TRIAD: Creating Synergies Between Memory, Disk and Log in Log Structured Key-Value Stores

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KV Stores

Very **simple** data stores.

KV pairs.

Simple operations: **update, read.**

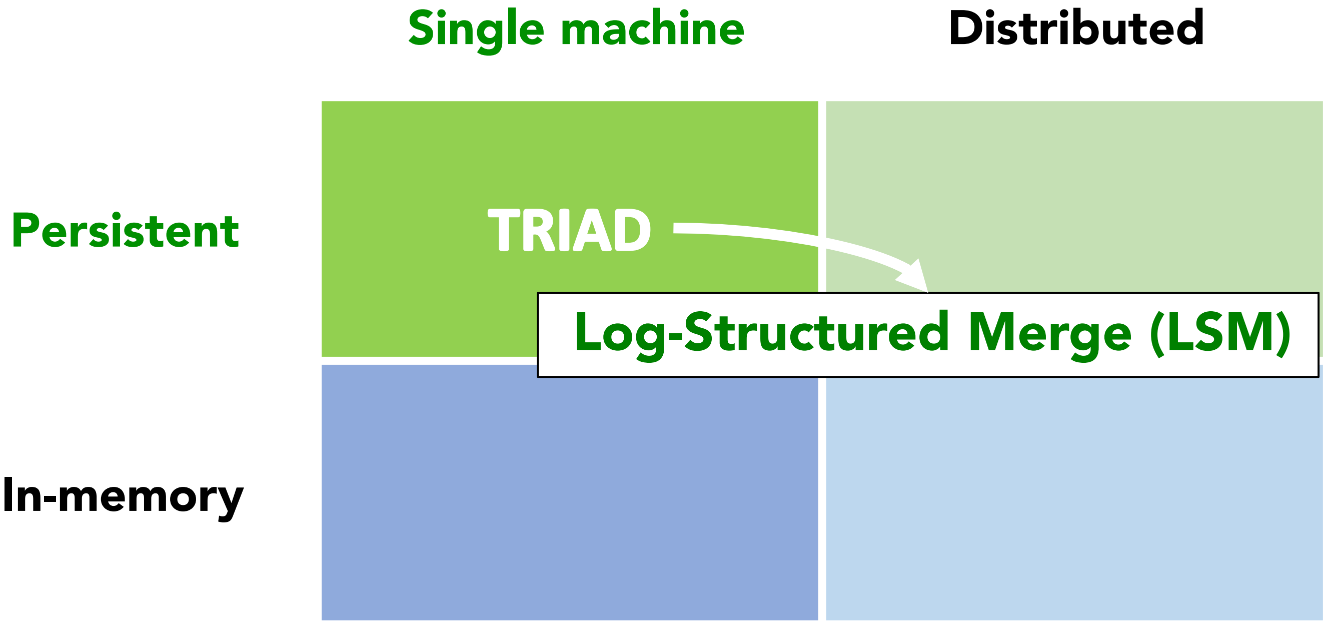
KV Stores

	Single machine	Distributed
Persistent	🟩	🟩
In-memory	🟦	🟦

KV Stores

	Single machine	Distributed
Persistent	TRIAD	
In-memory		

KV Stores



Single machine

Distributed

Persistent

In-memory

TRIAD

Log-Structured Merge (LSM)

TRIAD in a Nutshell

TRIAD LSM KV: achieves 2x throughput on production wklds.

Methods: Reducing background I/O in LSMs.

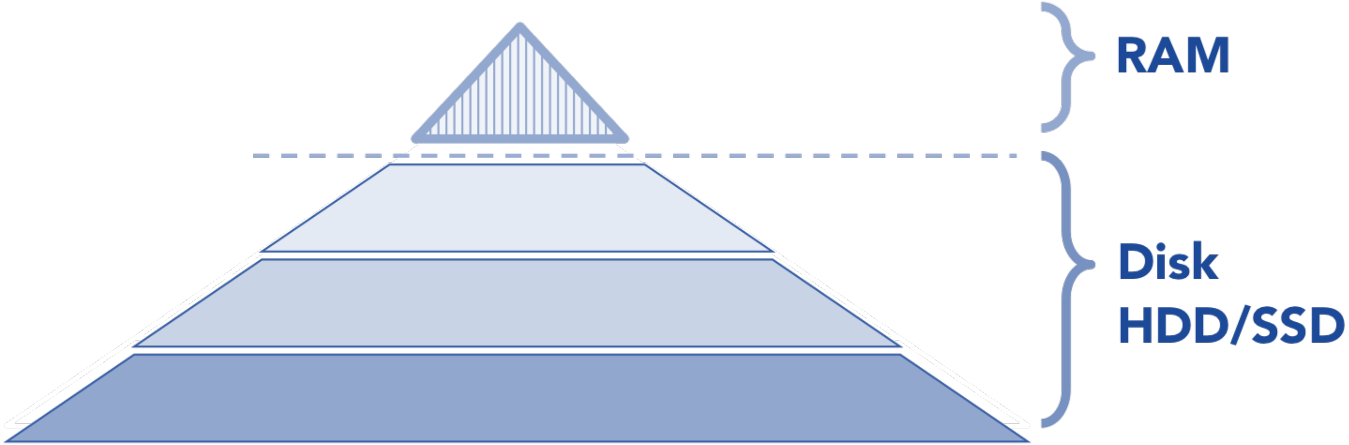
TRIAD in a Nutshell

TRIAD LSM KV: achieves 2x throughput on production wklds.

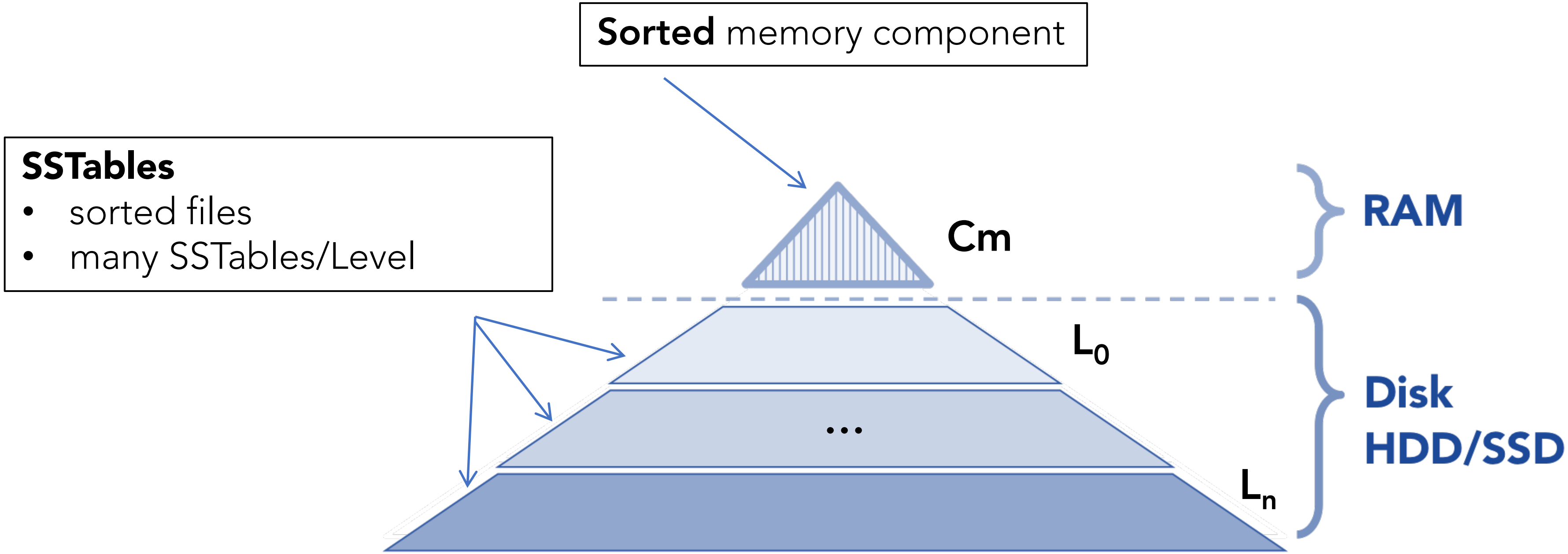
Methods: Reducing background I/O in LSMs.

- ☺ No need to know workload a priori.
- ☺ LSM KV semantics preserved.

LSM Overview



LSM Components

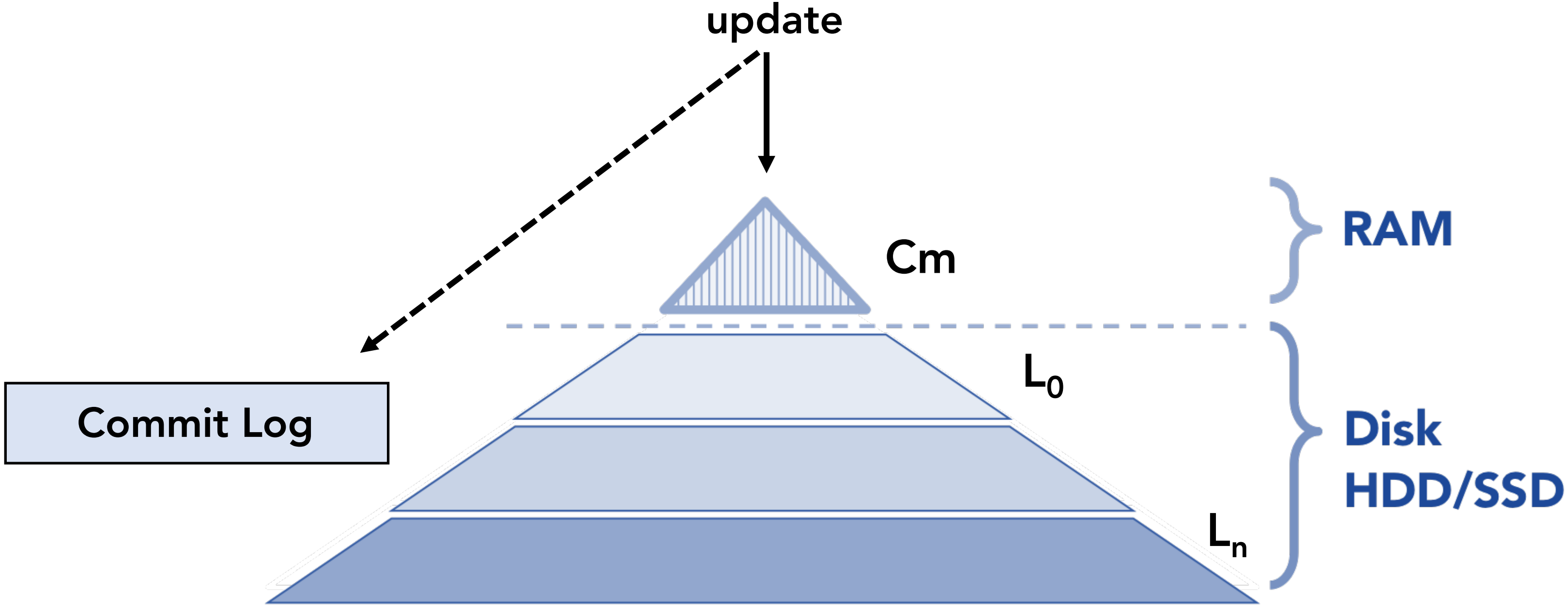


Sorted memory component

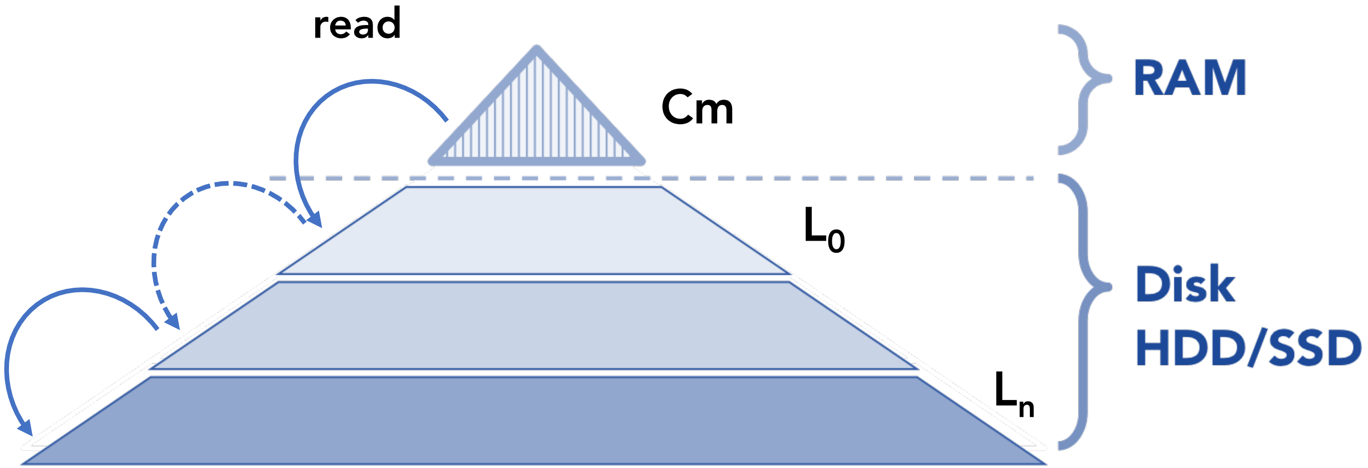
SSTables

- sorted files
- many SSTables/Level

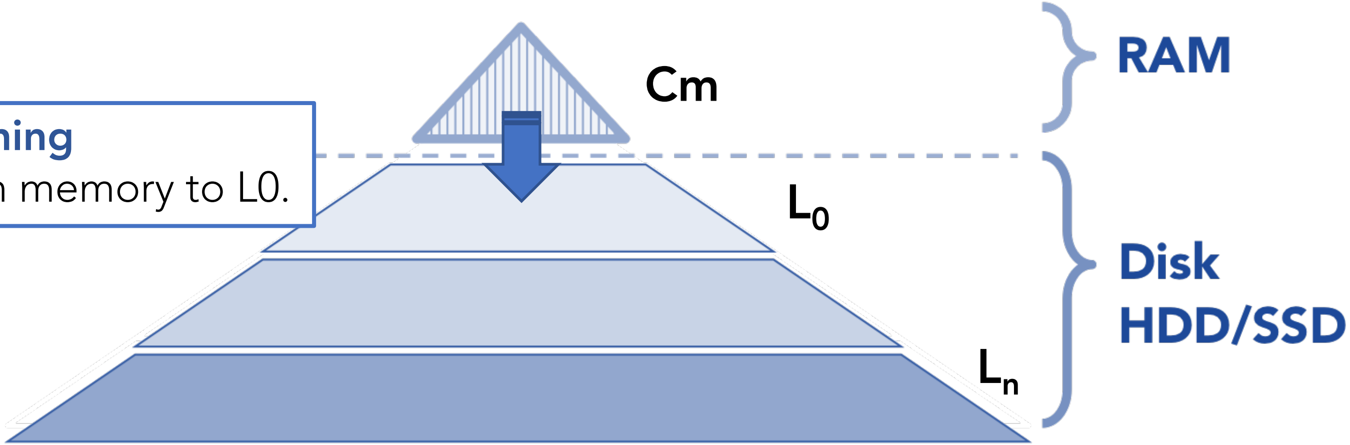
LSM Updates



LSM Reads

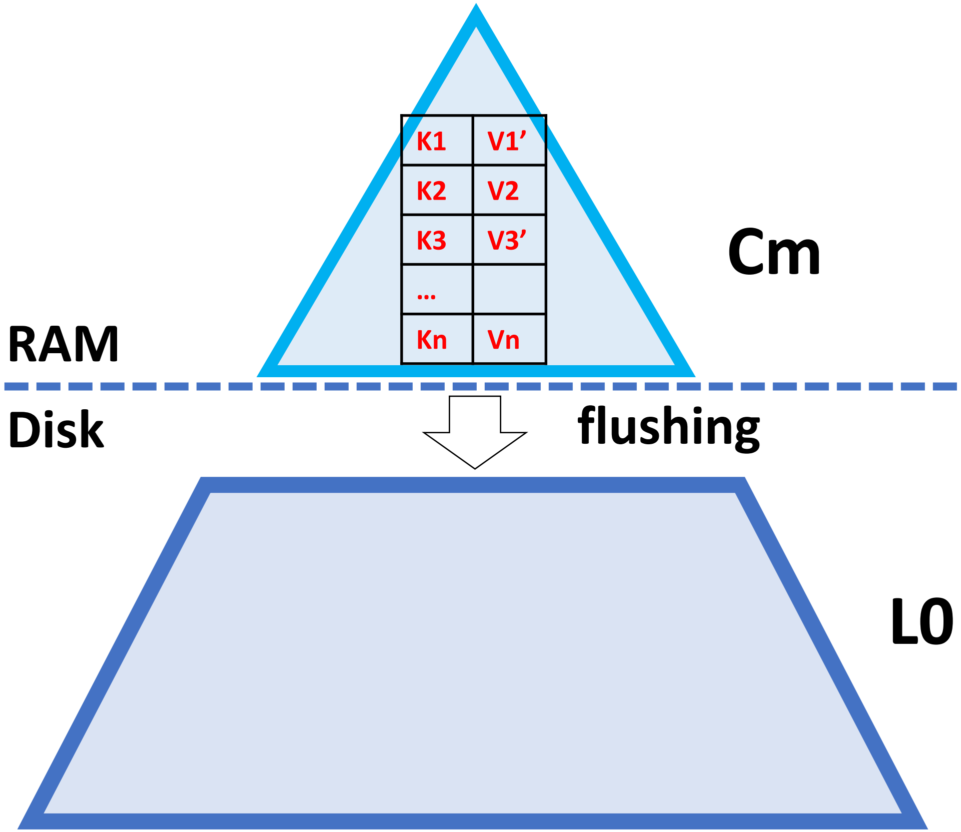


LSM Background Ops: Flushing



Flushing
From memory to L0.

LSM Background Ops: Flushing



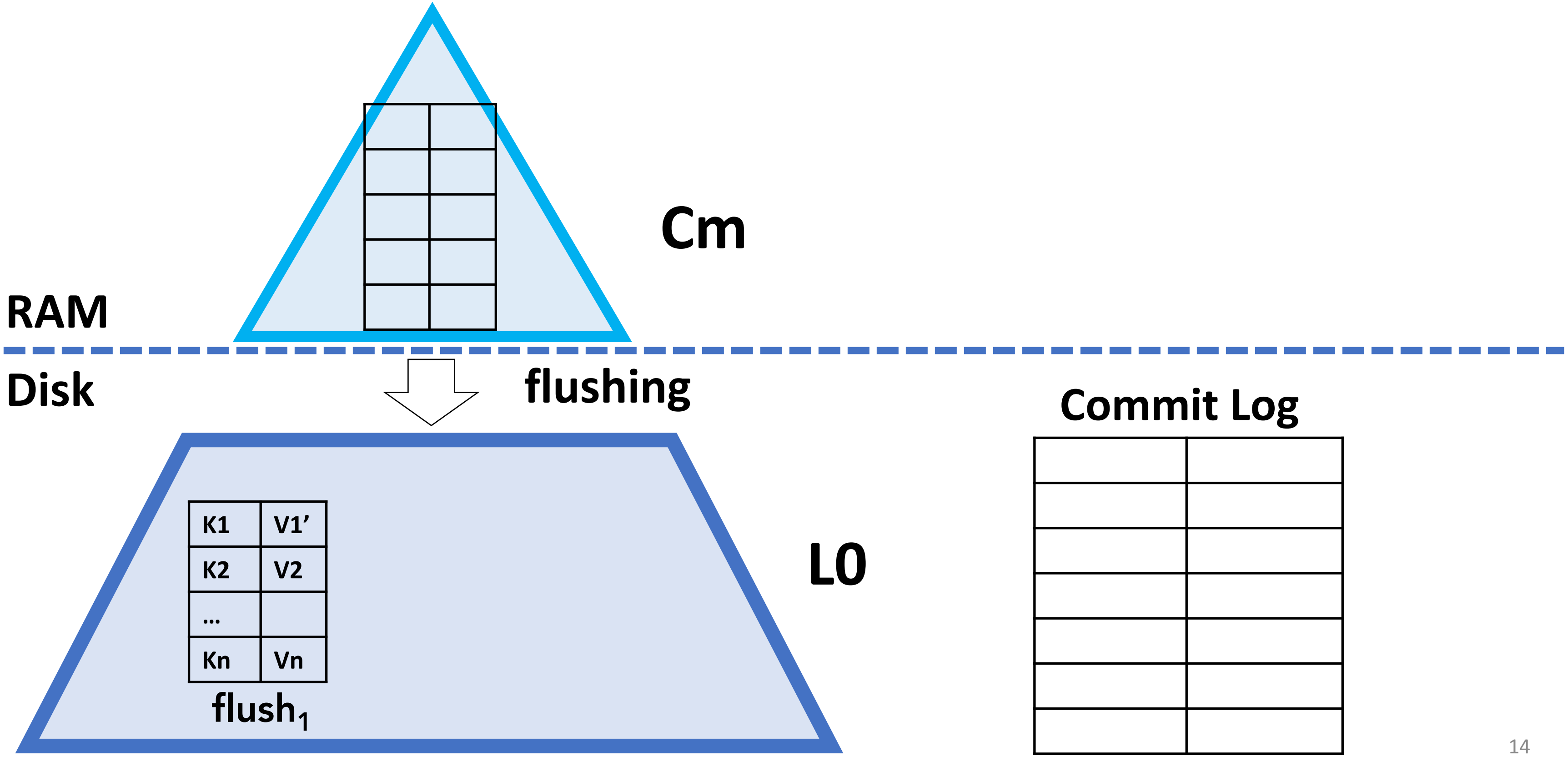
K1	V1’
K2	V2
K3	V3’
…	
Kn	Vn

Mem component full

Commit Log

K1	V1
K2	V2
K1	V1’
K3	V3

LSM Background Ops: Flushing



Cm

RAM

Disk

flushing

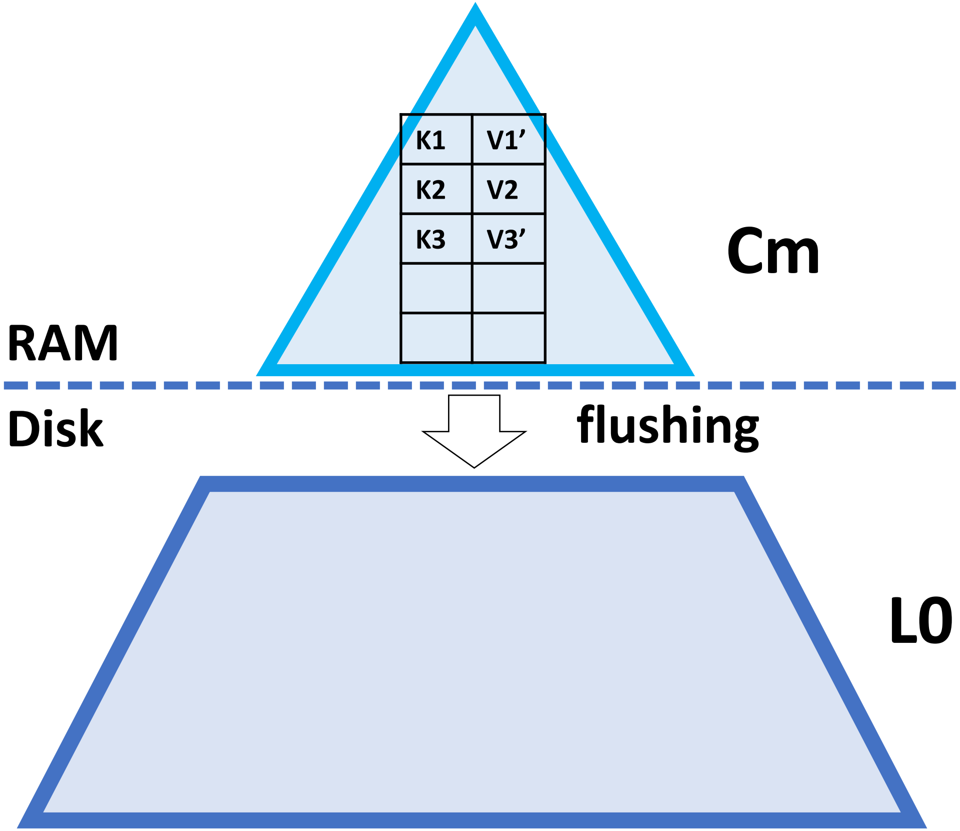
Commit Log

L0

K1	V1’
K2	V2
…	
Kn	Vn

flush_1

LSM Background Ops: Flushing



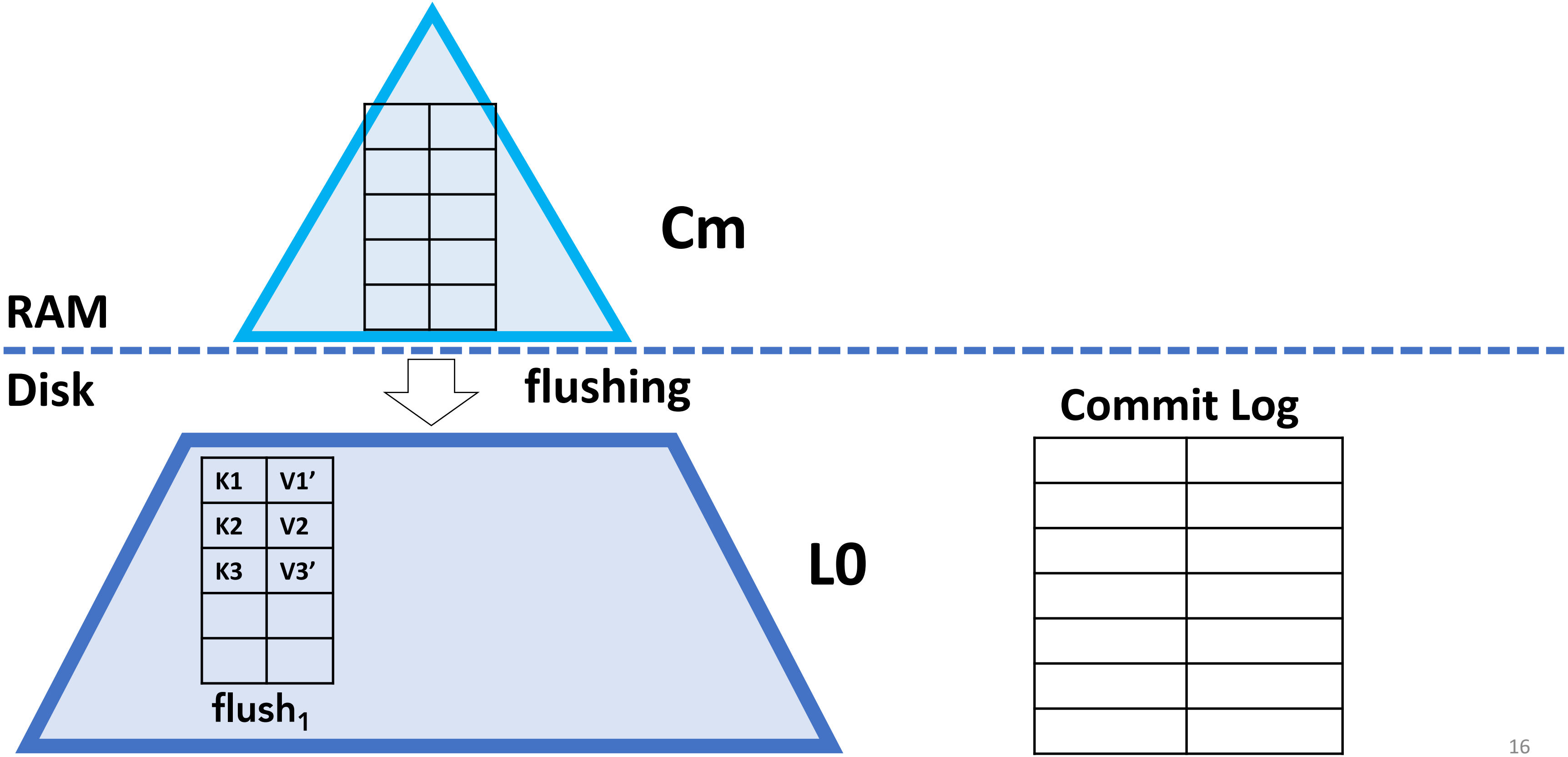
K1	V1’
K2	V2
K3	V3’

Commit log full

Commit Log

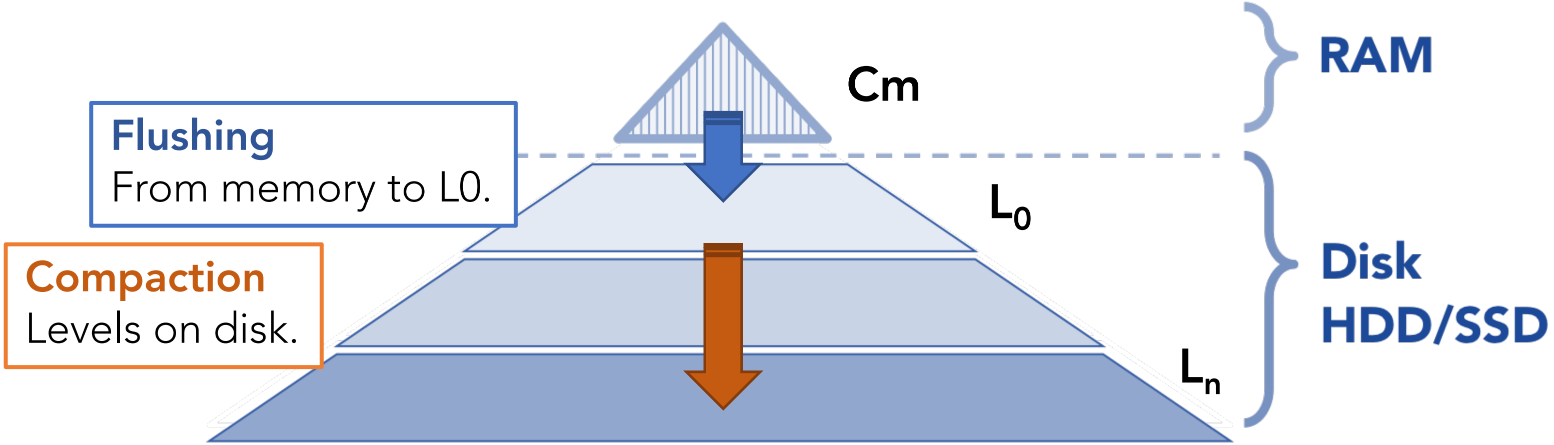
K1	V1
K2	V2
K1	V1”
K3	V3
…	
K1	V1’
K3	V3’

LSM Background Ops: Flushing



K1	V1’
K2	V2
K3	V3’

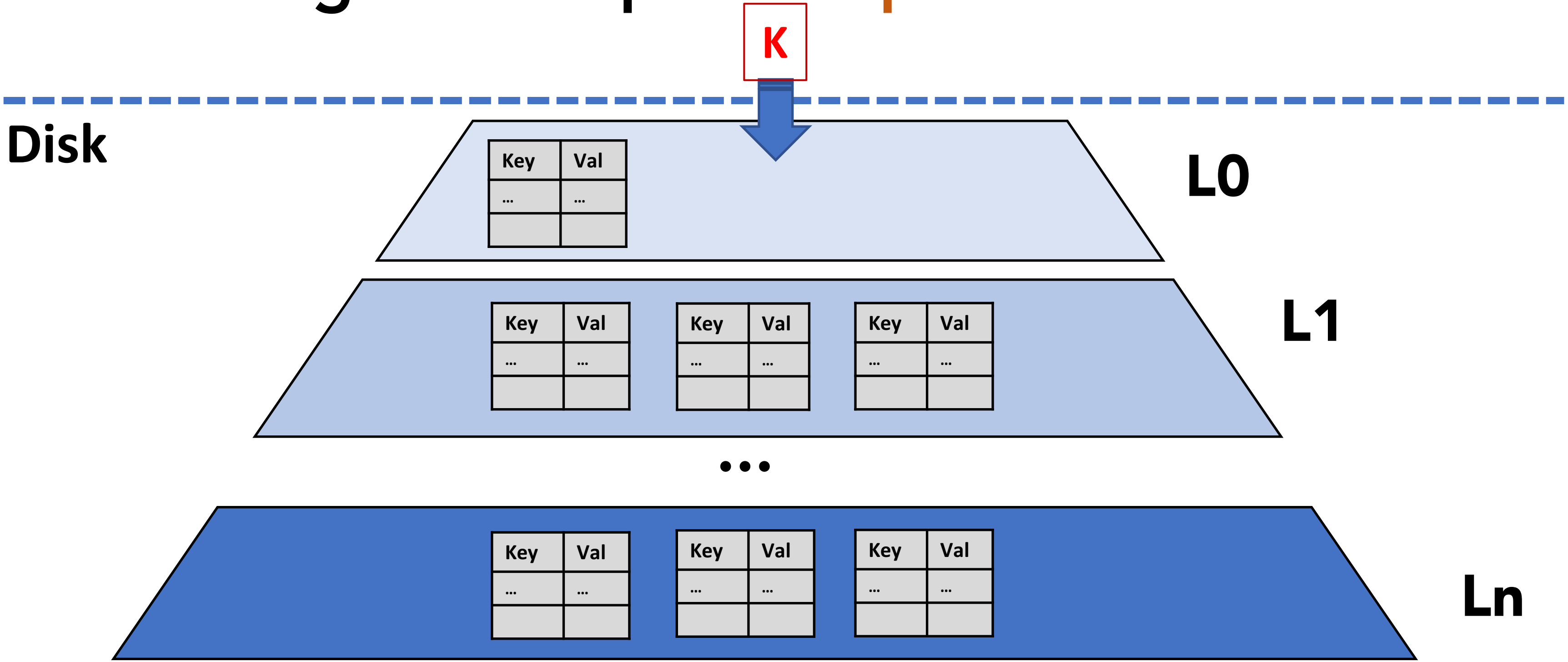
LSM Background Ops: Compaction



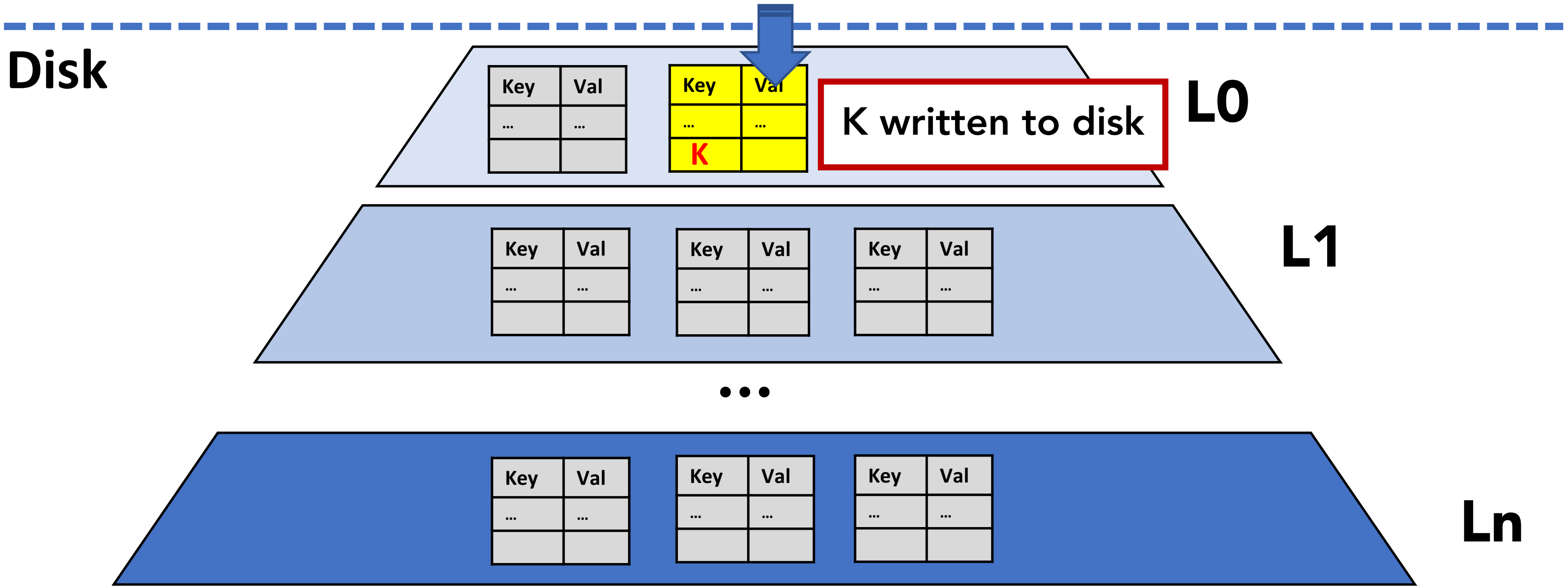
Flushing
From memory to L0.

Compaction
Levels on disk.

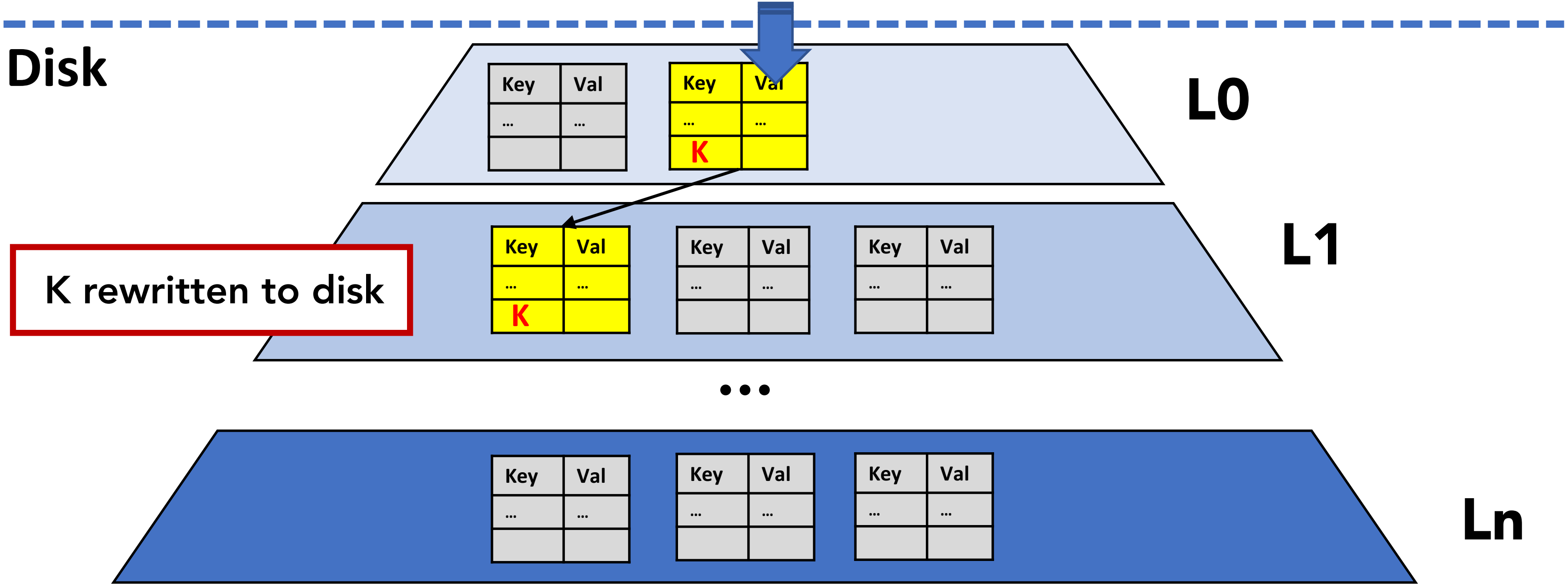
LSM Background Ops: Compaction



LSM Background Ops: Compaction

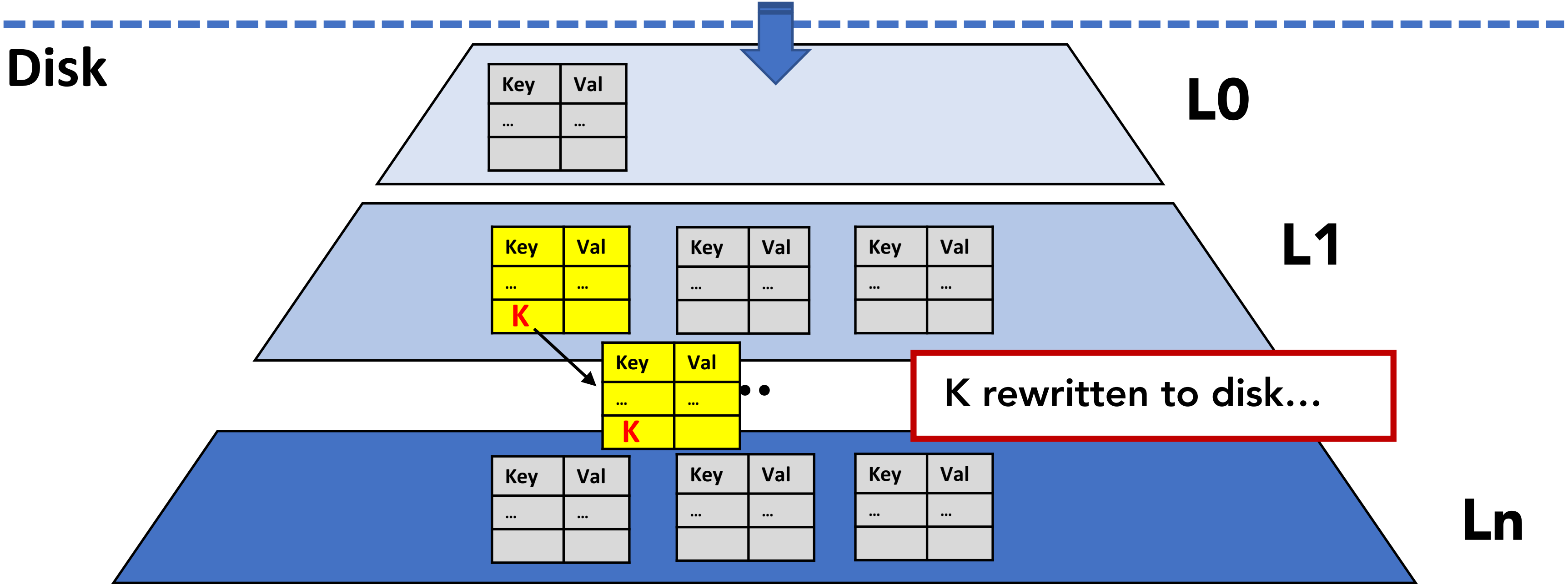


LSM Background Ops: Compaction



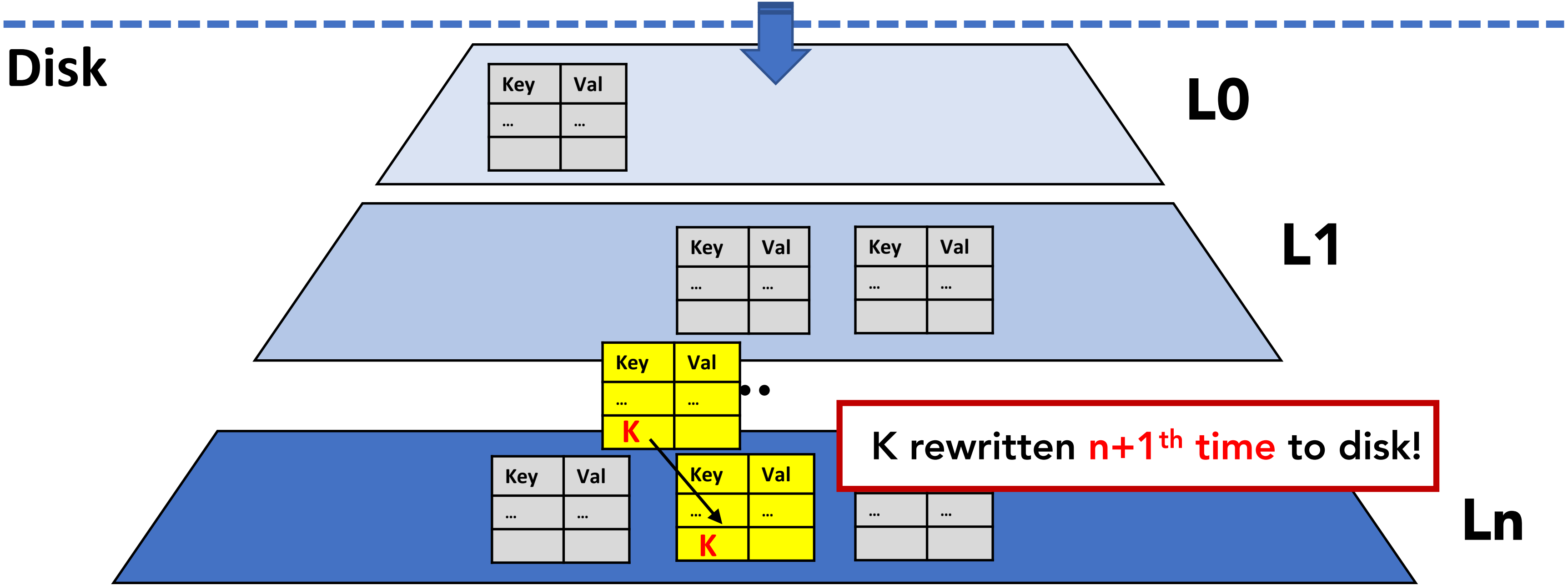
K rewritten to disk

LSM Background Ops: Compaction



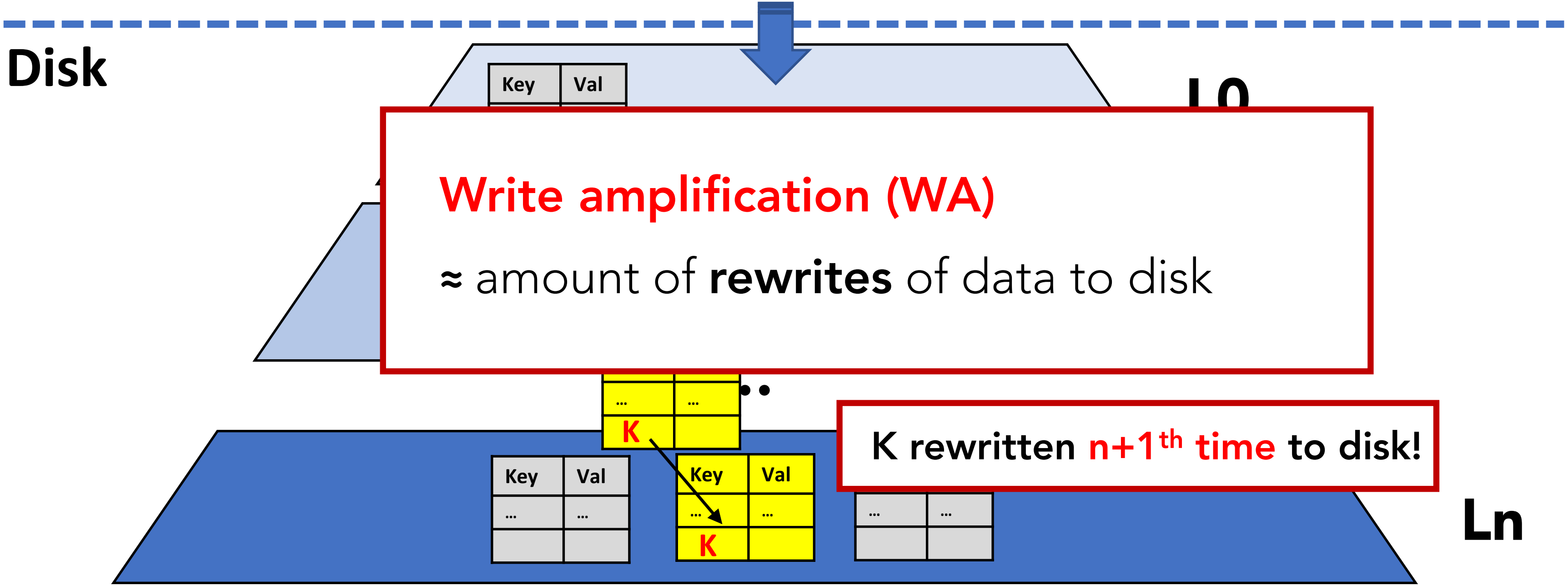
K rewritten to disk…

LSM Background Ops: Compaction



K rewritten n+1th time to disk!

LSM Background Ops: Compaction



Write amplification (WA)

≈ amount of **rewrites** of data to disk

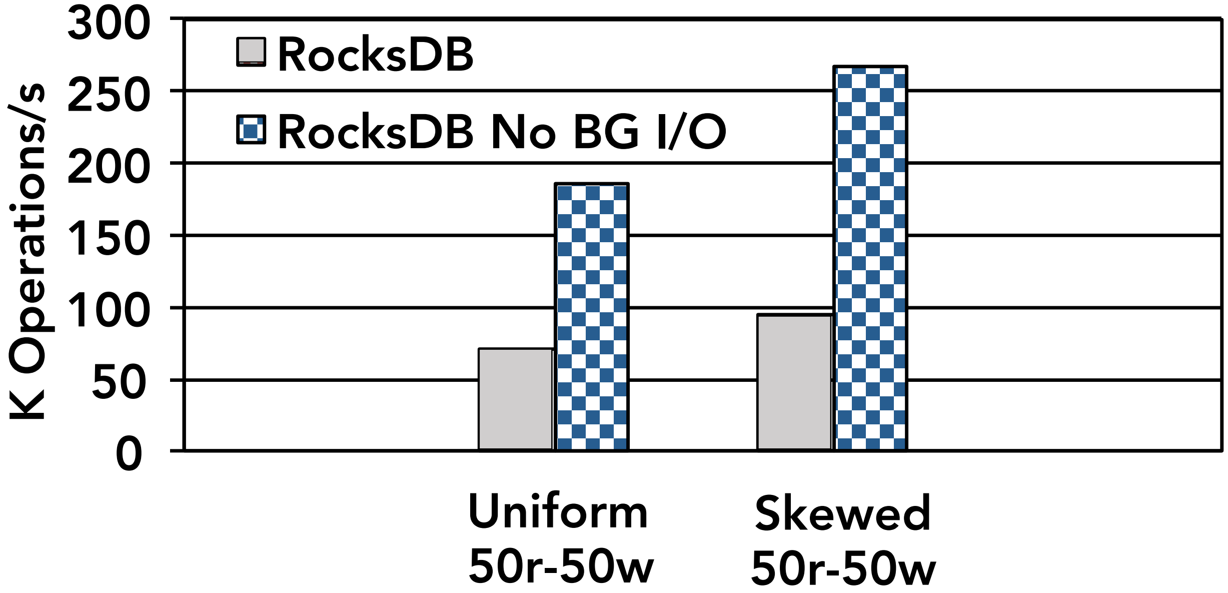
K rewritten n+1th time to disk!

Insight

Severe competition for compute/storage resources between LSM background ops and user ops.

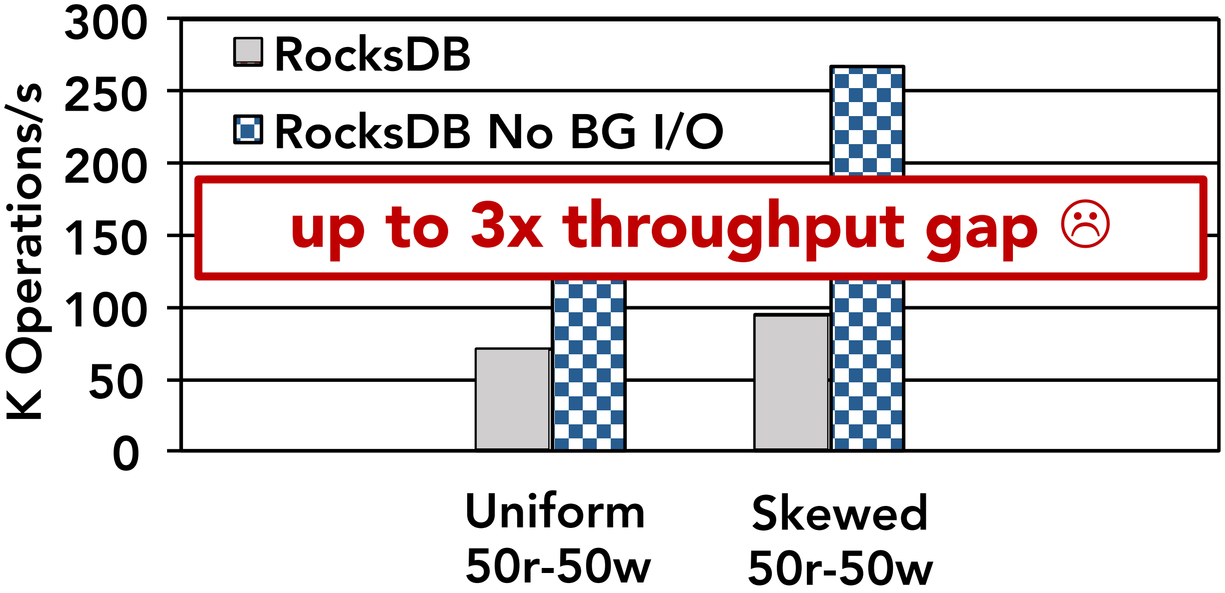
Background I/O Overhead

- Long & slow bg. ops ⟶ slowdown of user ops.



Background I/O Overhead

- **Long & slow bg. ops ⟶ slowdown of user ops.**



up to 3x throughput gap ☹

Goal

Decrease background ops overhead to increase user throughput.

TRIAD

TRIAD

	Workload	Improve WA in
TRIAD-MEM	Skewed workloads	Flushing and Compaction
TRIAD-DISK	In-between	Compaction
TRIAD-LOG	Uniform workloads	Flushing

Three techniques work together and are complementary.

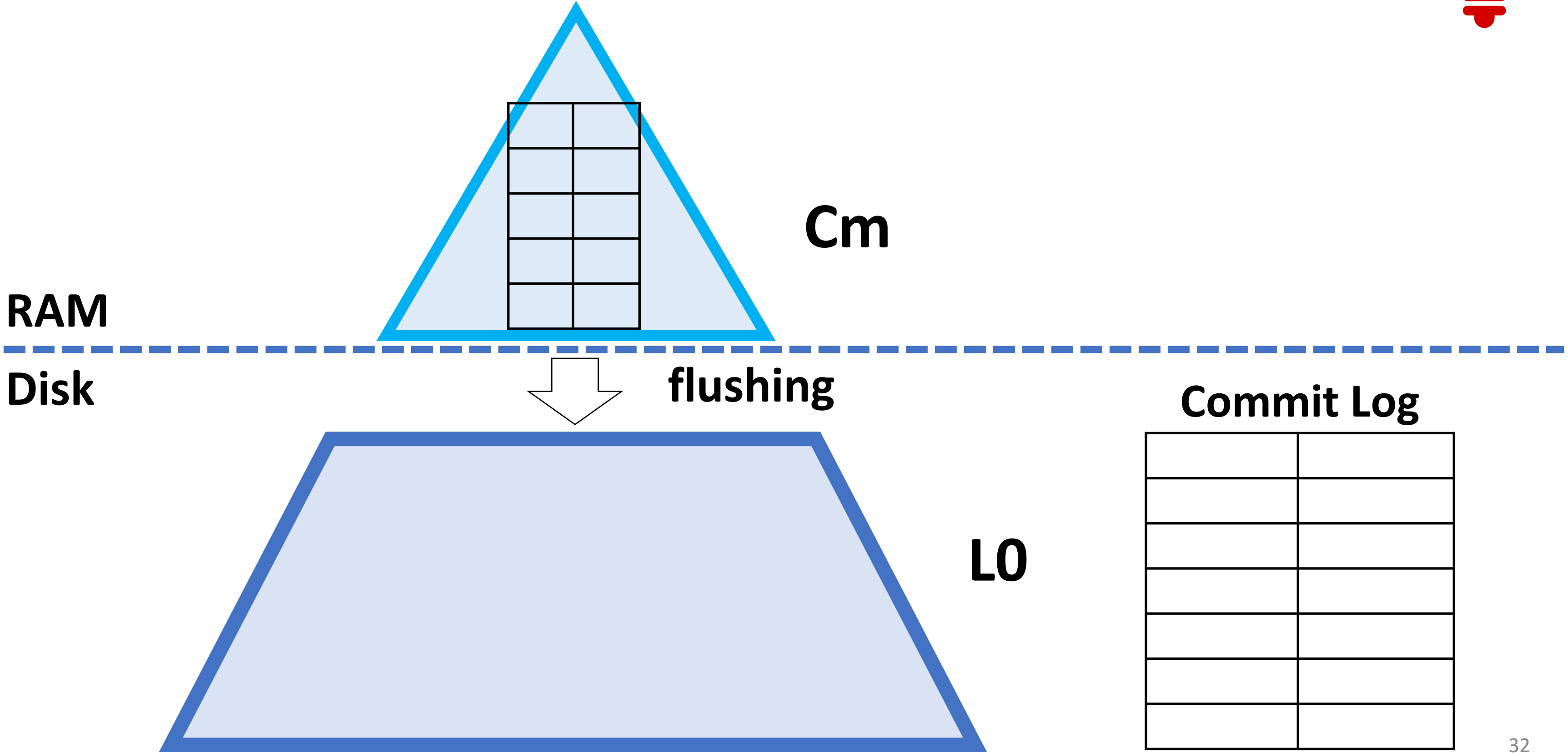
TRIAD

	Workload	Improve WA in
TRIAD-MEM	Skewed workloads	Flushing and Compaction
TRIAD-LOG	Uniform workloads	Flushing

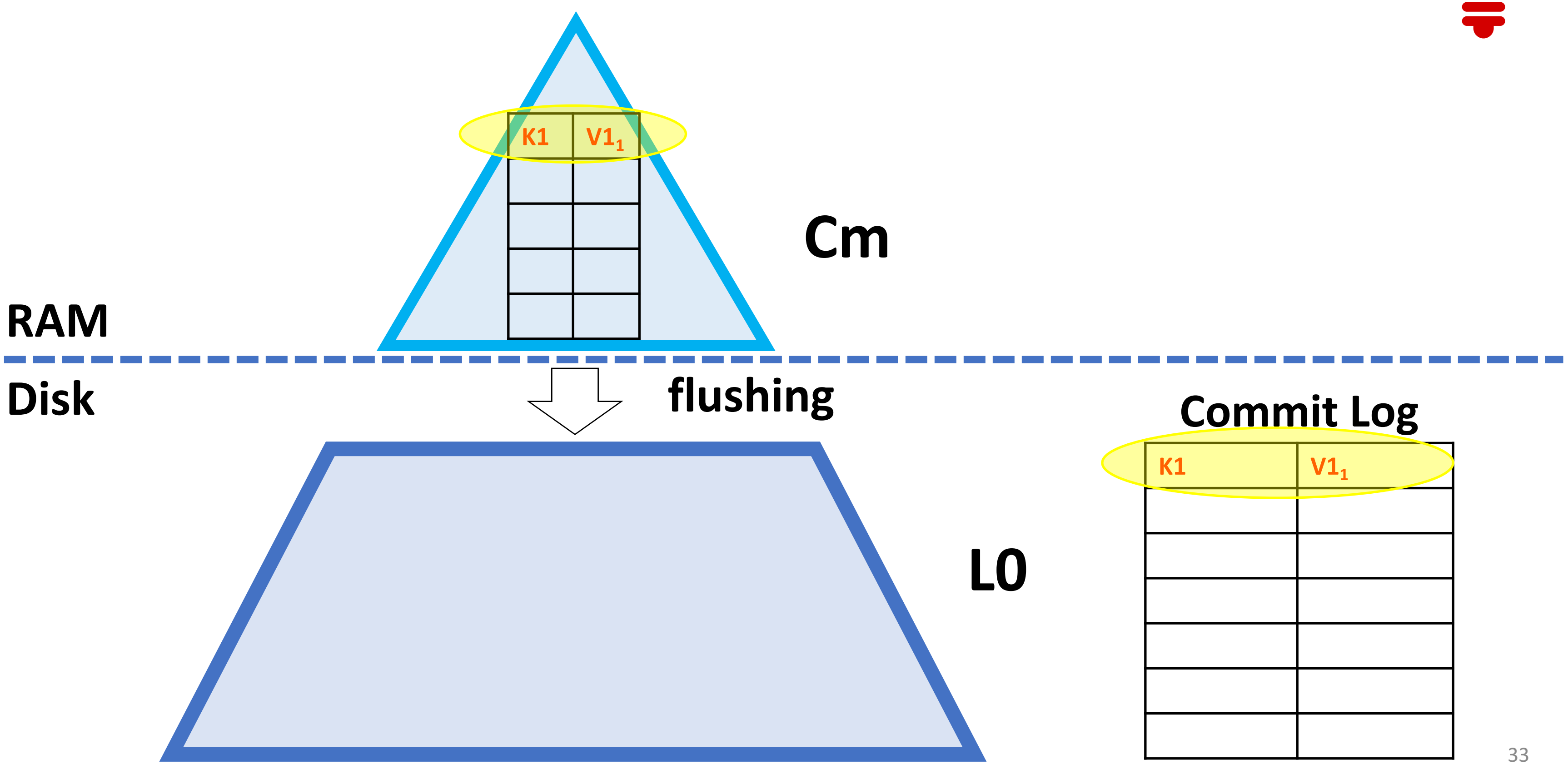
TRIAD-MEM

	Workload	Improve WA in
TRIAD-MEM	Skewed workloads	Flushing and Compaction

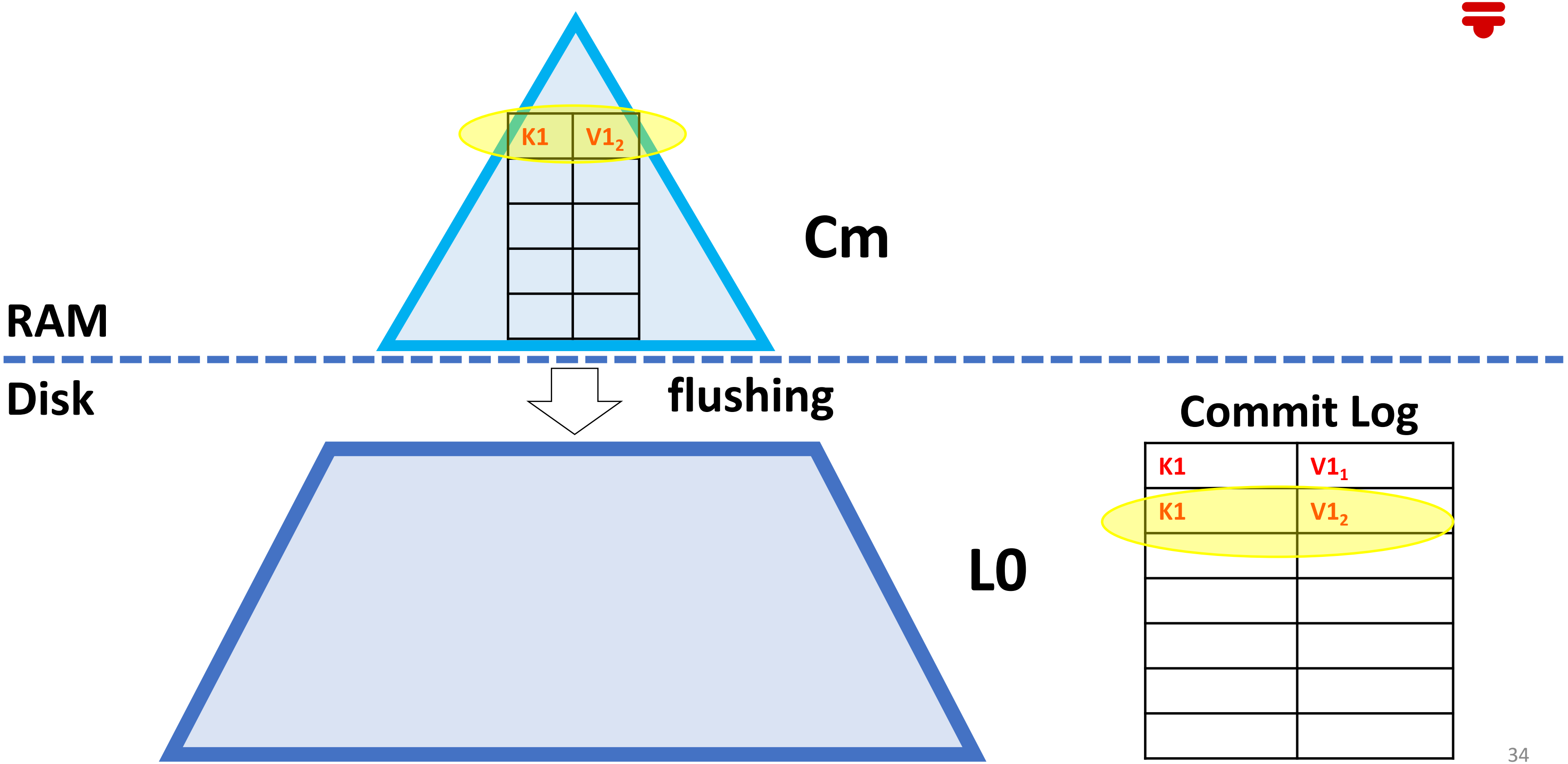
Problem: Flushing with Skewed Workloads



Problem: Flushing with Skewed Workloads



Problem: Flushing with Skewed Workloads

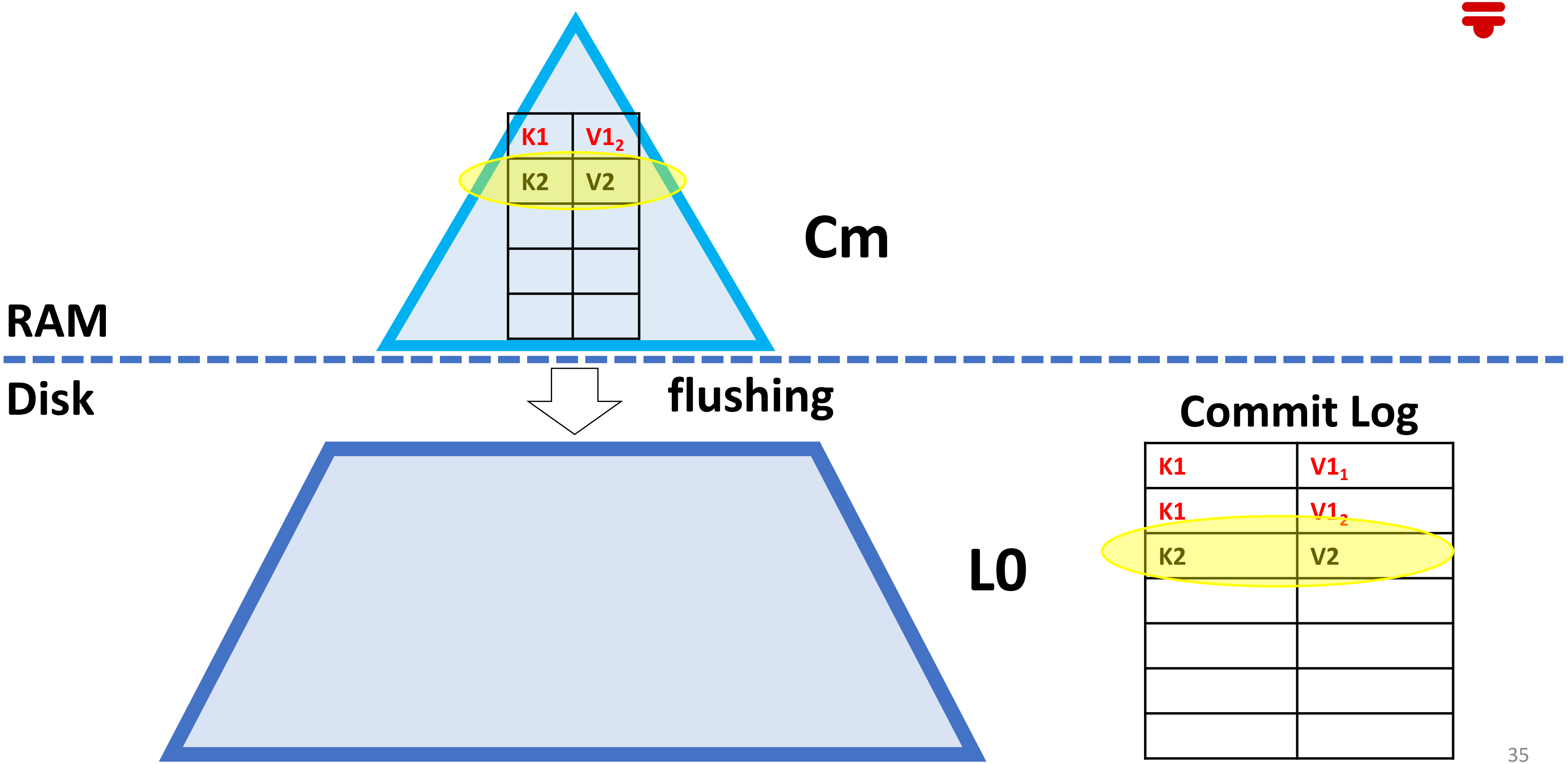


K1	$V1_2$

Commit Log

K1	$V1_1$
K1	$V1_2$

Problem: Flushing with Skewed Workloads

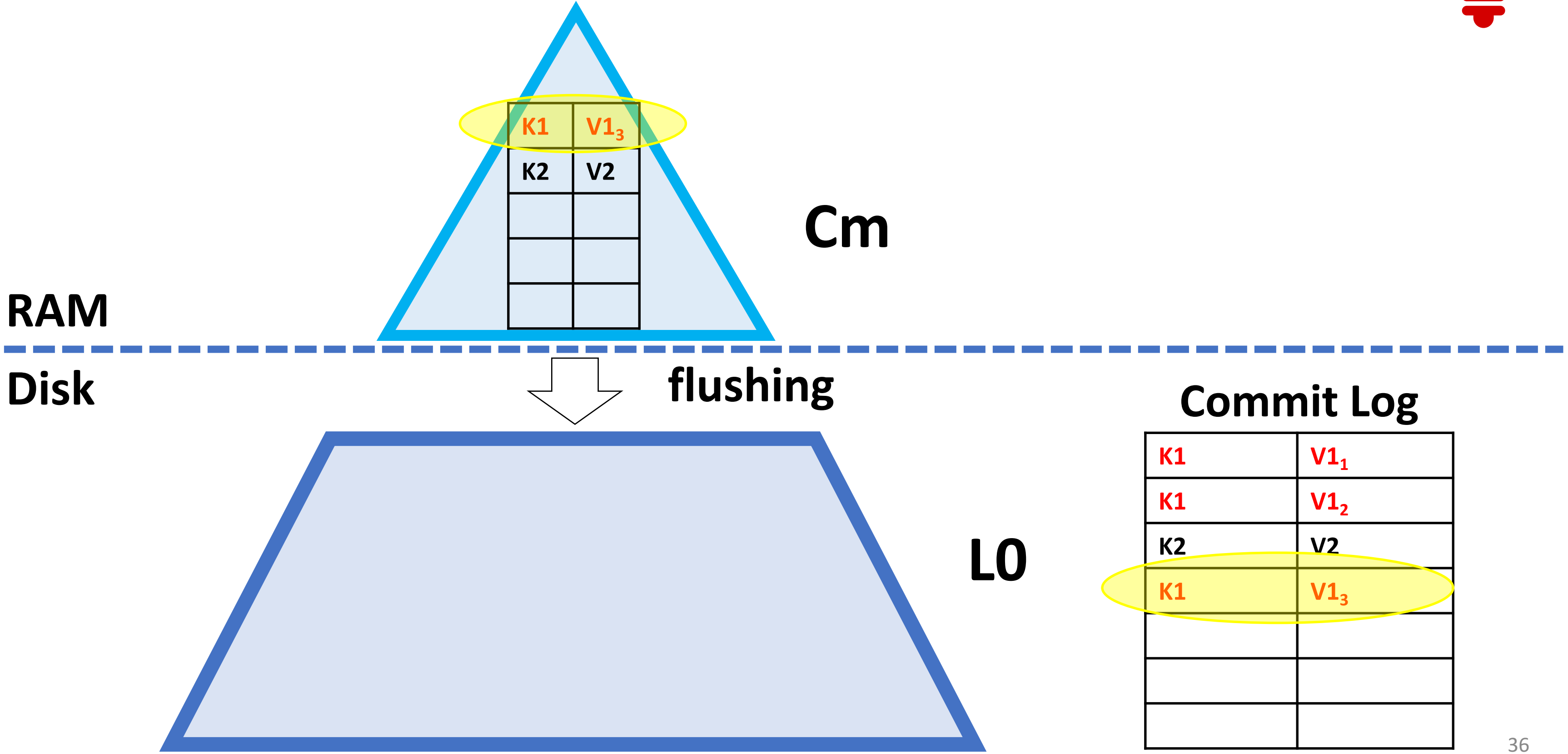


K1	$V1_2$
K2	V2

Commit Log

K1	$V1_1$
K1	$V1_2$
K2	V2

Problem: Flushing with Skewed Workloads

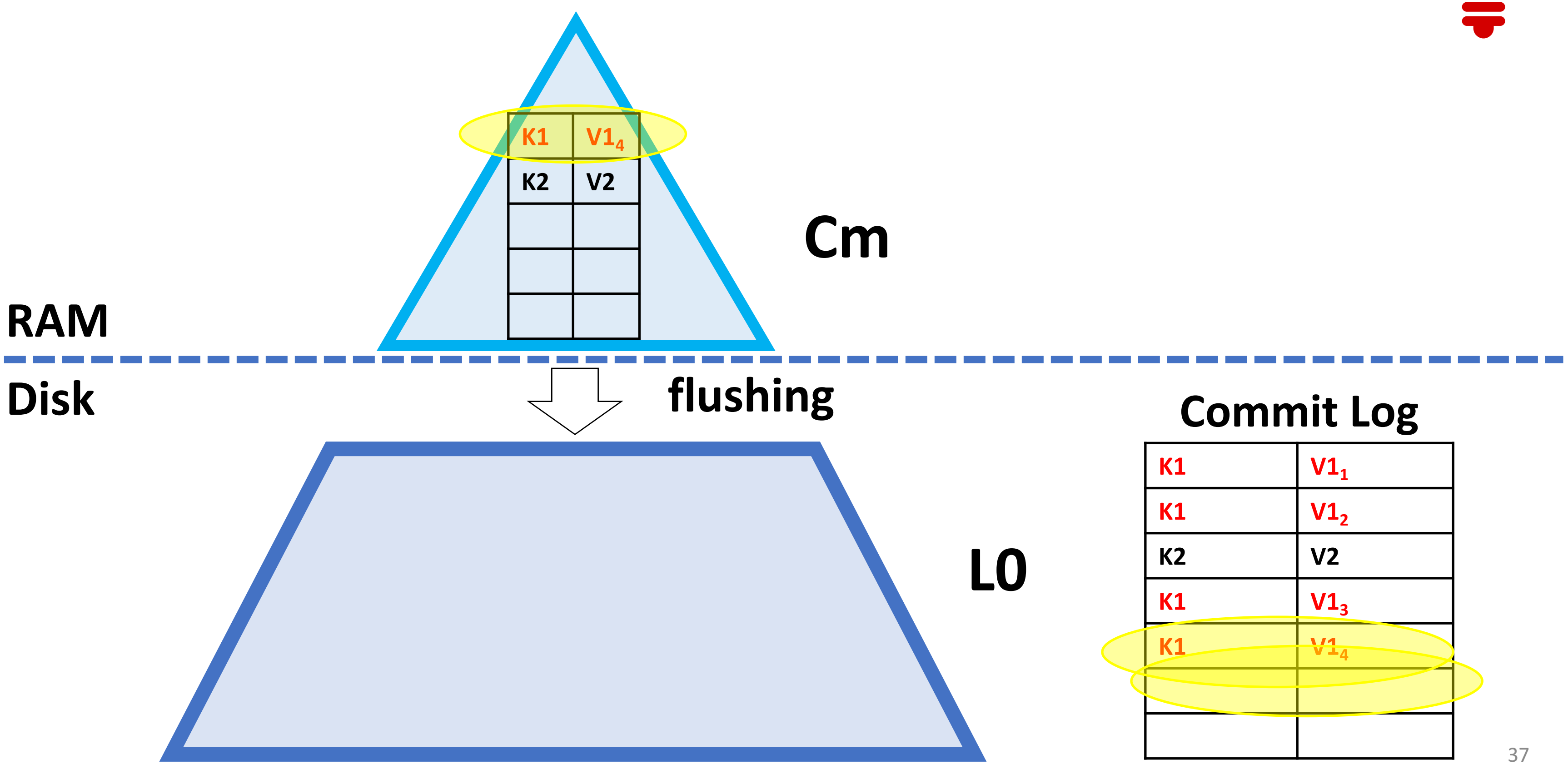


K1	$V1_3$
K2	V2

Commit Log

K1	$V1_1$
K1	$V1_2$
K2	V2
K1	$V1_3$

Problem: Flushing with Skewed Workloads

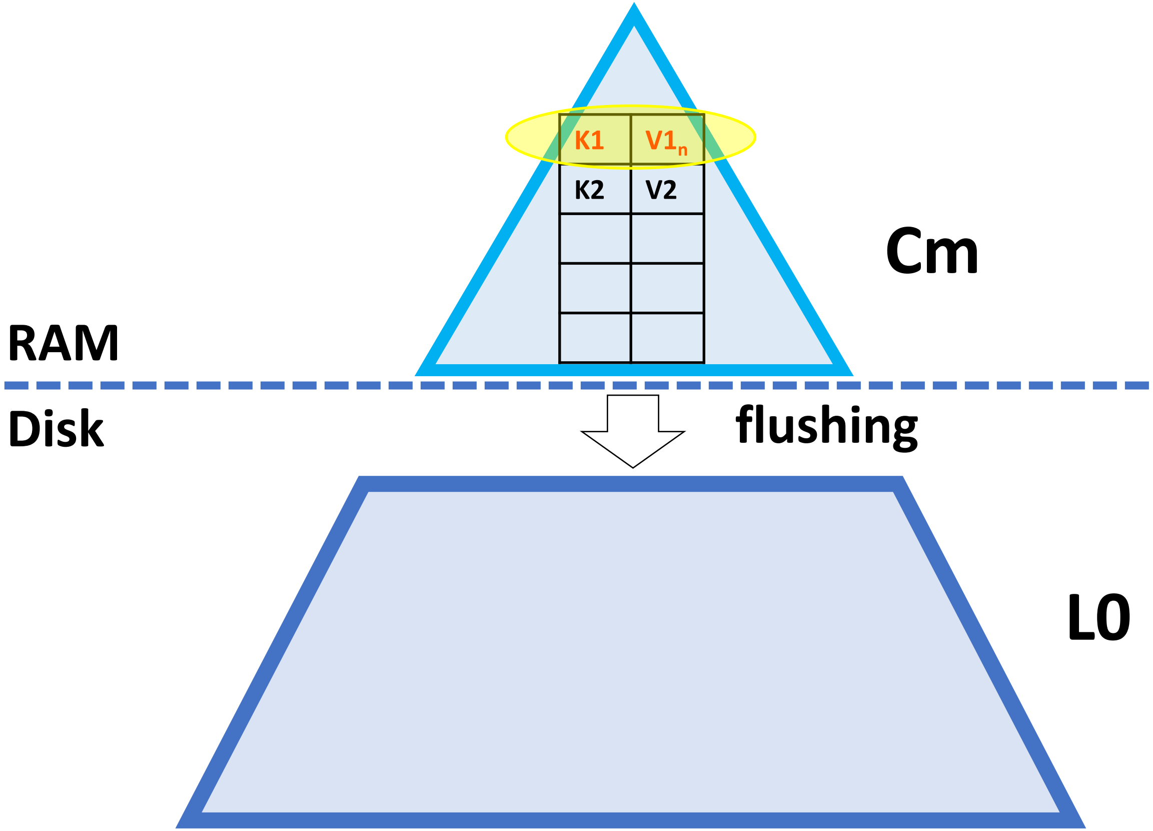


K1	$V1_4$
K2	V2

Commit Log

K1	$V1_1$
K1	$V1_2$
K2	V2
K1	$V1_3$
K1	$V1_4$

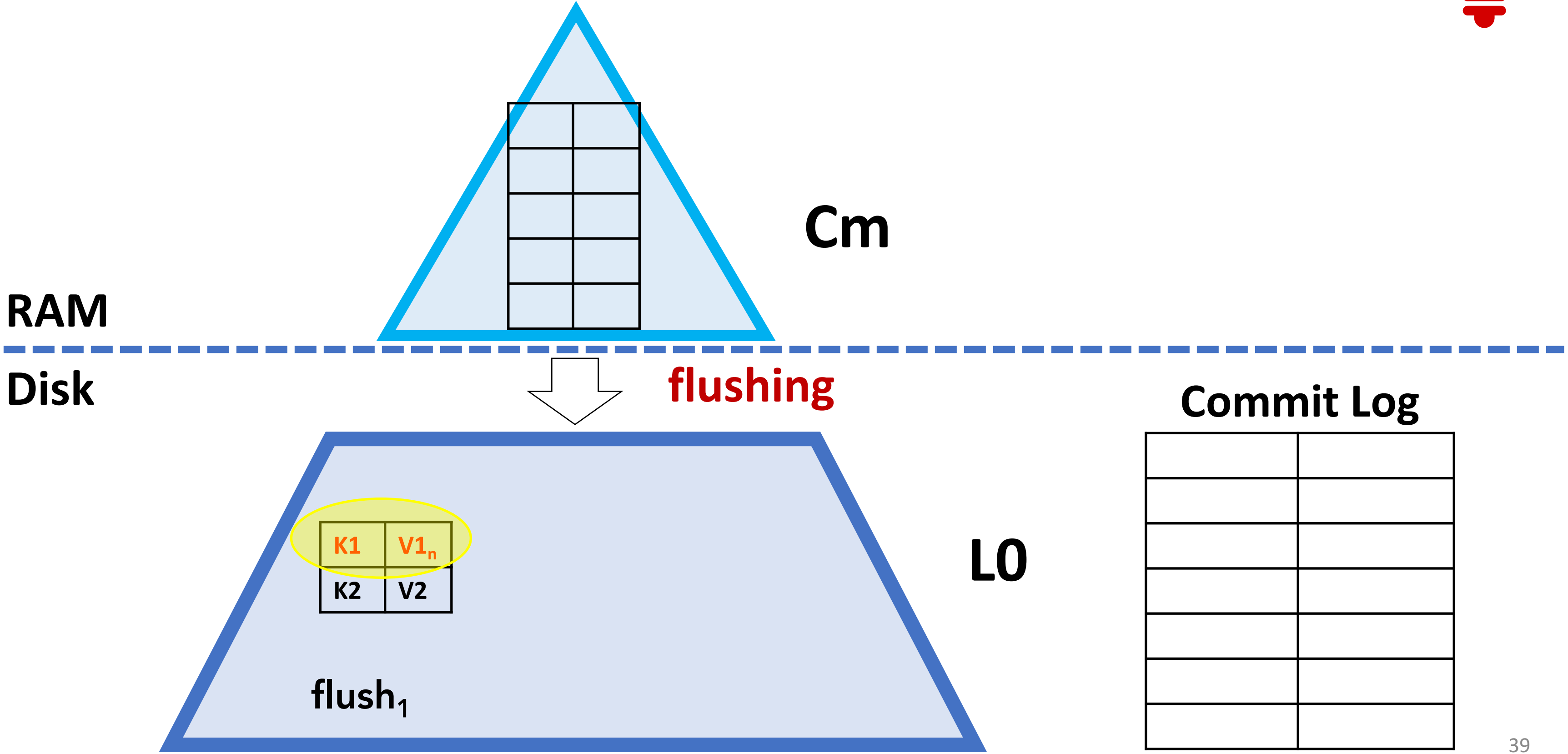
Problem: Flushing with Skewed Workloads



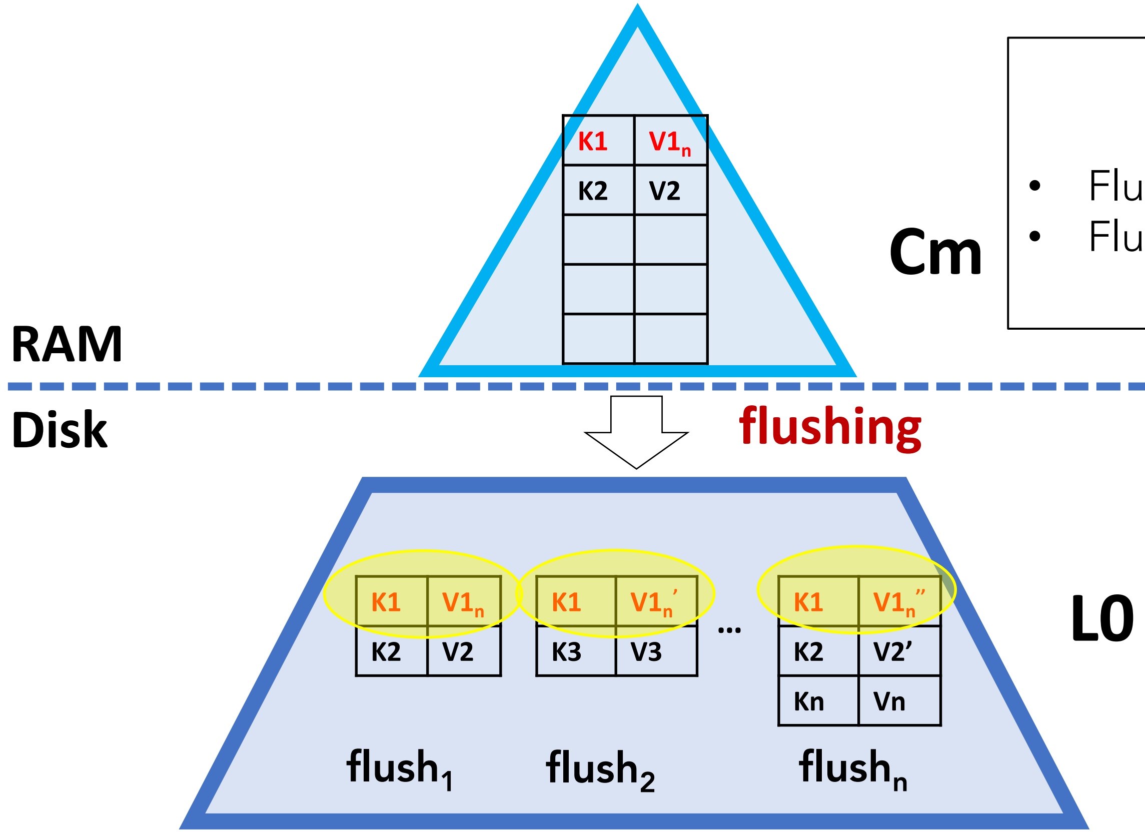
Commit Log

K1	$V1_1$
K1	$V1_2$
K2	V2
K1	$V1_3$
K1	$V1_4$
…	
K1	$V1_n$

Problem: Flushing with Skewed Workloads



Problem: Flushing with Skewed Workloads



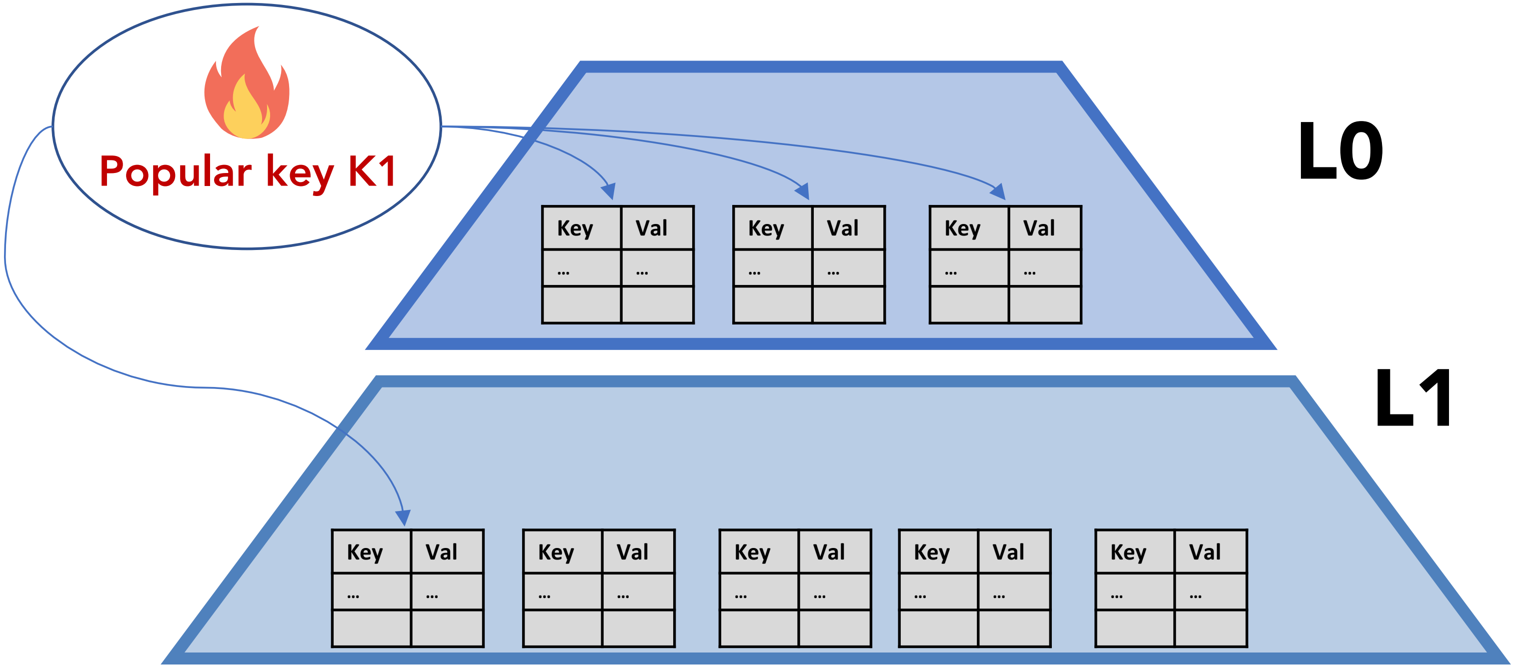
High data skew

- Flush because commit log is full
- Flush mostly empty mem comp

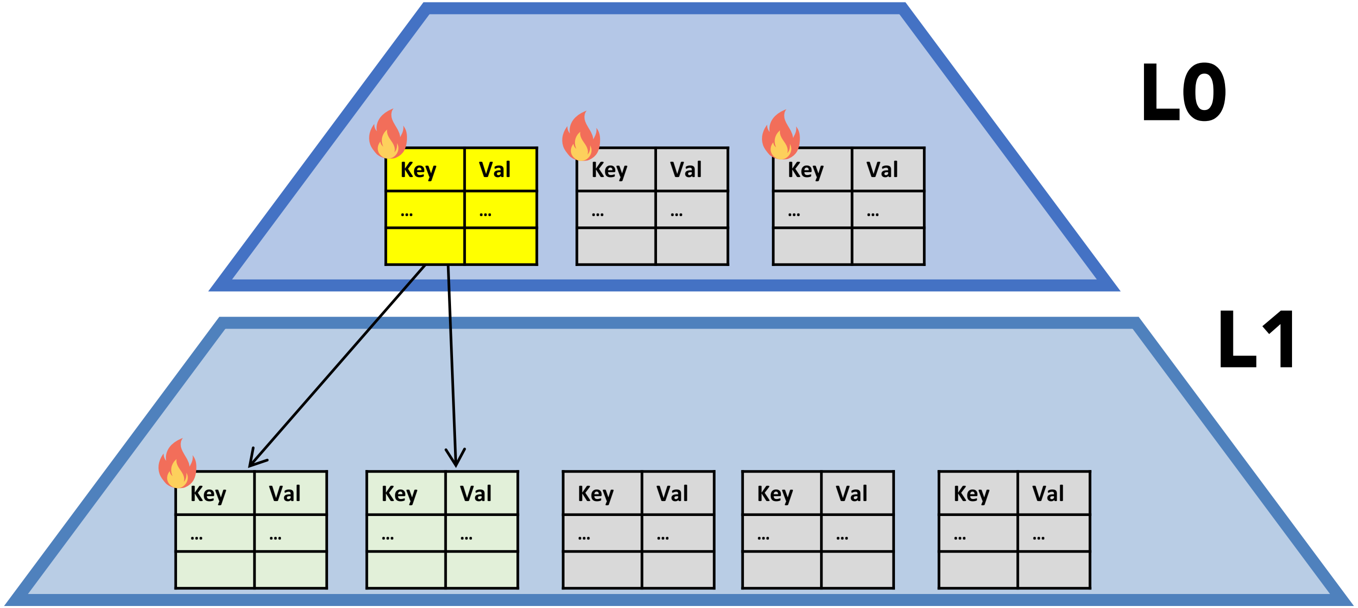
Commit Log

K1	V1$_1$
K2	V2
K1	V1$_2$
K1	V1$_3$
K1	V1$_4$
…	
K1	V1$_n$

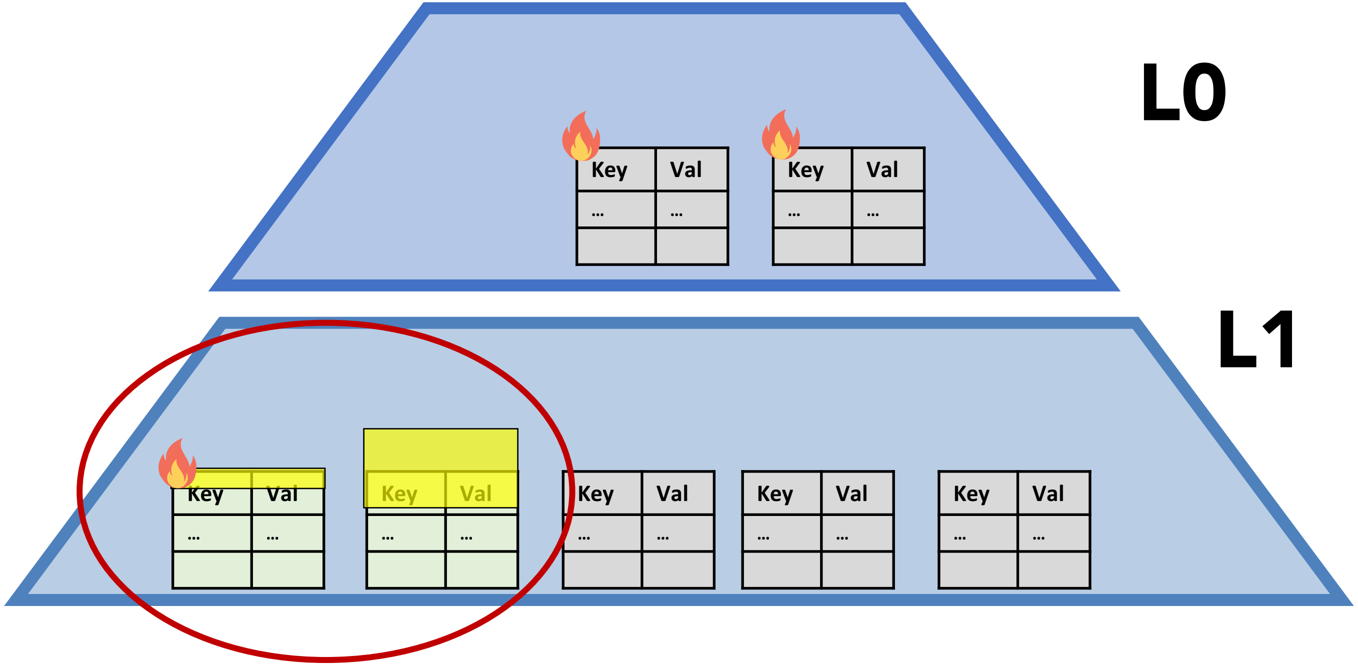
Problem: Compaction with Skewed Workloads



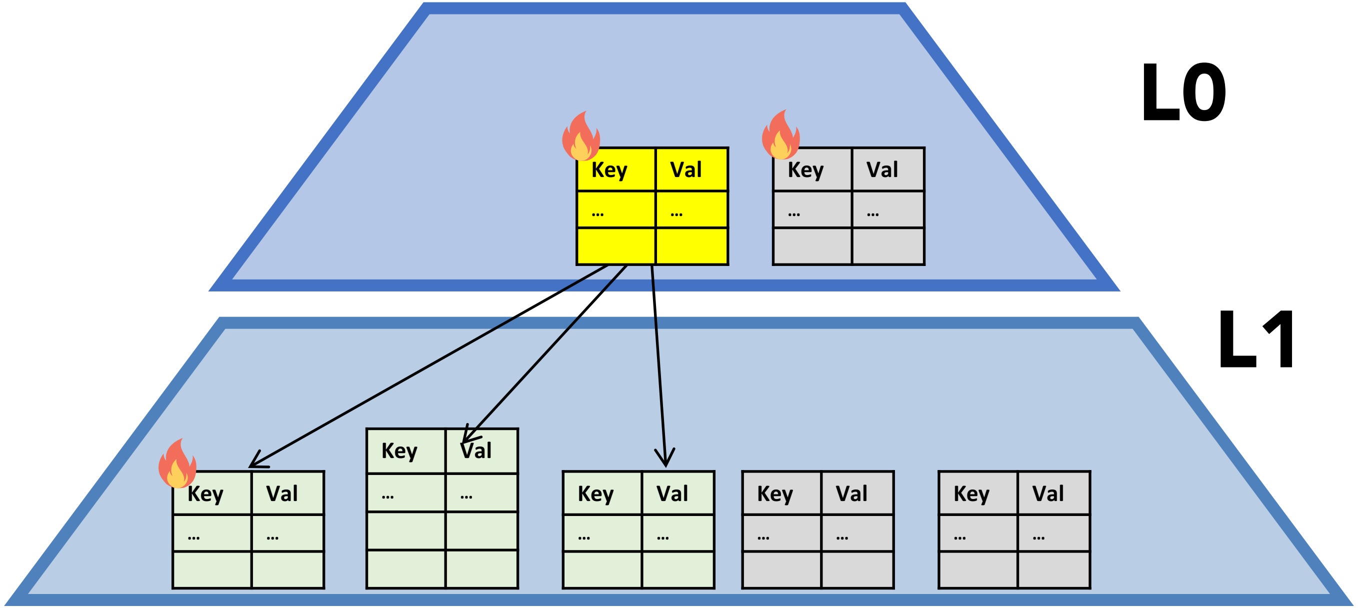
Problem: Compaction with Skewed Workloads



Problem: Compaction with Skewed Workloads

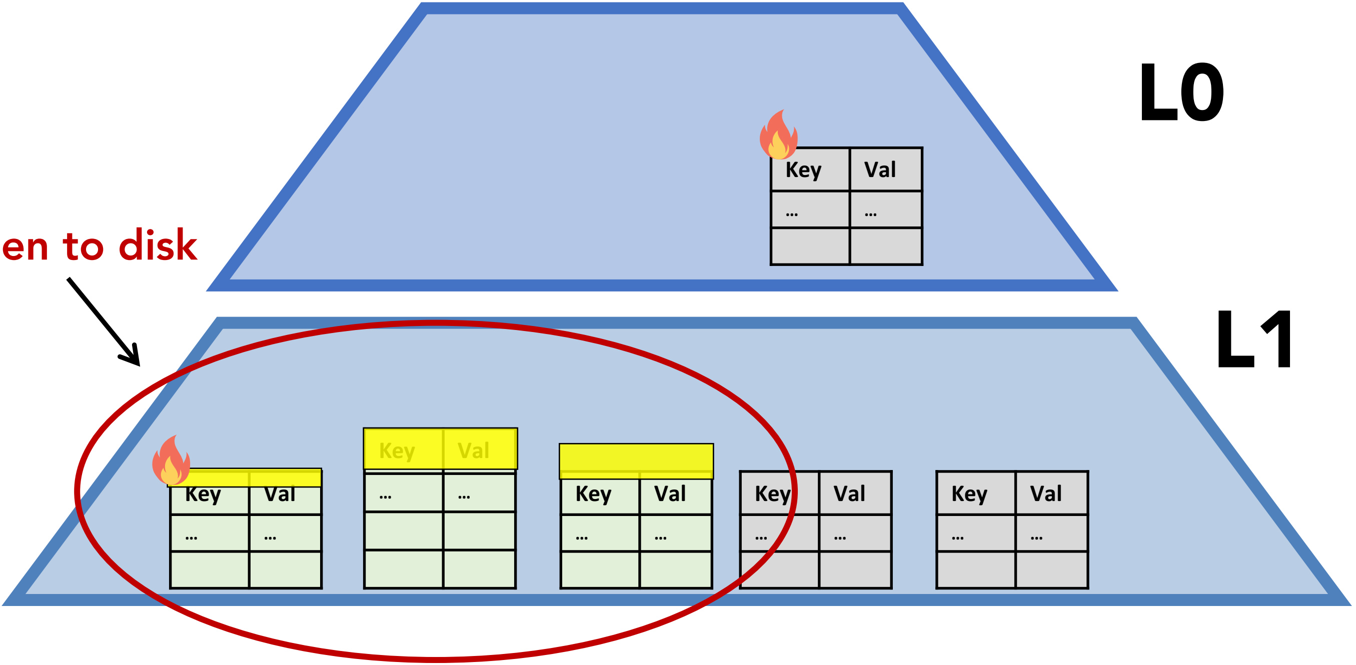


Problem: Compaction with Skewed Workloads



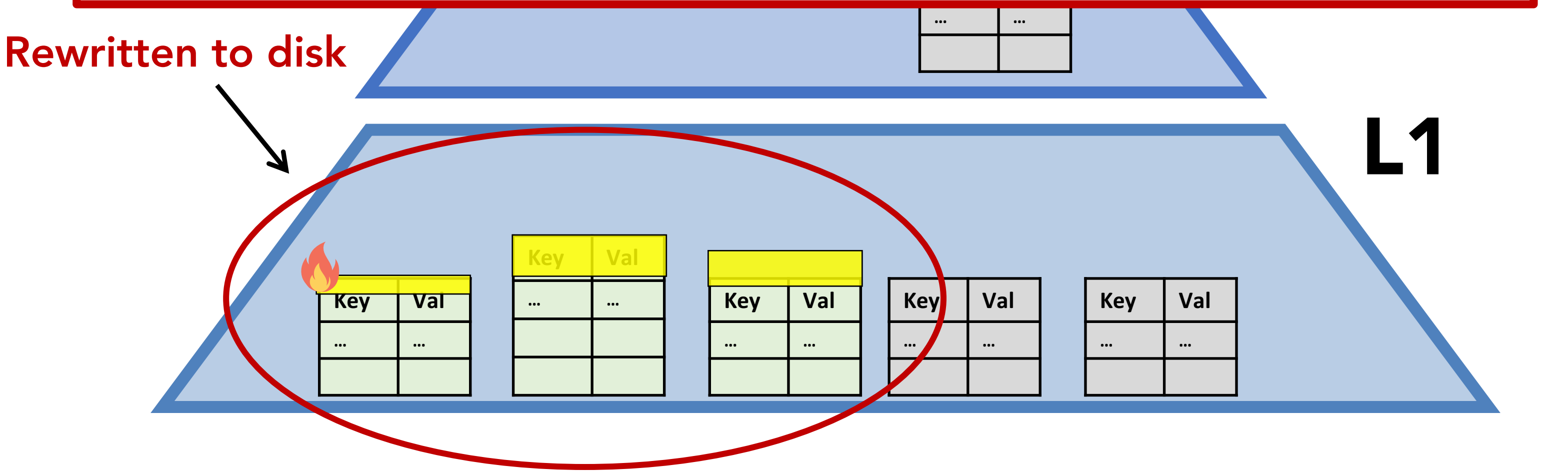
Problem: Compaction with Skewed Workloads

Rewritten to disk

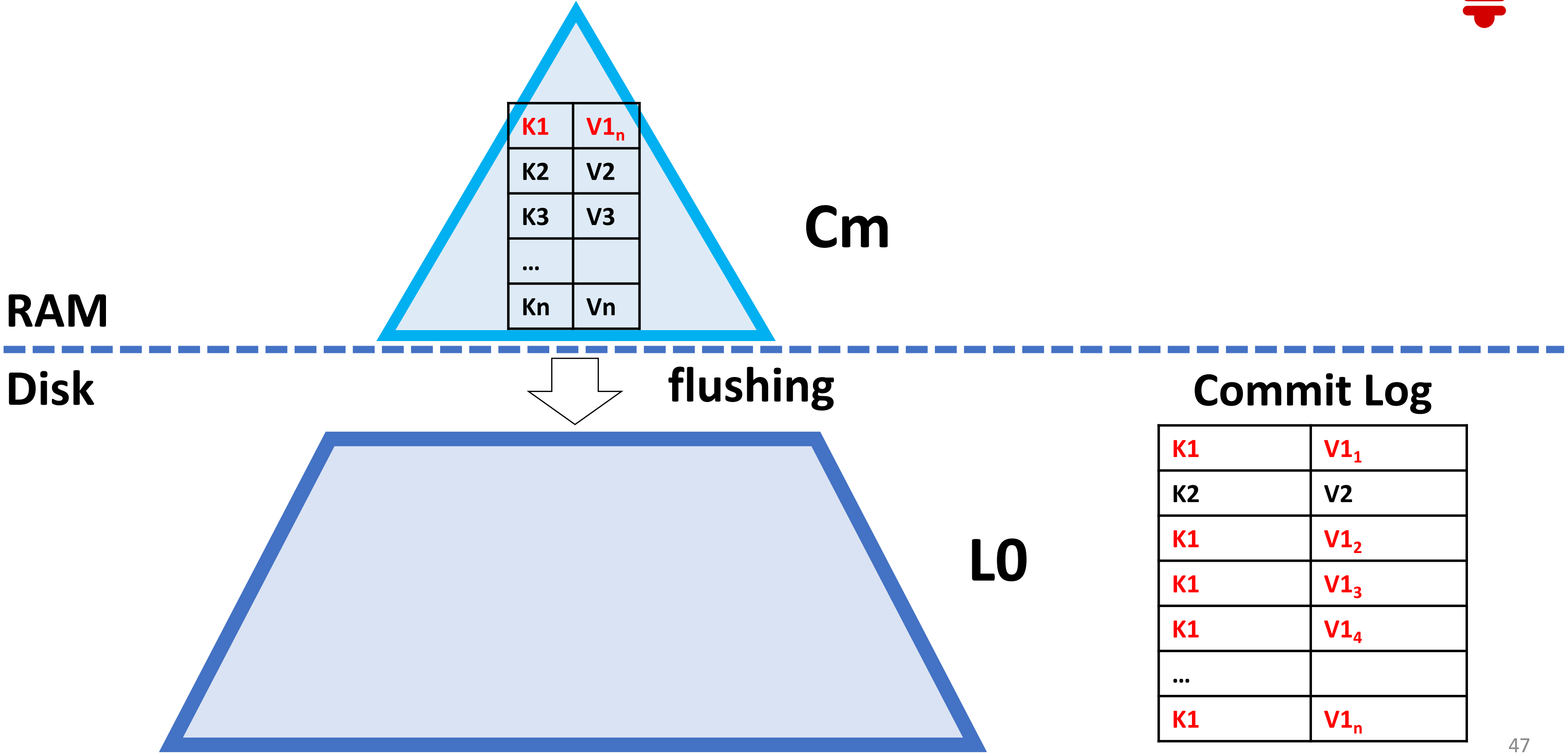


Problem: Compaction with Skewed Workloads

File on L1 **rewritten to disk twice** because of one key ☹



TRIAD-MEM: Hot-cold key separation



K1	$V1_n$
K2	V2
K3	V3
…	
Kn	Vn

Commit Log

K1	$V1_1$
K2	V2
K1	$V1_2$
K1	$V1_3$
K1	$V1_4$
…	
K1	$V1_n$

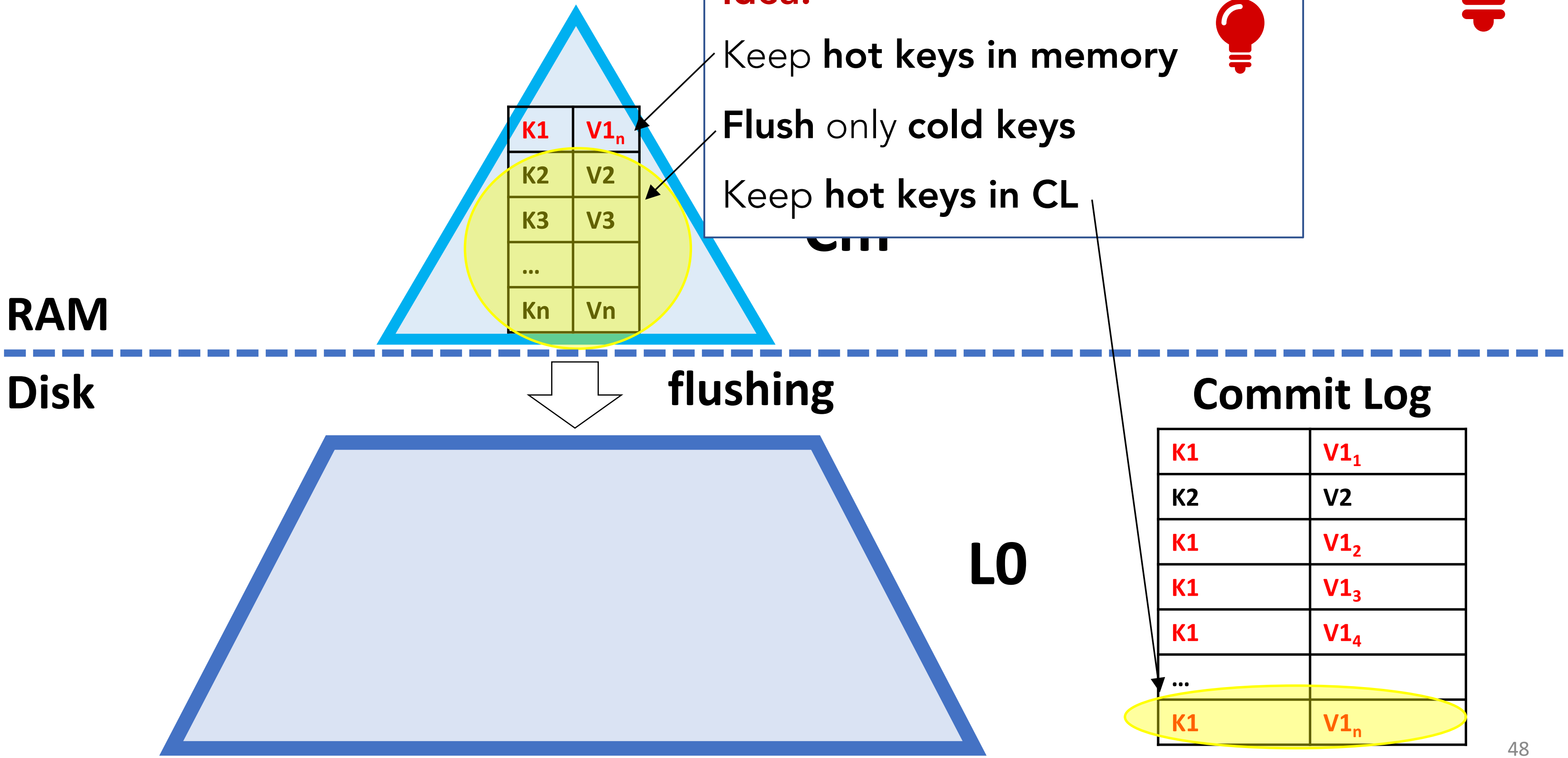
TRIAD-MEM: Hot-cold key separation

Idea:

Keep **hot keys in memory**

Flush only **cold keys**

Keep **hot keys in CL**



K1	$V1_n$
K2	V2
K3	V3
…	
Kn	Vn

Commit Log

K1	$V1_1$
K2	V2
K1	$V1_2$
K1	$V1_3$
K1	$V1_4$
…	
K1	$V1_n$

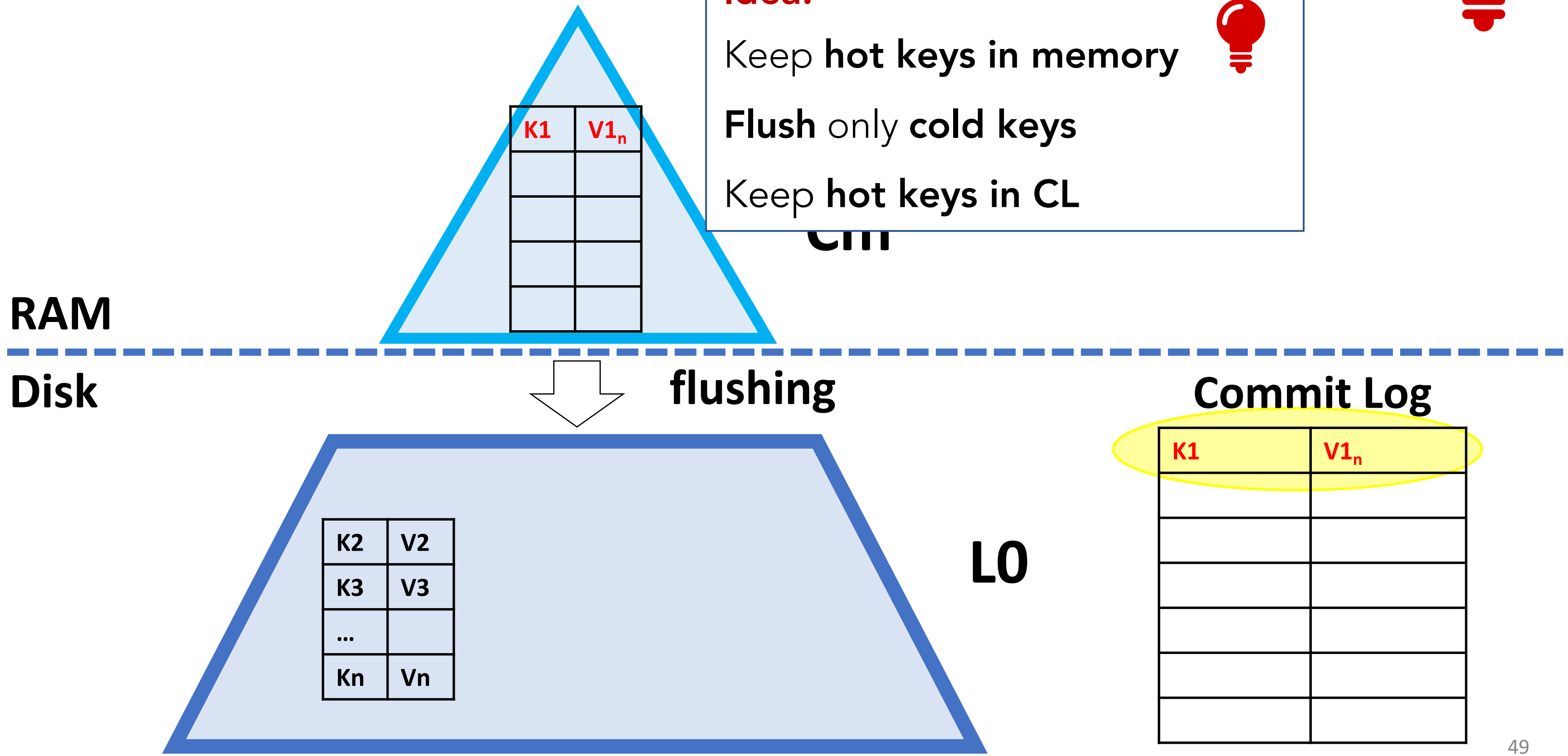
TRIAD-MEM: Hot-cold key separation

Idea:

Keep **hot keys in memory**

Flush only **cold keys**

Keep **hot keys in CL**



K1	$V1_n$

K2	V2
K3	V3
…	
Kn	Vn

K1	$V1_n$

TRIAD-MEM Summary

✓ **Good for skewed workloads.**

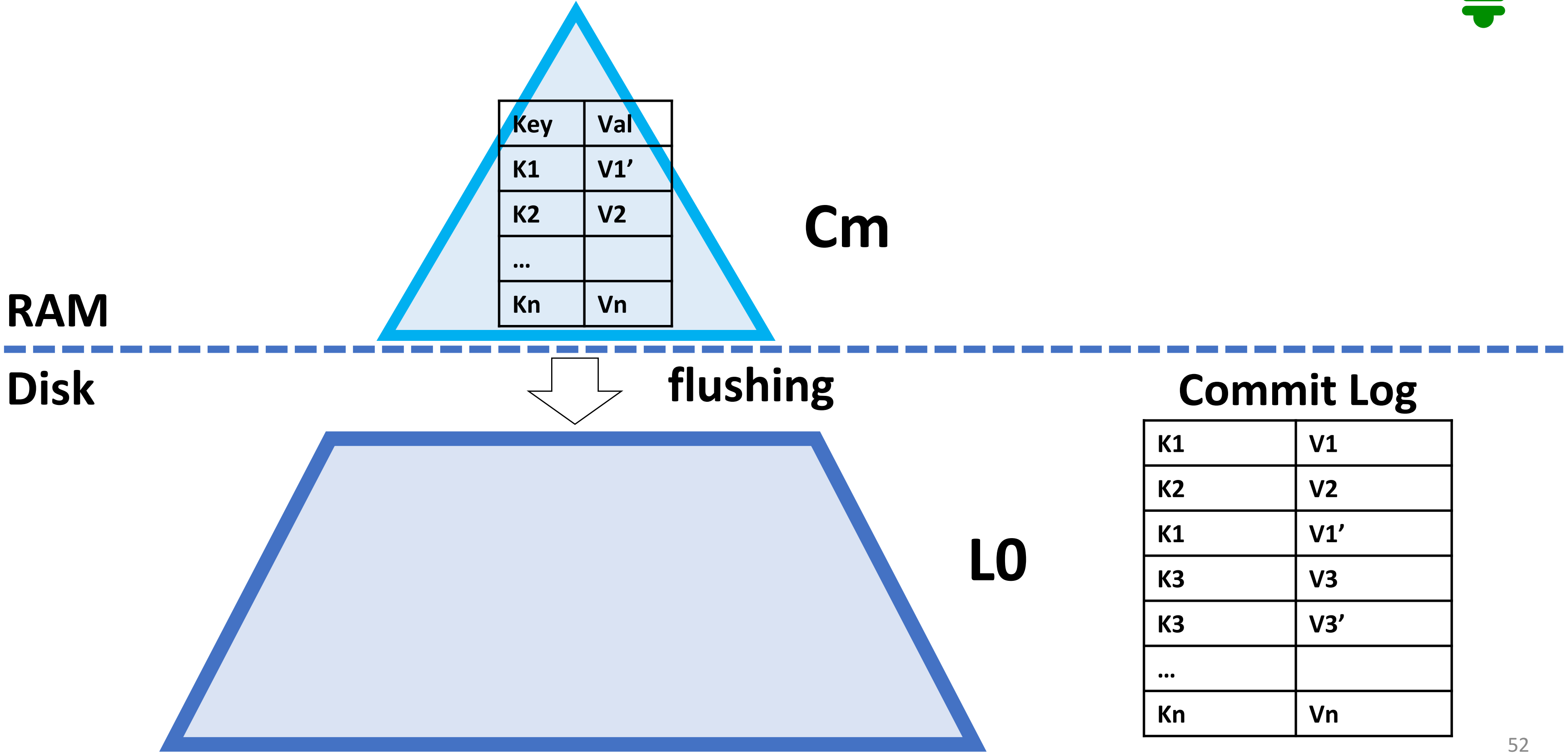
✓ **Reduce flushing WA: less data written from memory to disk.**

✓ **Reduce compaction WA: avoid repeatedly compacting hot keys.**

TRIAD-LOG

	Workload	Improve WA in
TRIAD-LOG	Uniform workloads	Flushing

Problem: Flushing with Uniform Workloads

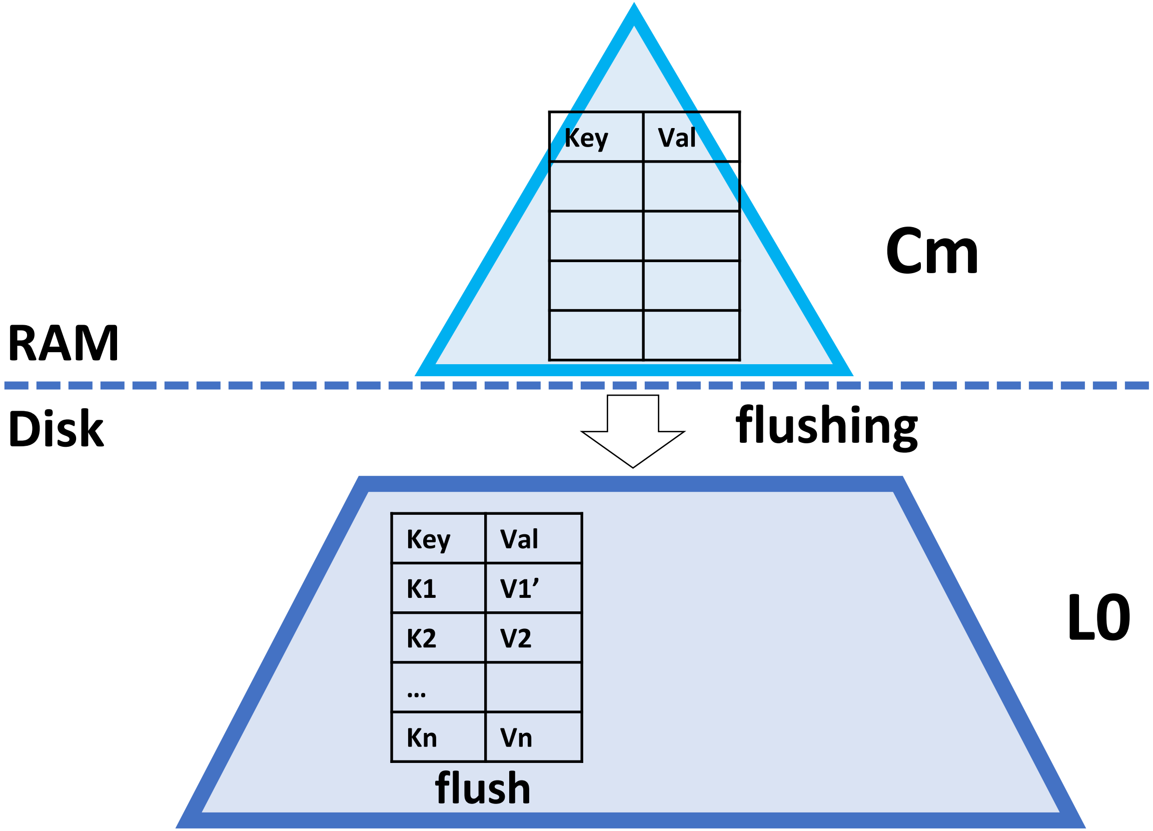


Key	Val
K1	V1’
K2	V2
…	
Kn	Vn

Commit Log

K1	V1
K2	V2
K1	V1’
K3	V3
K3	V3’
…	
Kn	Vn

Problem: Flushing with Uniform Workloads



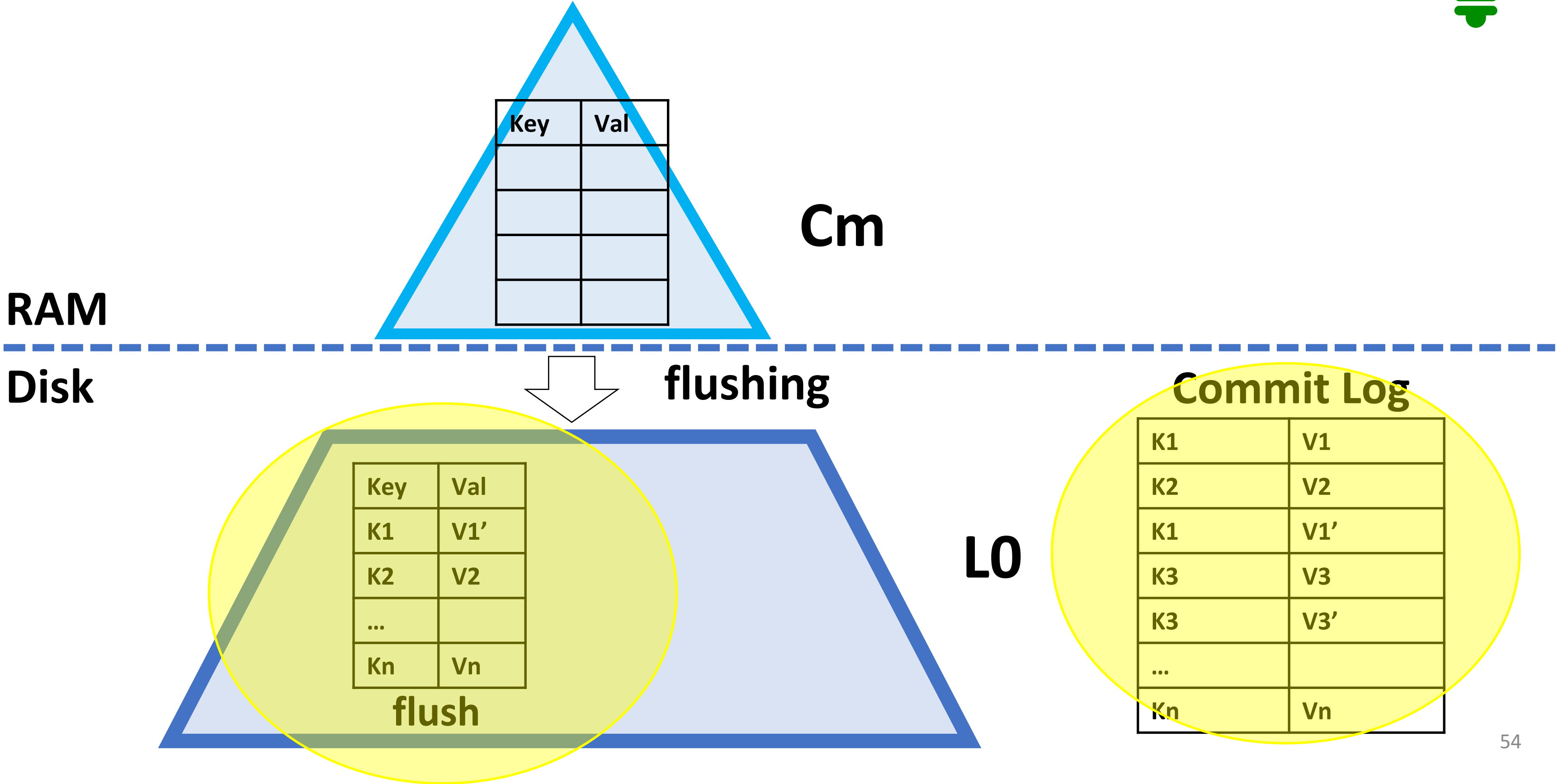
Key	Val

Key	Val
K1	V1’
K2	V2
…	
Kn	Vn

Commit Log

K1	V1
K2	V2
K1	V1’
K3	V3
K3	V3’
…	
Kn	Vn

Problem: Flushing with Uniform Workloads



Key	Val

Key	Val
K1	V1’
K2	V2
…	
Kn	Vn

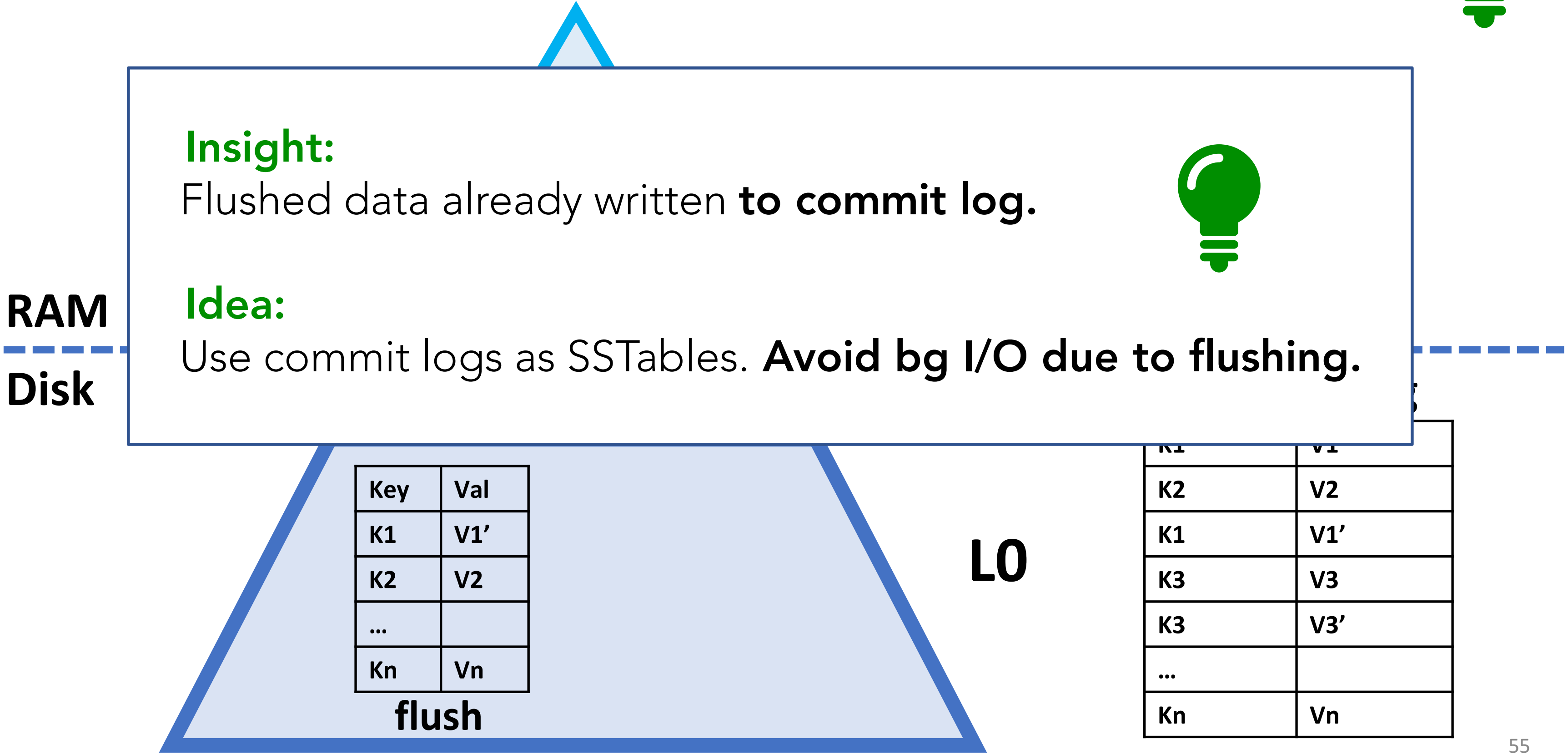
Commit Log

K1	V1
K2	V2
K1	V1’
K3	V3
K3	V3’
…	
Kn	Vn

Problem: Flushing with Uniform Workloads

Insight:
Flushed data already written **to commit log.**

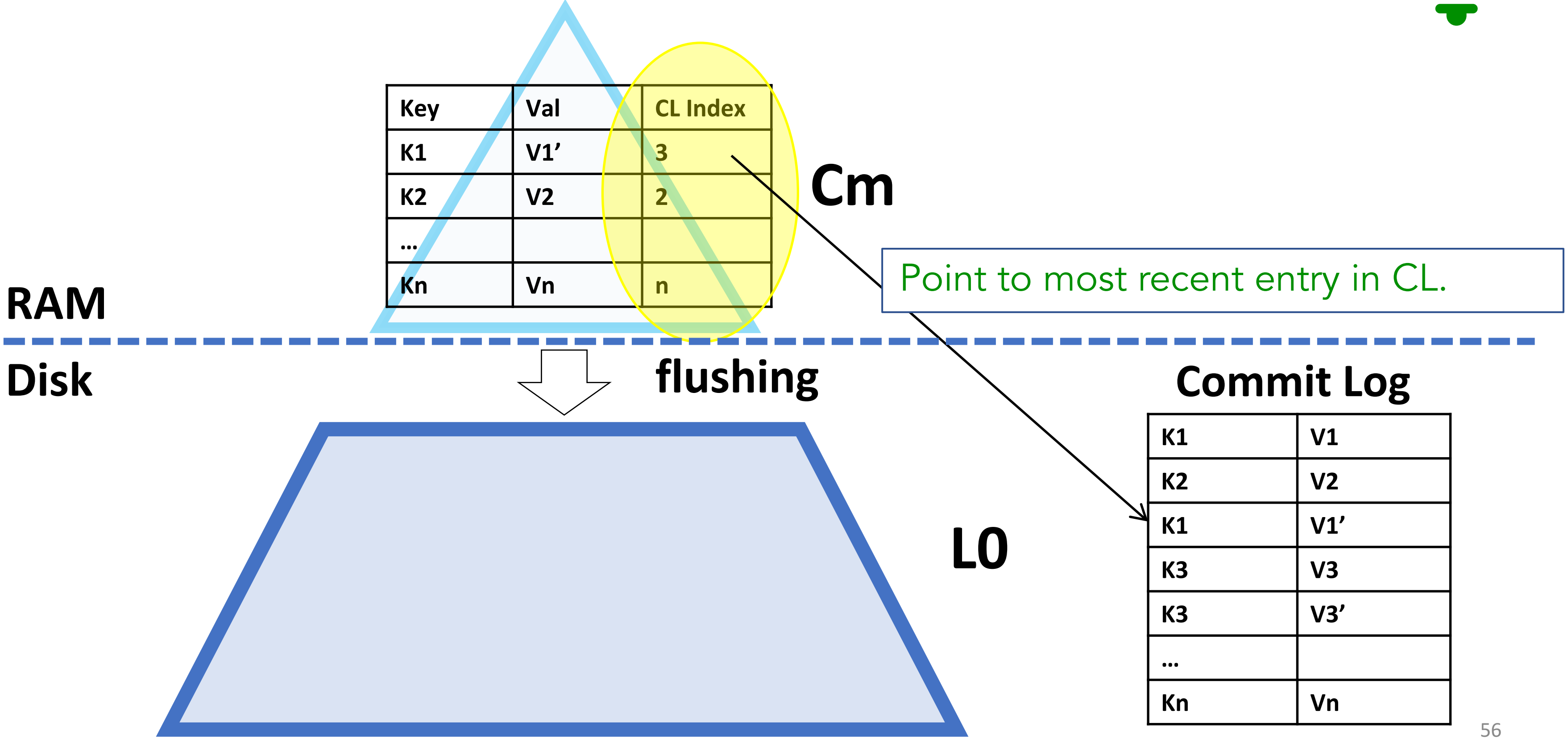
Idea:
Use commit logs as SSTables. **Avoid bg I/O due to flushing.**



Key	Val
K1	V1’
K2	V2
…	
Kn	Vn

K1	V1
K2	V2
K1	V1’
K3	V3
K3	V3’
…	
Kn	Vn

TRIAD-LOG



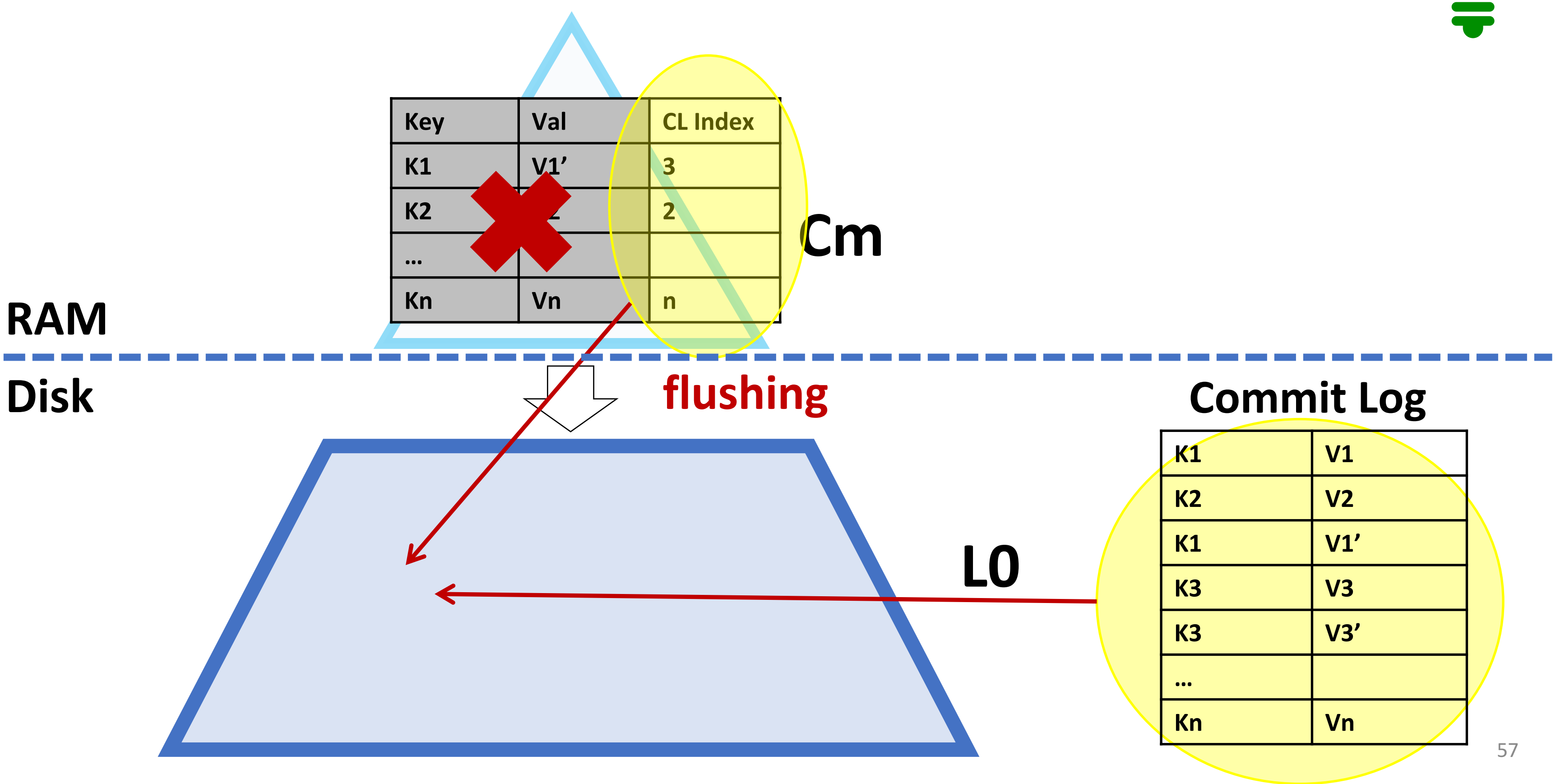
Key	Val	CL Index
K1	V1’	3
K2	V2	2
…		
Kn	Vn	n

Point to most recent entry in CL.

Commit Log

K1	V1
K2	V2
K1	V1’
K3	V3
K3	V3’
…	
Kn	Vn

TRIAD-LOG

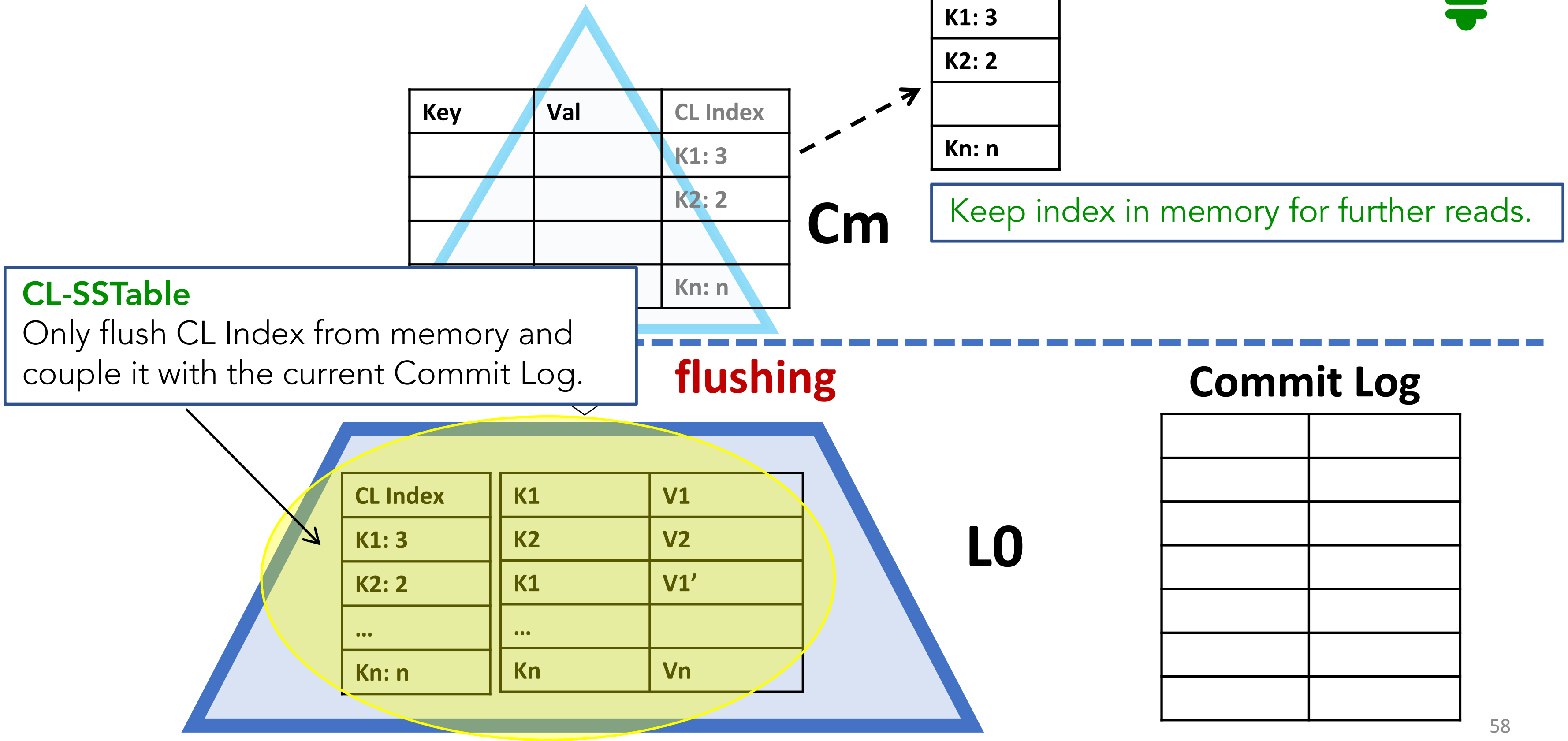


Key	Val	CL Index
K1	V1’	3
K2	2	2
…		
Kn	Vn	n

Commit Log

K1	V1
K2	V2
K1	V1’
K3	V3
K3	V3’
…	
Kn	Vn

TRIAD-LOG



Key	Val	CL Index
		K1: 3
		K2: 2
		Kn: n

CL Index
K1: 3
K2: 2
Kn: n

Keep index in memory for further reads.

CL-SSTable
Only flush CL Index from memory and couple it with the current Commit Log.

CL Index
K1: 3
K2: 2
…
Kn: n

K1	V1
K2	V2
K1	V1’
…	
Kn	Vn

Commit Log

TRIAD-LOG Summary

- ✓ **Good for uniform workloads.**
- ✓ **Reuse Commit Log as L0 SST.**
- ✓ **No more flushing of mem component to disk.**

TRIAD Summary

TRIAD-MEM, TRIAD-DISK, TRIAD-LOG:

- **Complementary**, targeting different wklds.
- Working **simultaneously**.
- **Transparent** to the workloads; no a priori knowledge needed.

Evaluation

Evaluation

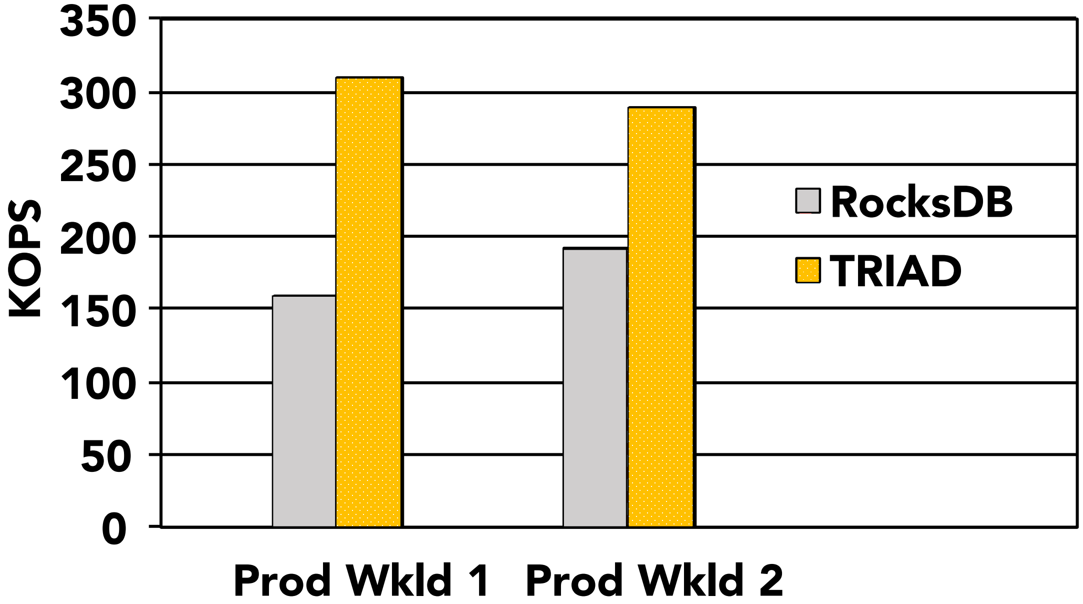
- **Compare TRIAD with RocksDB**
- **Workloads:** Production, Synthetic
- **Metrics:** Throughput, Write Amplification (WA)
- **Code:** `https://github.com/epfl-labos/TRIAD`

Write Amplification (WA)

$$\text{WA} = \frac{\text{total data written to storage}}{\text{data written by app}}$$

Production Workloads: Throughput

higher
is better

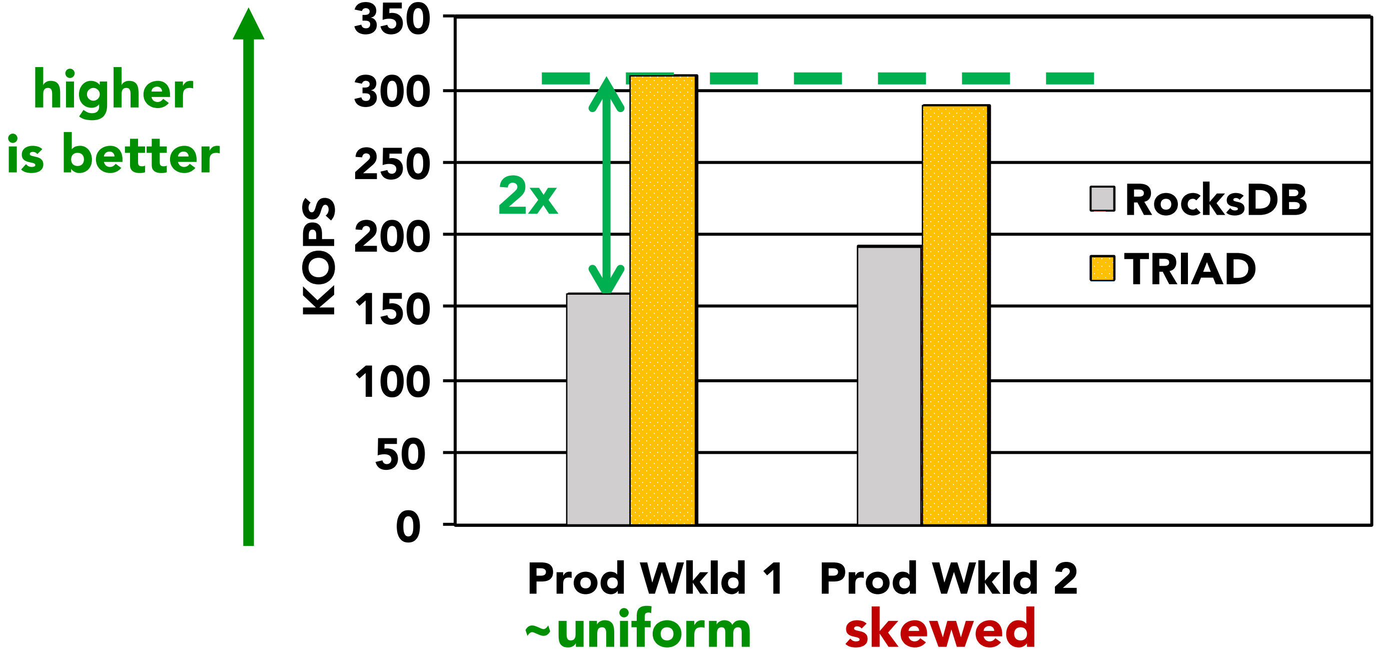


~uniform

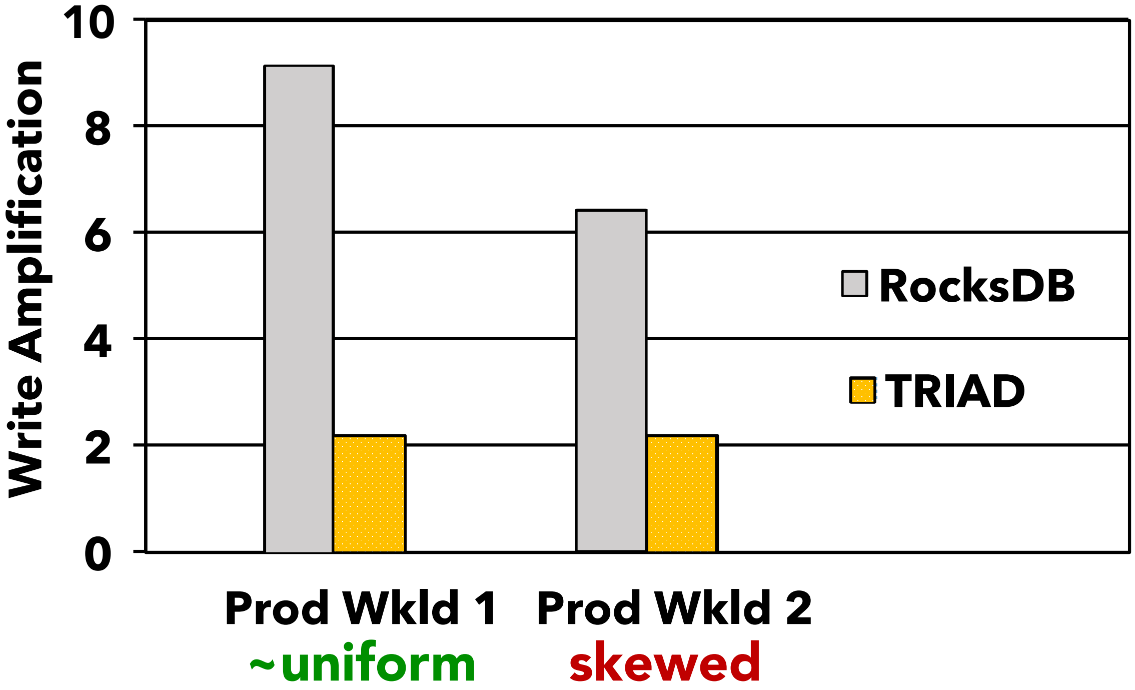
skewed

Production Workloads: Throughput

TRIAD: stable throughput across wklds.

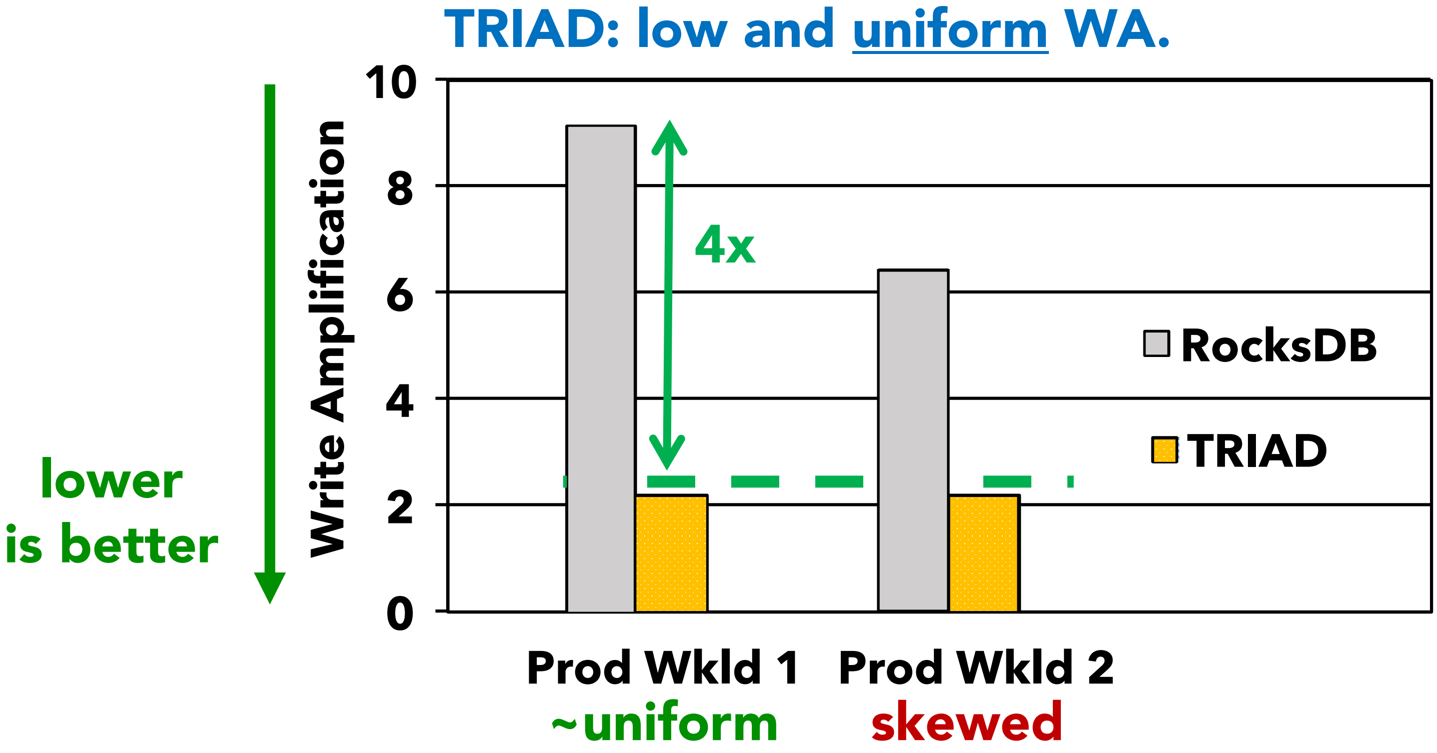


Production Workloads: Write Amplification



lower is better

Production Workloads: Write Amplification



TRIAD: Throughput Breakdown Synthetic Workloads

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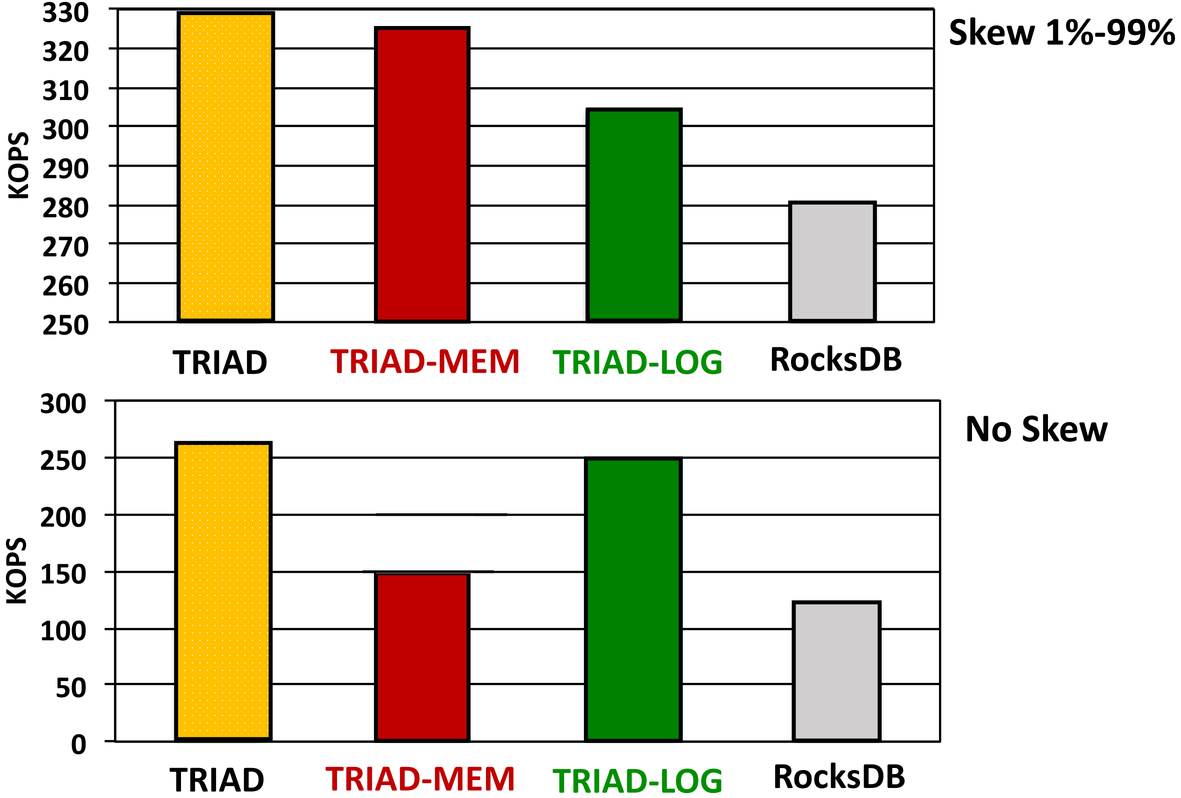

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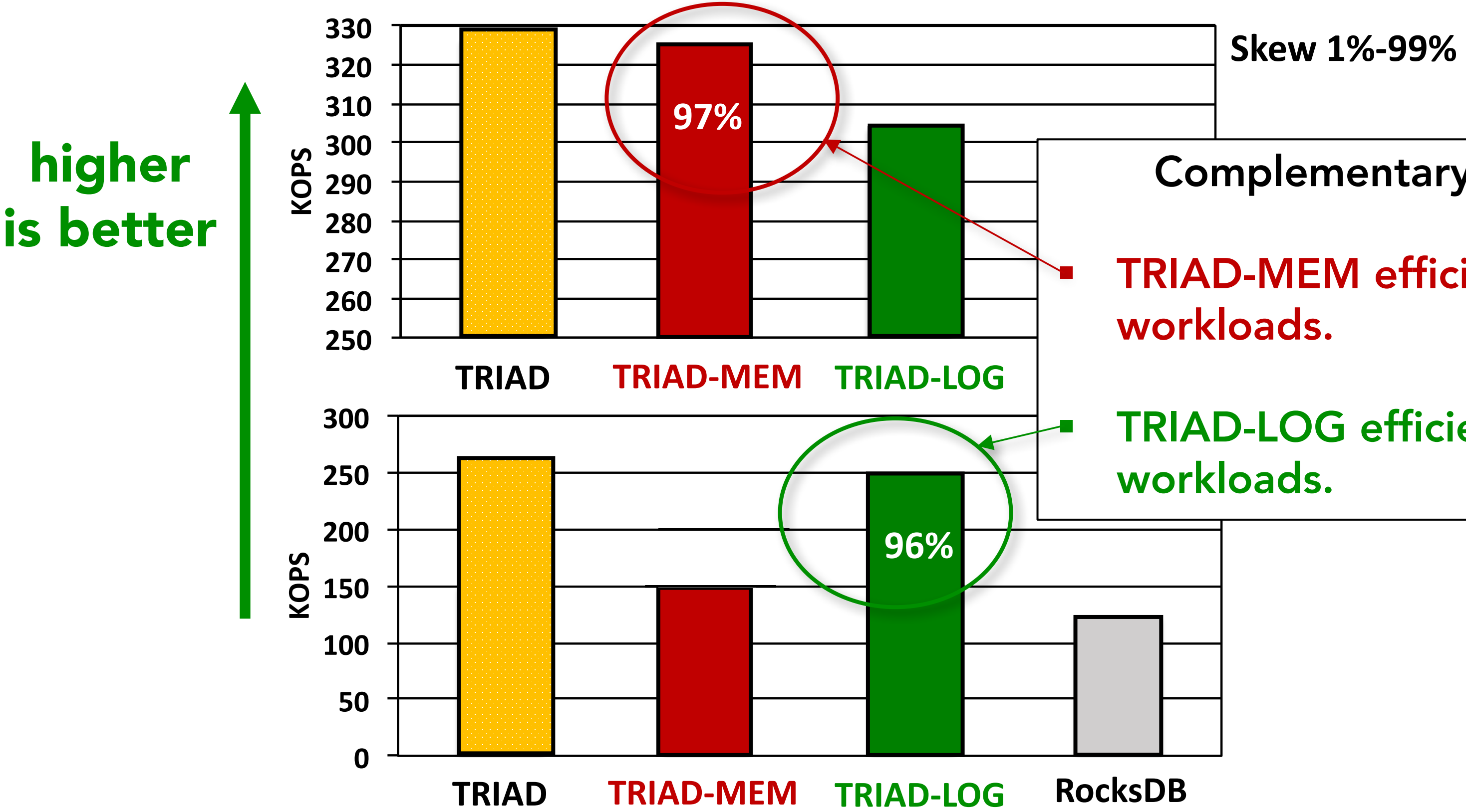

Complementary techniques

- TRIAD-MEM efficient for skewed workloads.
- TRIAD-LOG efficient for uniform workloads.

More in Our Paper

- More production workloads
- More synthetic workloads
- Detailed breakdown of TRIAD techniques
- TRIAD-DISK

Related work

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- Hot/cold key separation idea used in different context.
  - **FLASH storage systems:** dual-pool algorithm (SAC '07), Application-Managed Flash (FAST '16)

Take-home Messages

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✓ **Impact of LSM I/O on user throughput reduced.**