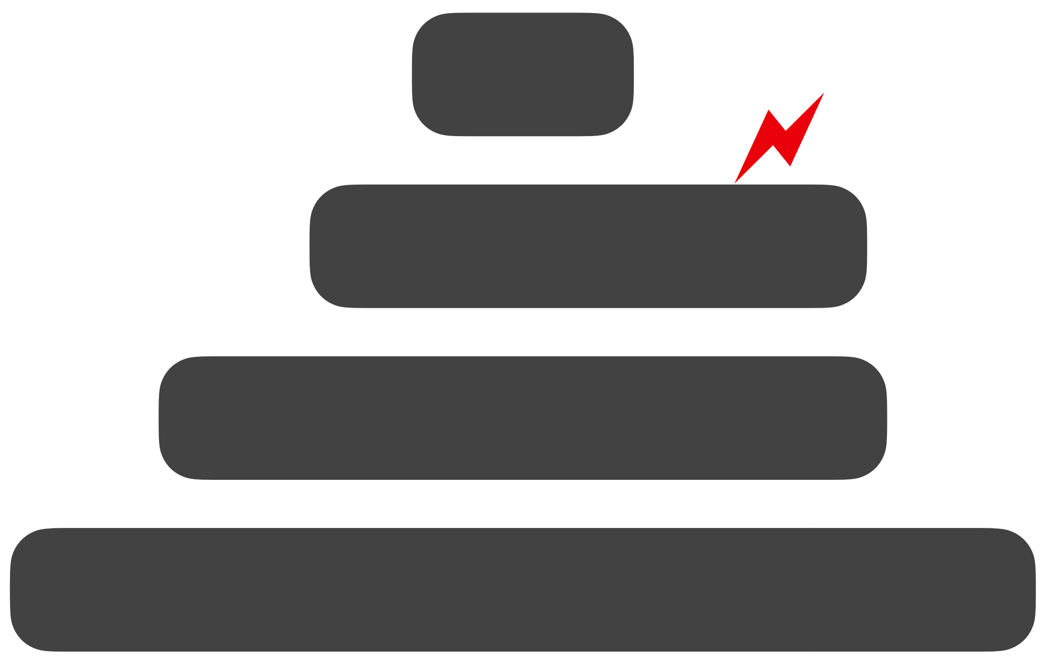
level **saturation**



4 Compaction Trigger

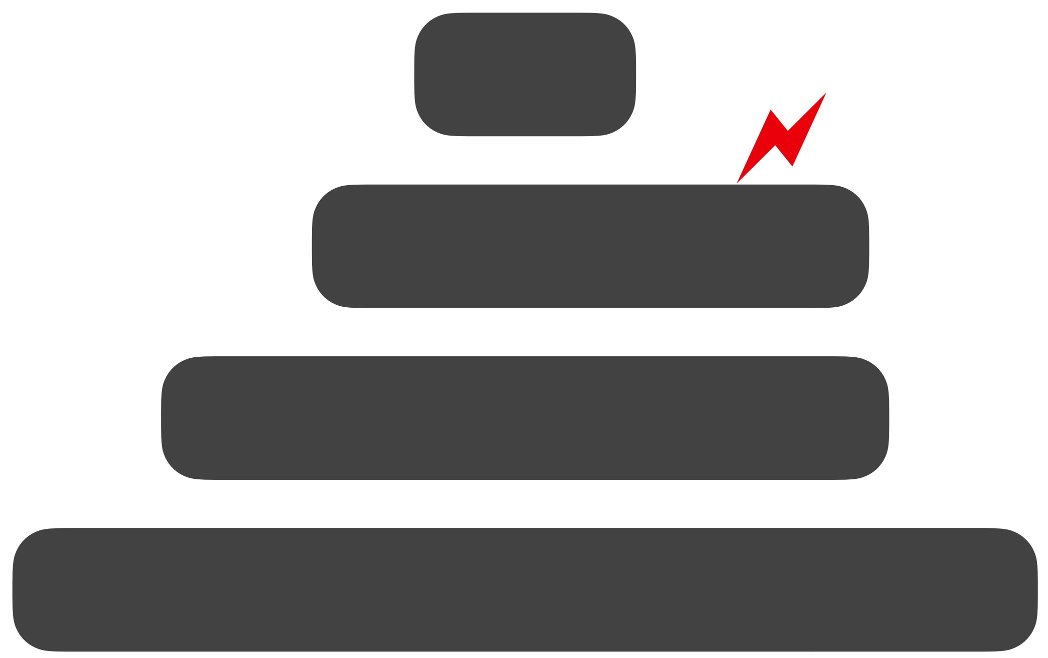
invoking the compaction routine

level **saturation**



4 Compaction Trigger

invoking the compaction routine



level **saturation**

number of **sorted runs**

age of a file

space amplification

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1 Data Layout

2 Compaction Granularity

3 Data Movement Policy

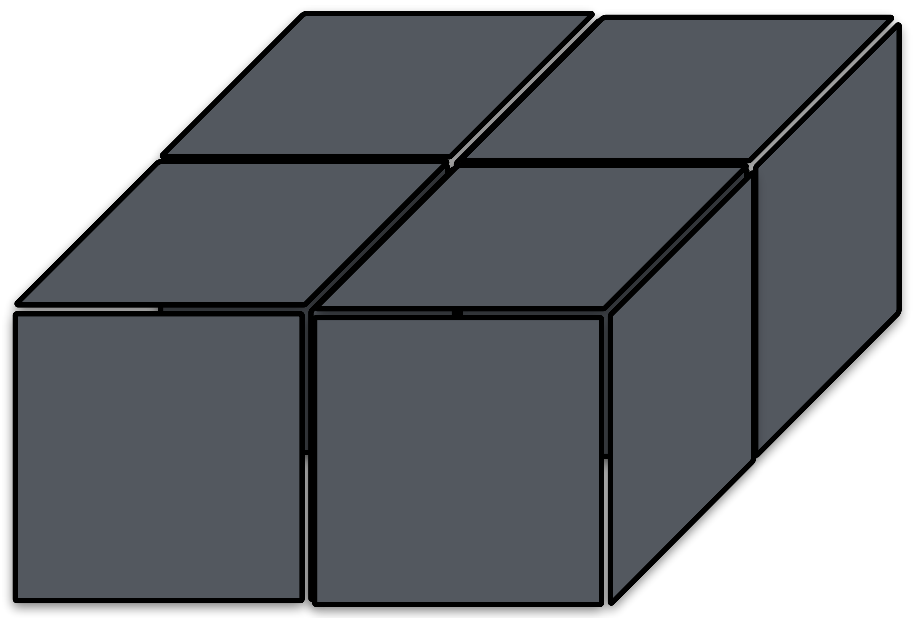
4 Compaction Trigger

Data Layout

Compaction Granularity

Data Movement Policy

Compaction Trigger



Any Compaction Algorithm

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Database	Data layout	Compaction Trigger					Compaction Granularity				Data Movement Policy							
		Level saturation	#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	✓		✓					✓	✓		✓		✓	✓	✓		
	Tiering		✓		✓	✓		✓										✓
LevelDB [32], Monkey (J.) [21]	Leveling	✓							✓		✓	✓	✓					
SlimDB [47]	Tiering	✓							✓	✓								✓
Dostoevsky [23]	L-leveling	✓^{L}	✓^{T}				✓^{L}	✓^{T}				✓^{L}						✓^{T}
LSM-Bush [24]	Hybrid leveling	✓^{L}	✓^{T}				✓^{L}	✓^{T}				✓^{L}						✓^{T}
Lethe [51]	Leveling	✓				✓			✓	✓		✓					✓	
Silk [11], Silk+ [12]	Leveling	✓							✓	✓	✓							
HyperLevelDB [35]	Leveling	✓							✓		✓	✓	✓					
PebblesDB [46]	Hybrid leveling	✓							✓	✓								✓
Cassandra [8]	Tiering		✓	✓		✓		✓										✓
	Leveling	✓				✓			✓	✓		✓				✓	✓	
WiredTiger [62]	Leveling	✓					✓											✓
X-Engine [34], Leaper [63]	Hybrid leveling	✓							✓	✓		✓				✓		
HBase [7]	Tiering		✓					✓										✓
AsterixDB [3]	Leveling	✓					✓											✓
	Tiering		✓					✓										✓

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Blueprint for **Experiments**

Blueprint for **Experiments**

10 compaction strategies

Blueprint for **Experiments**

10 compaction strategies

612 metrics

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Blueprint for **Experiments**

10 compaction strategies

primitives

612 metrics

Blueprint for **Experiments**

10 compaction strategies

primitives

workloads

[distribution
+
composition]

612 metrics

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Blueprint for **Experiments**

10 compaction strategies

primitives

workloads

[distribution
+
composition]

LSM tuning

612 metrics

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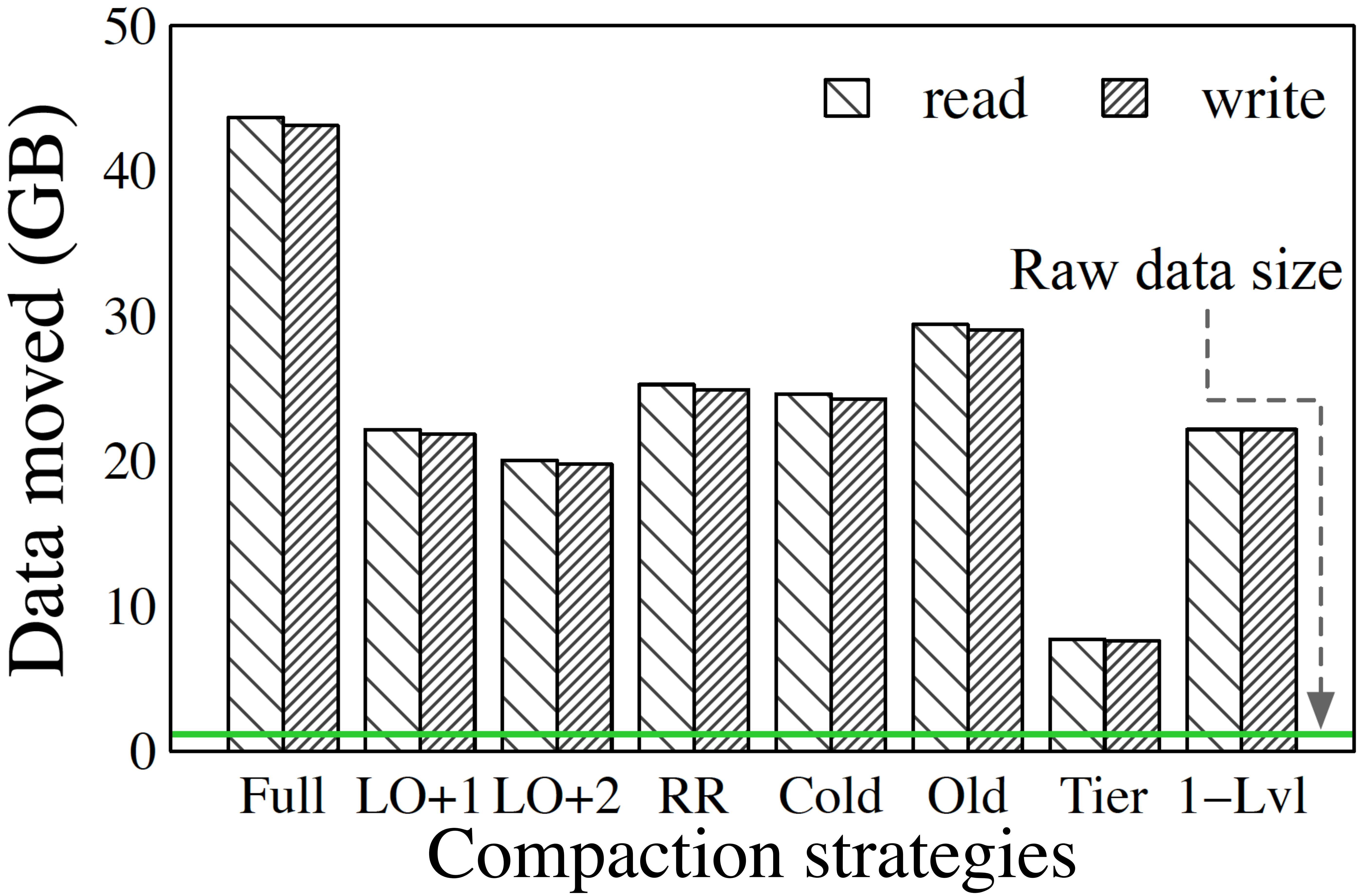

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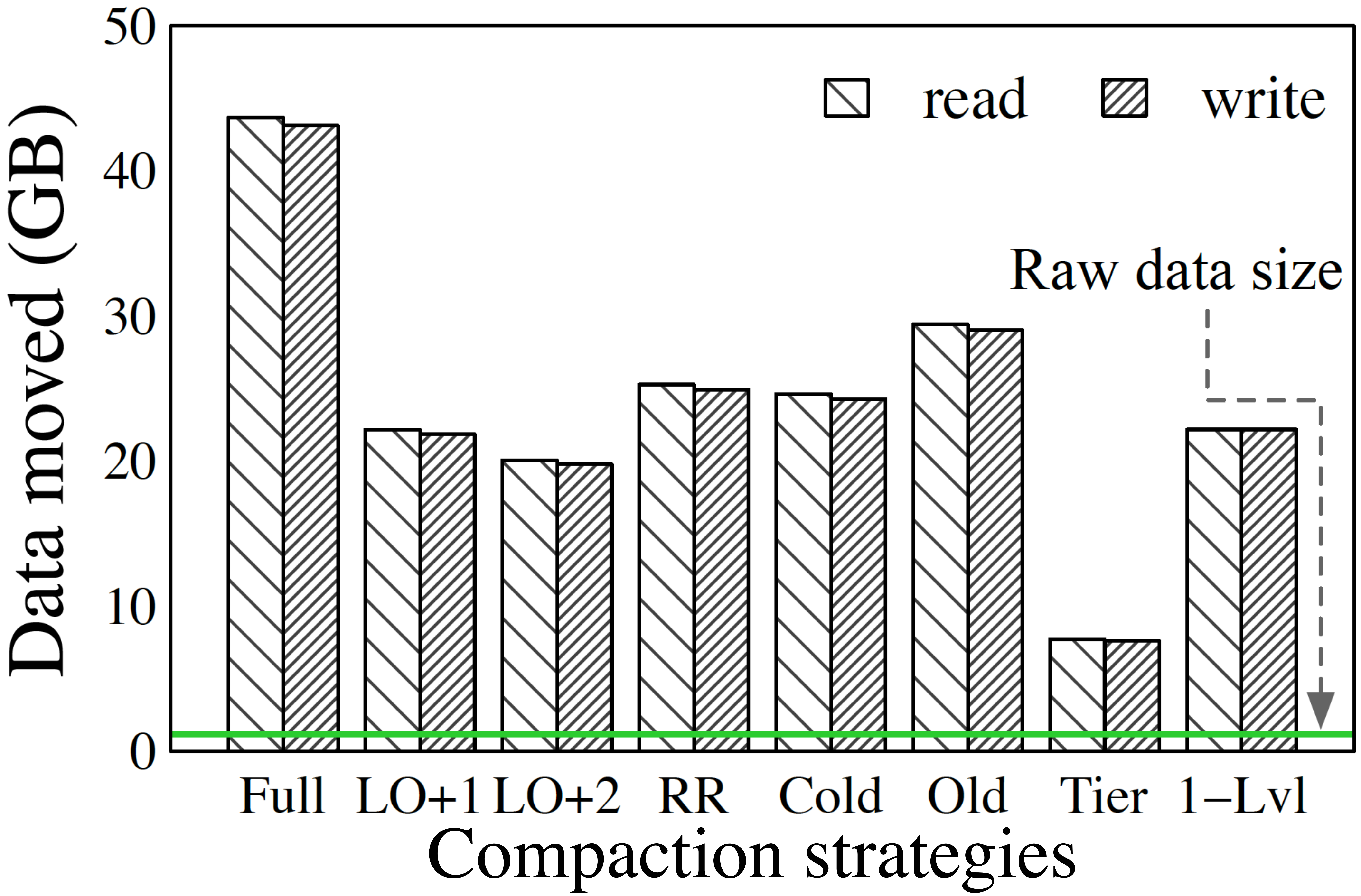
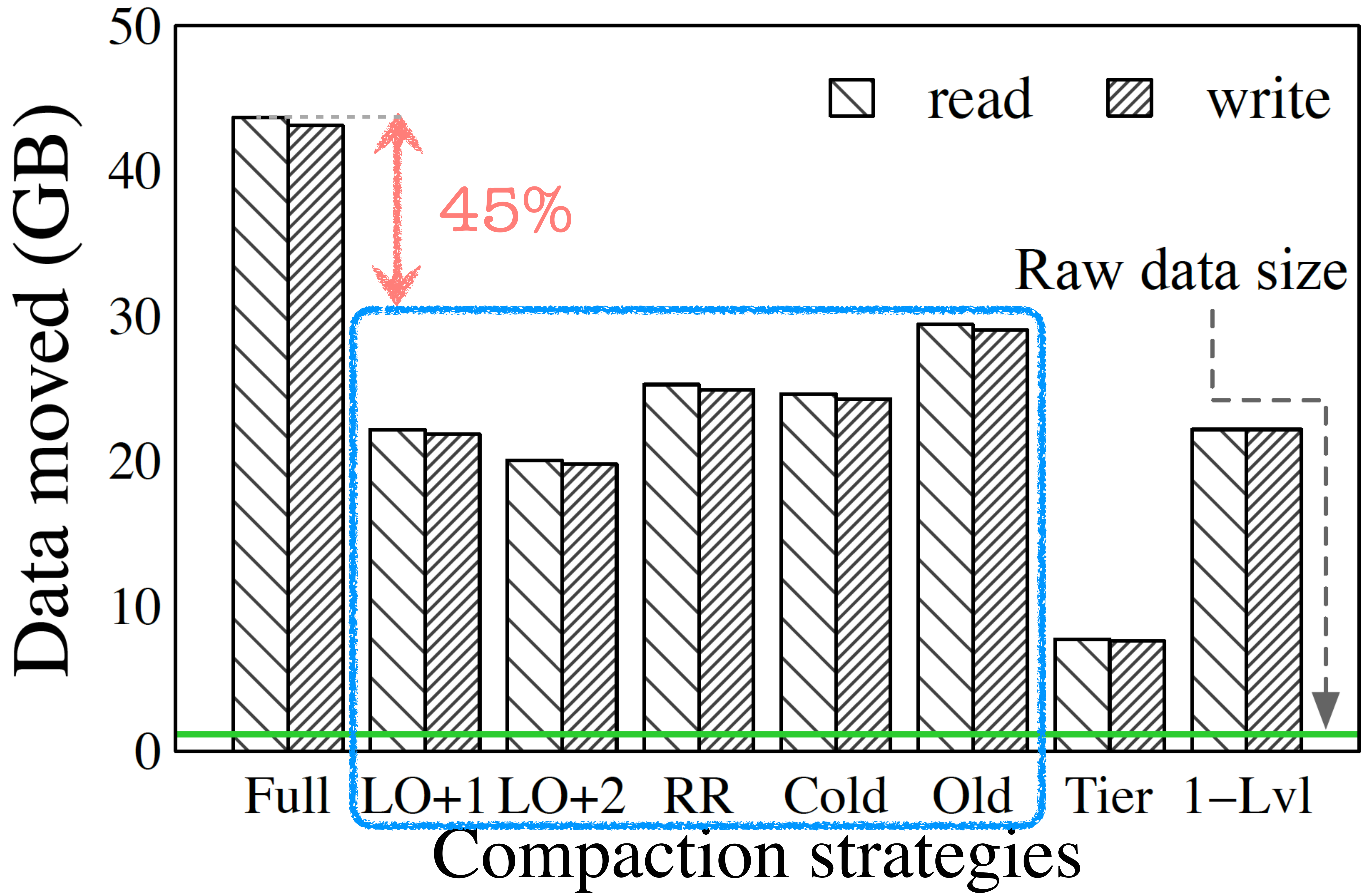
Compacting data at smaller granularity reduces data movement.



Compacting data at smaller granularity reduces data movement.



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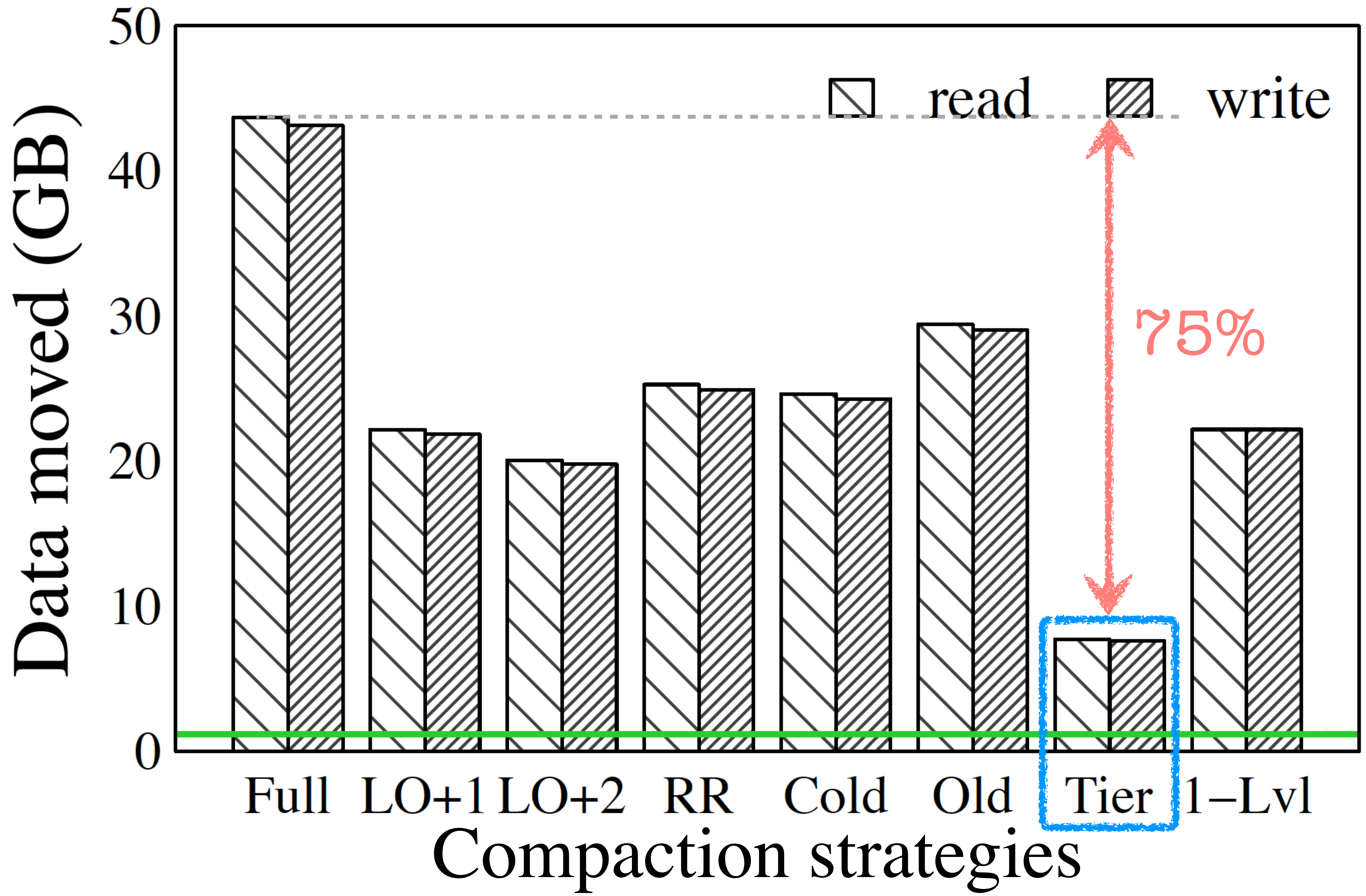

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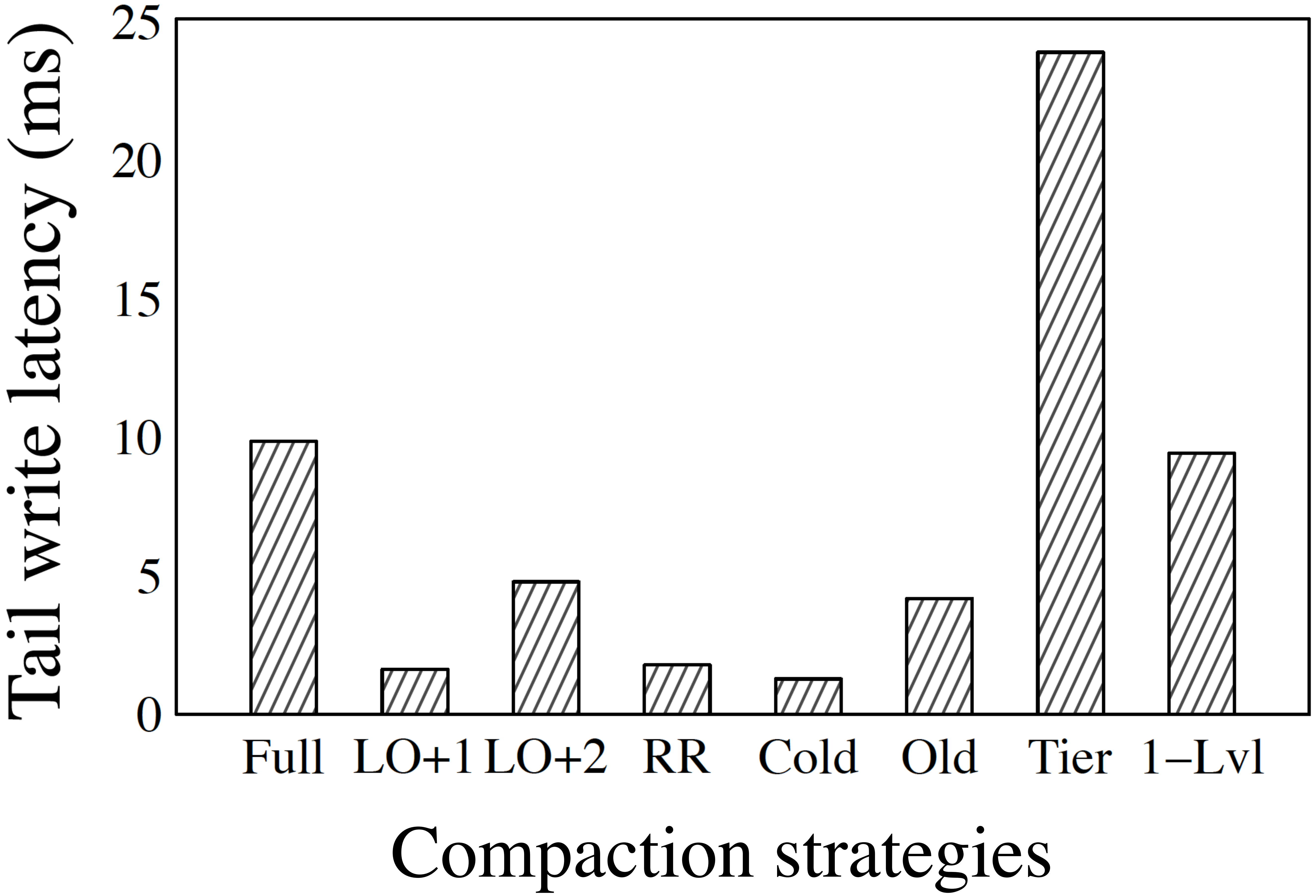

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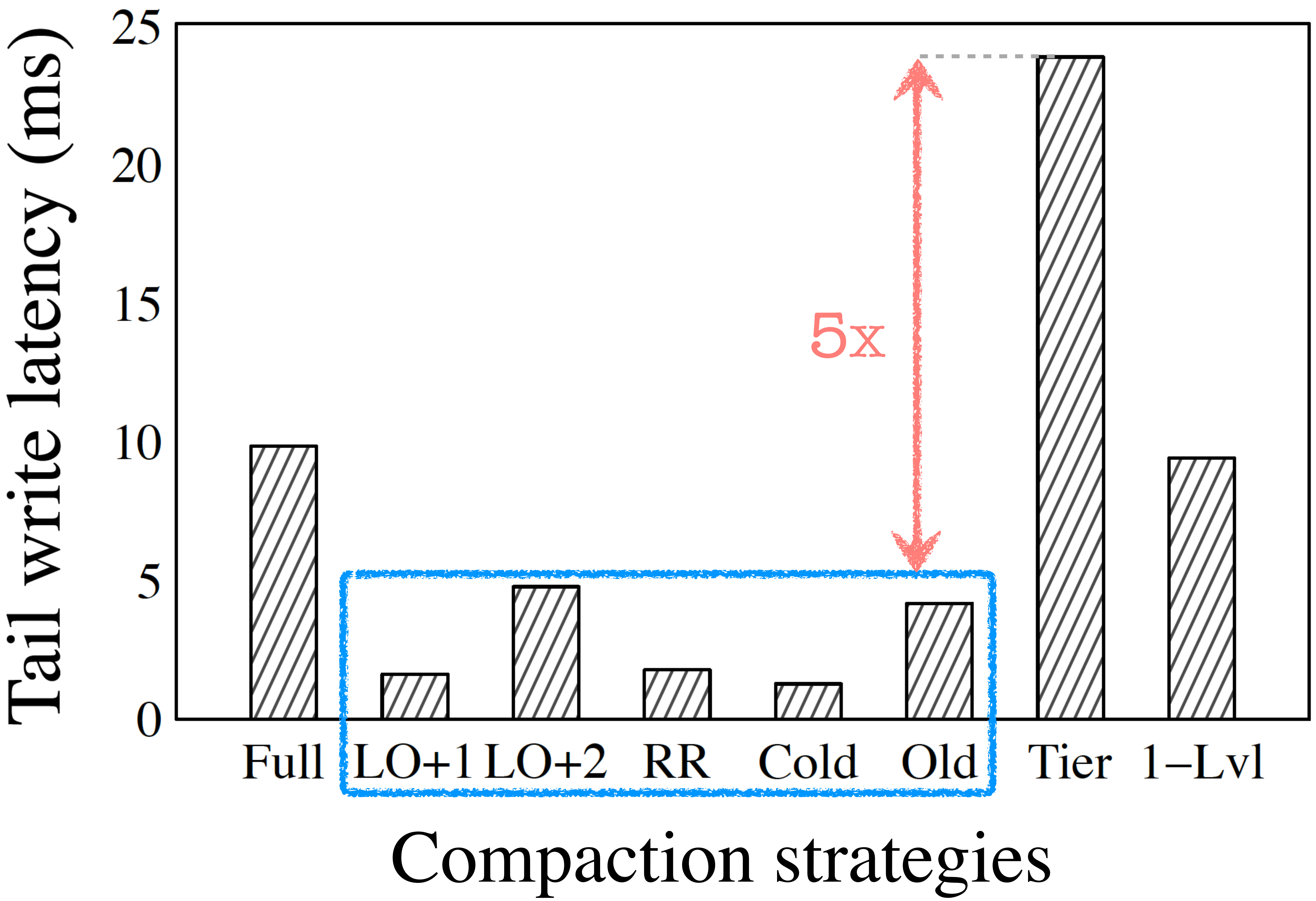
Tiered data layout has the highest write throughput but also the highest tail write latency.



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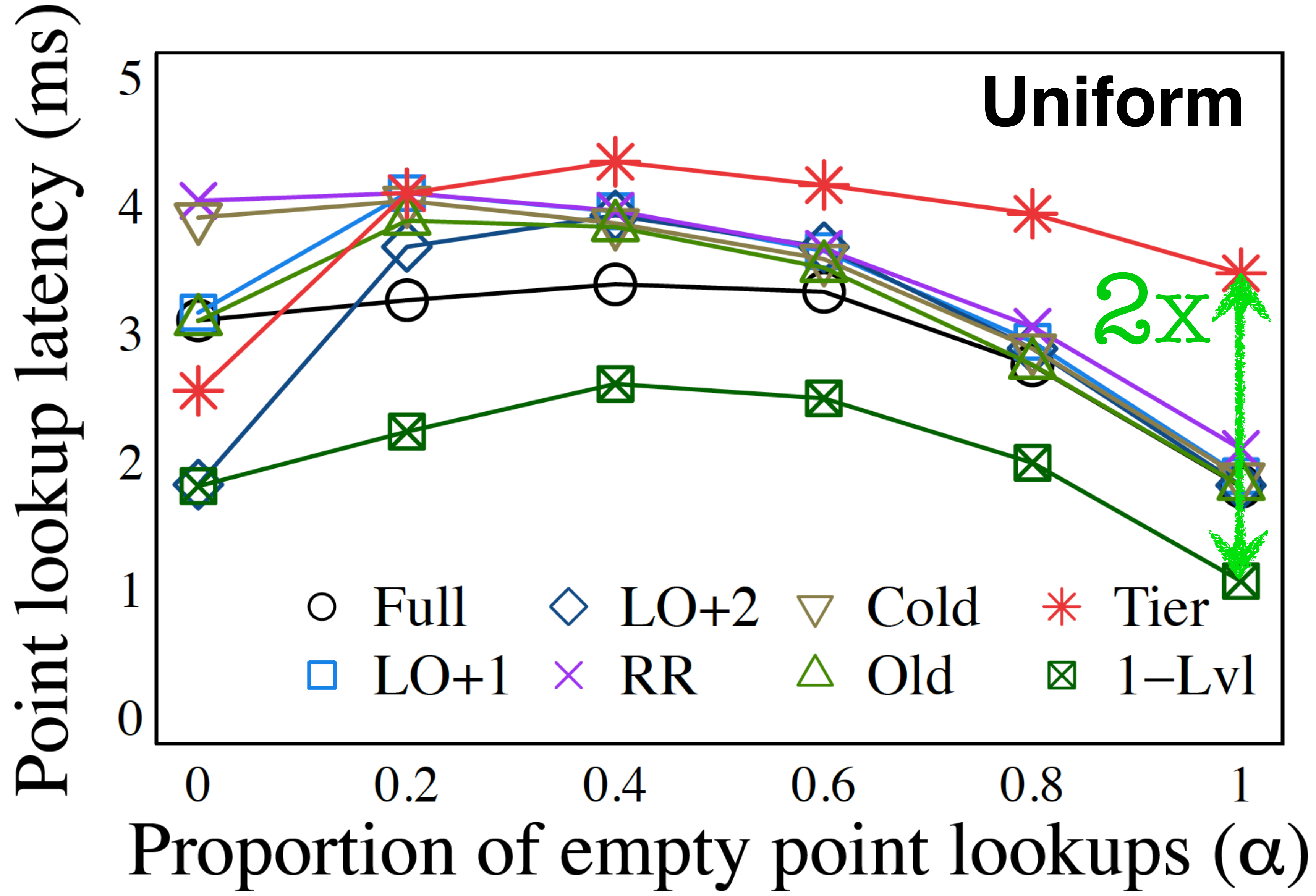

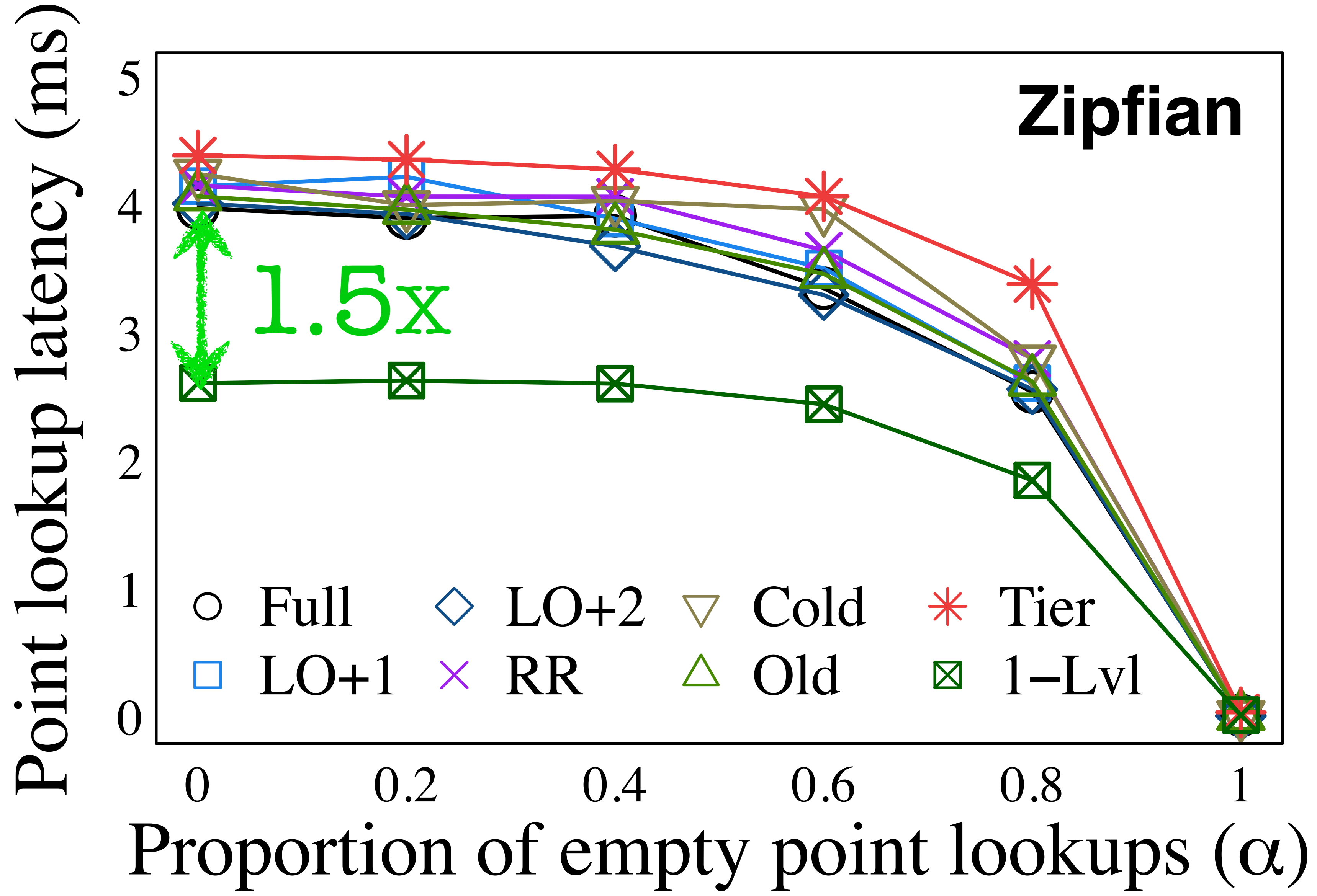

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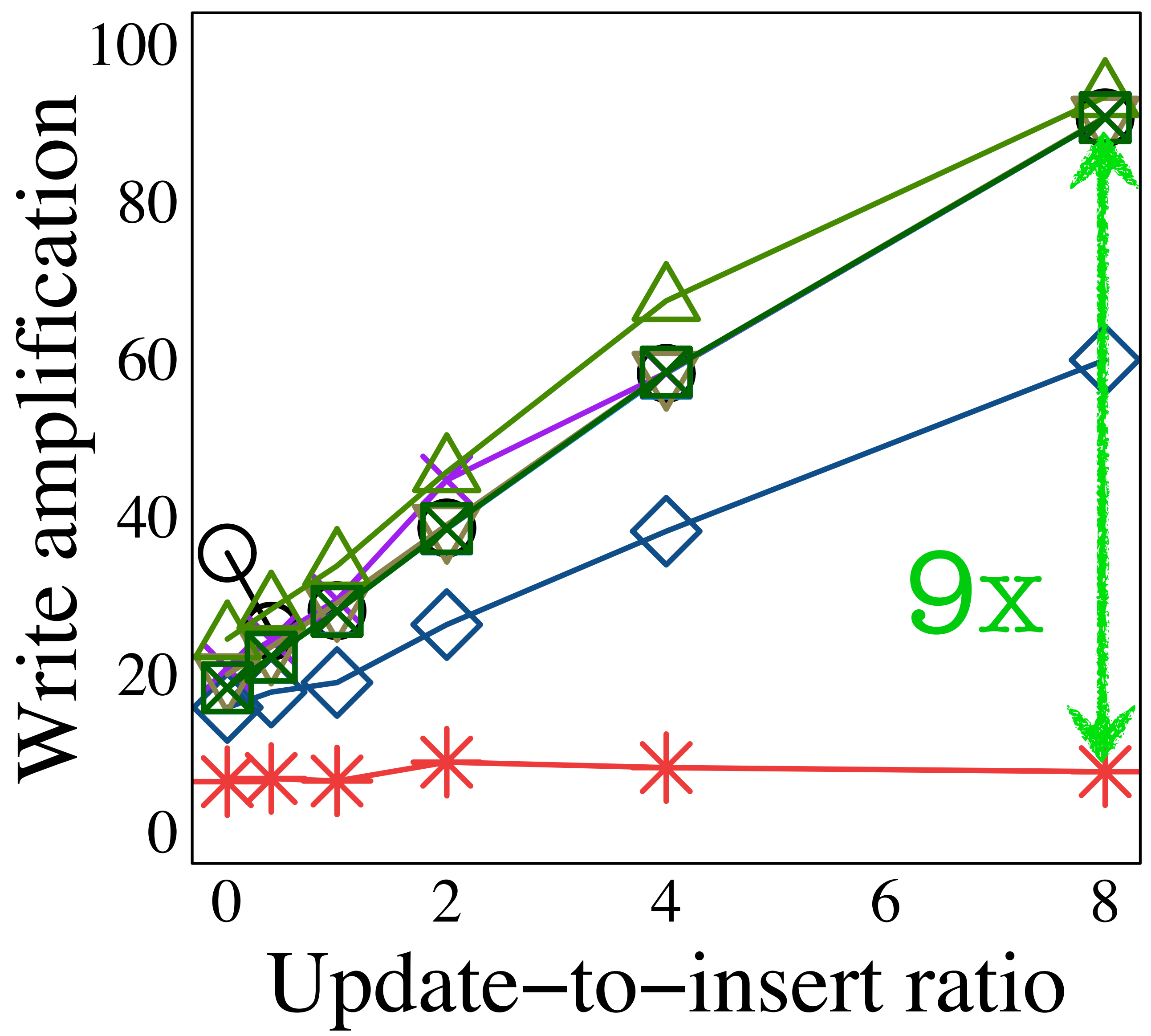

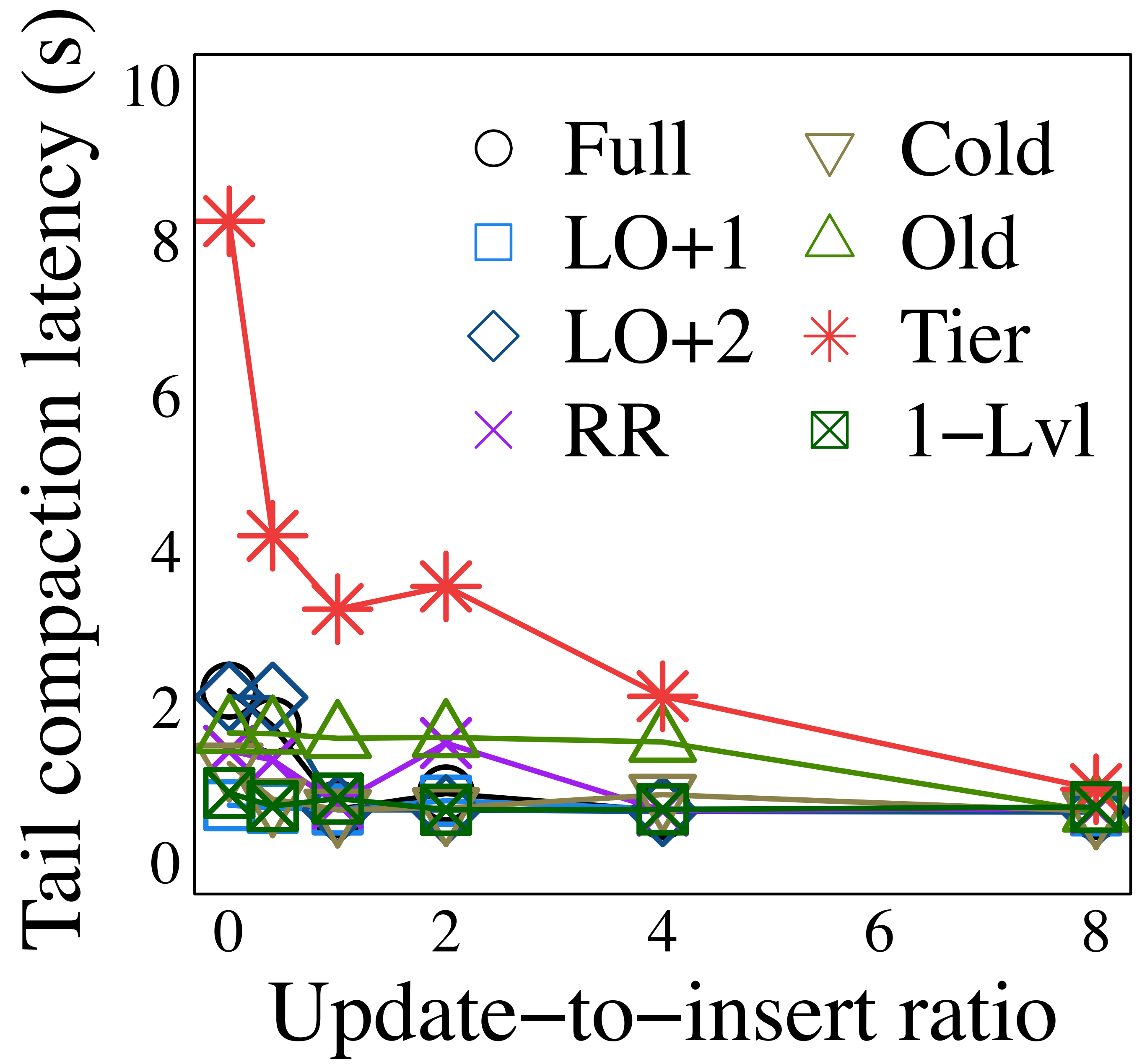

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Thank You!