The Dangers and Complexities of SQLite Benchmarking

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SQLite

Benchmarking SQLite is Non-trivial !

- Benchmarking complex systems in a repeatable fashion is error prone
- The main issues with benchmarking :
  - Inconsistency in the industrial benchmarking tools
  - Incorrect reporting of benchmarking results

- Benchmarking SQLite is hard
- Depends on several configuration parameters
- Current tools provide conflicting results(3X) for the same set of parameters
- Easy to show **conflicting results** by tuning parameters
- Right configuration can provide massive **performance gains(28X)**

Outline

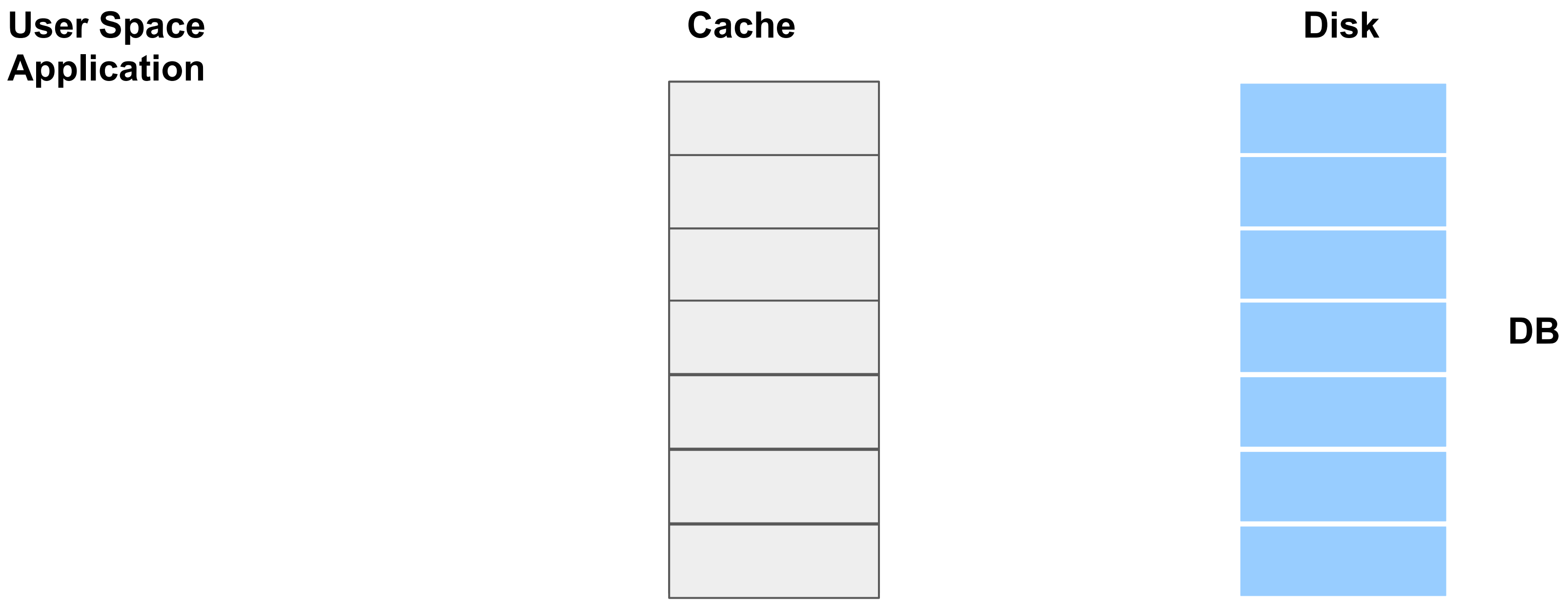
- Overview of SQLite
- Motivation
- Existing tools to benchmark SQLite
- Parameters affecting performance of SQLite
- Conclusion

SQLite

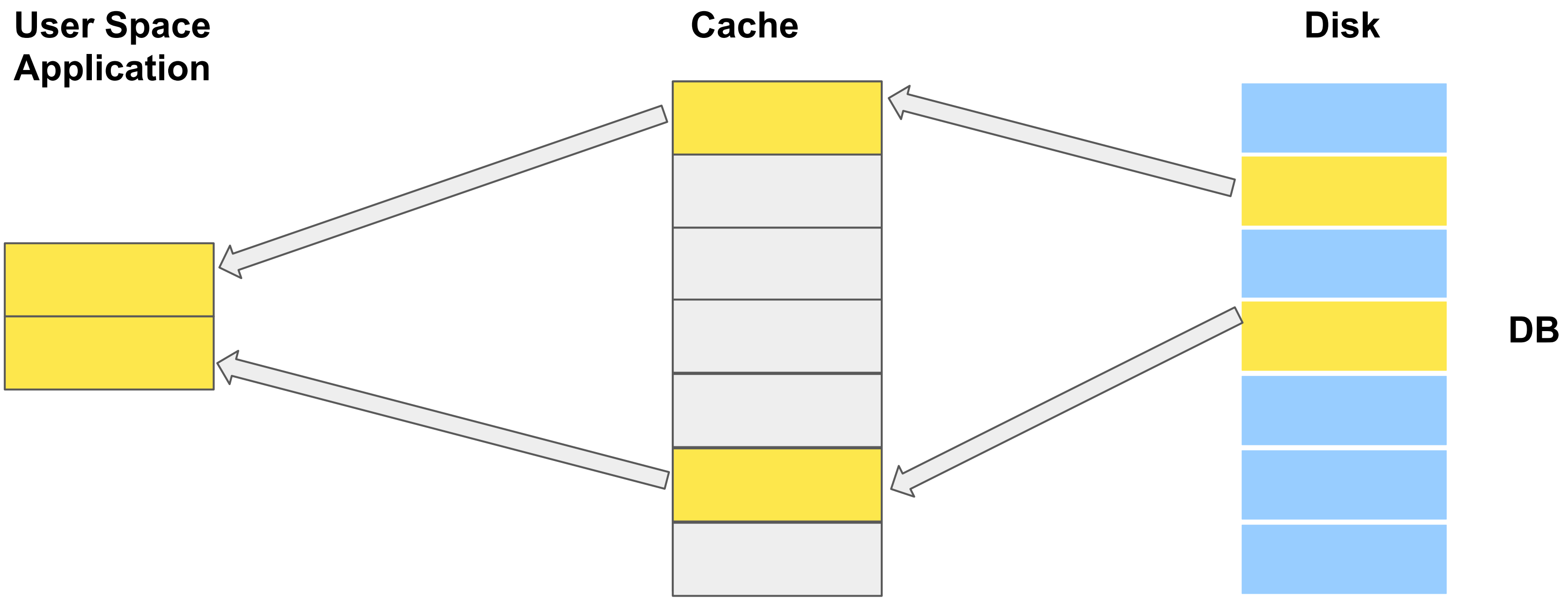
- Lightweight, embedded, relational database popular in mobile systems
- Commonly used benchmark in many mobile applications to store their data
  - E.g. Twitter and Facebook
- Used as a benchmark for evaluating several systems
  - E.g. I/O scheduling frameworks (Yang et.al., SOSP '15), the Linux read-ahead mechanism (Olivier et.al., SIGBED '15)

Benchmarking SQLite is an important part of evaluating these systems.

SQLite architecture



SQLite architecture



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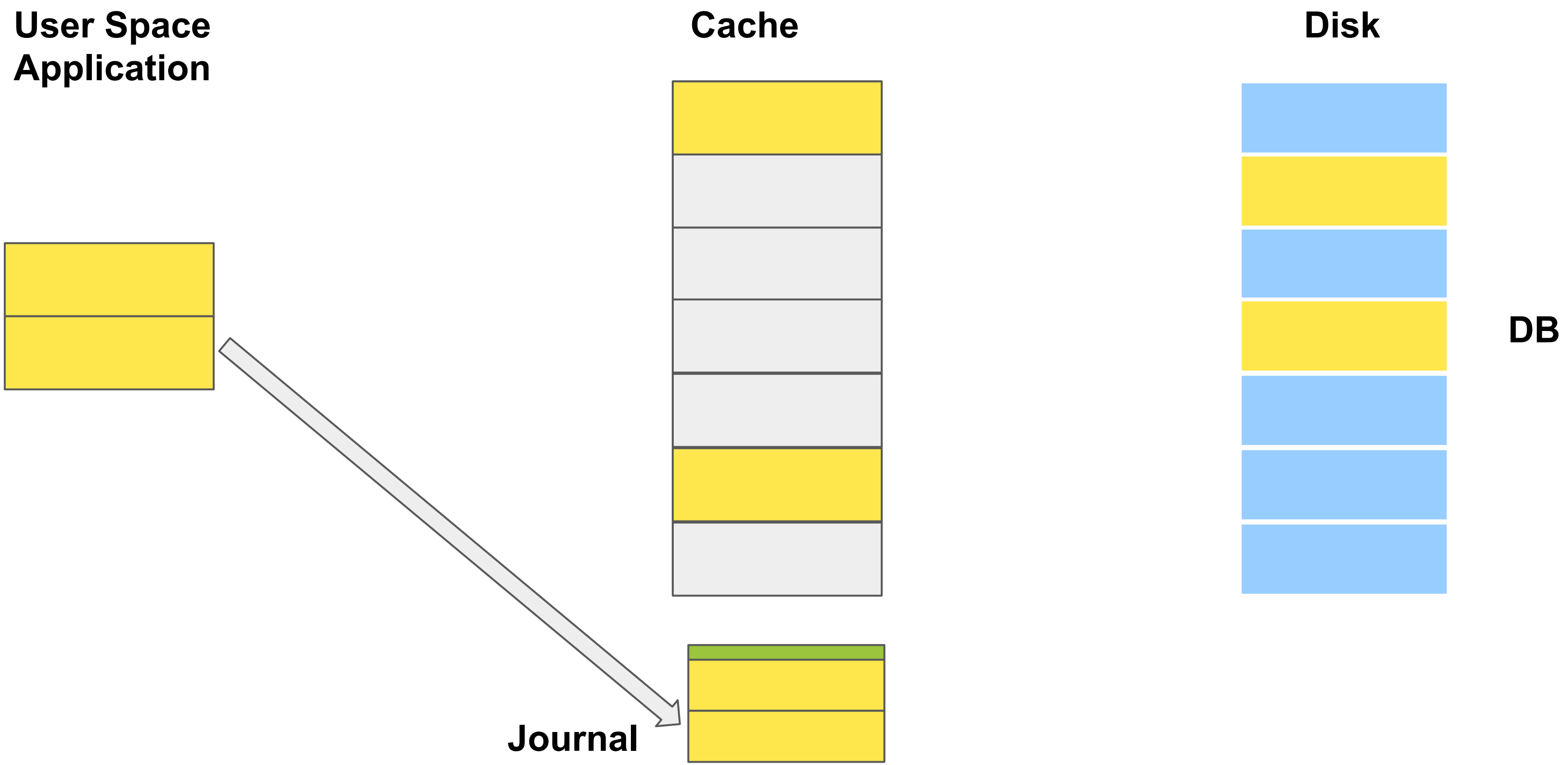

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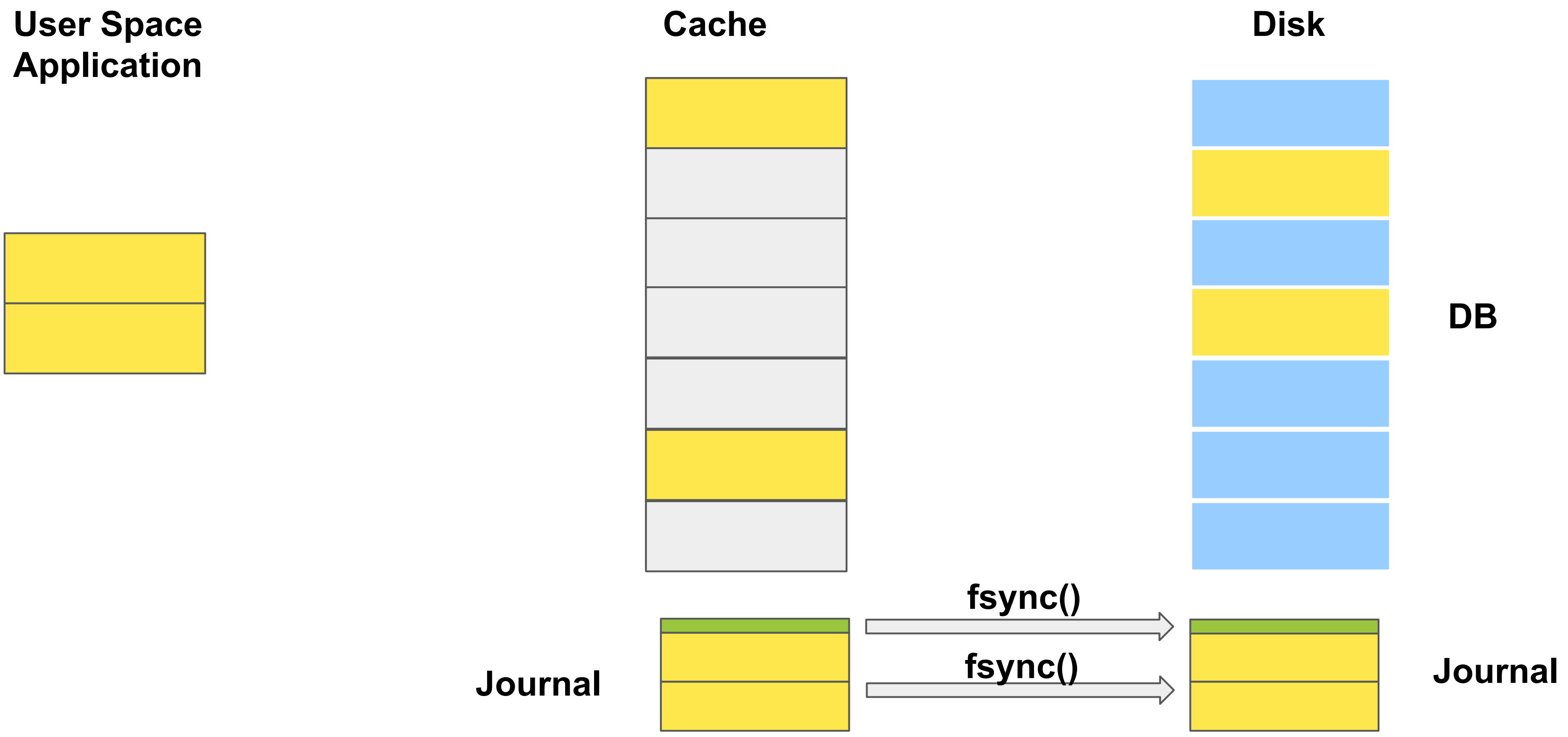

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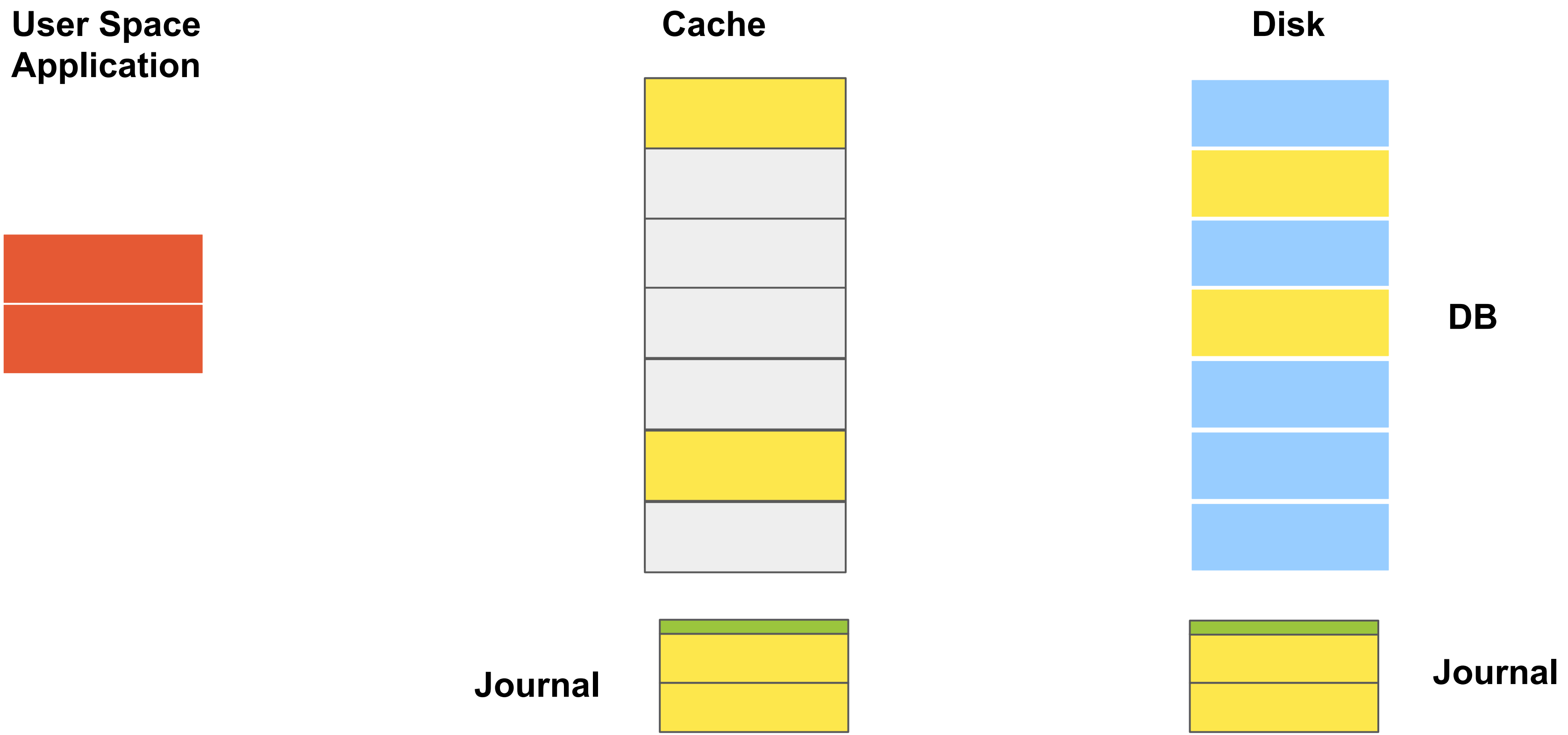

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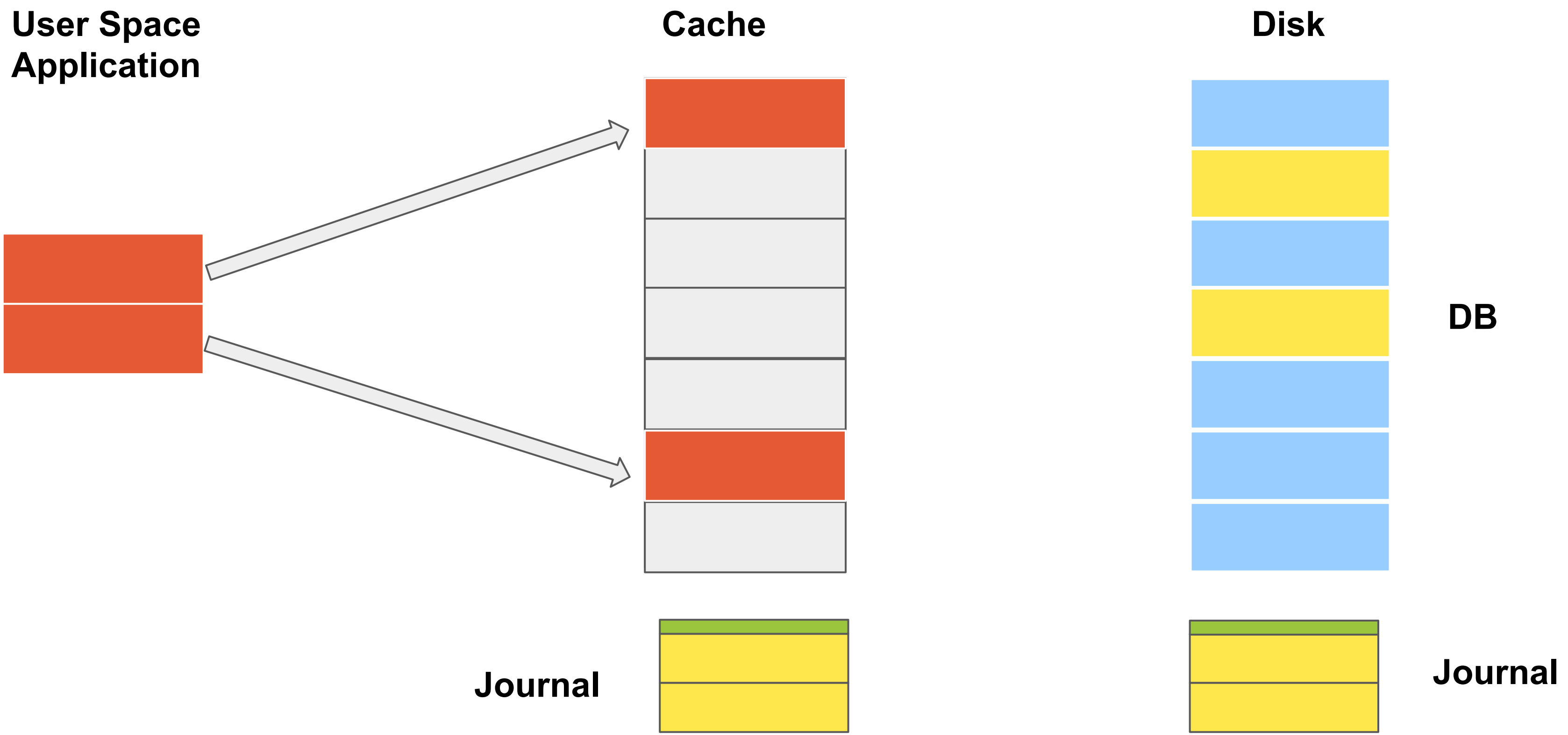

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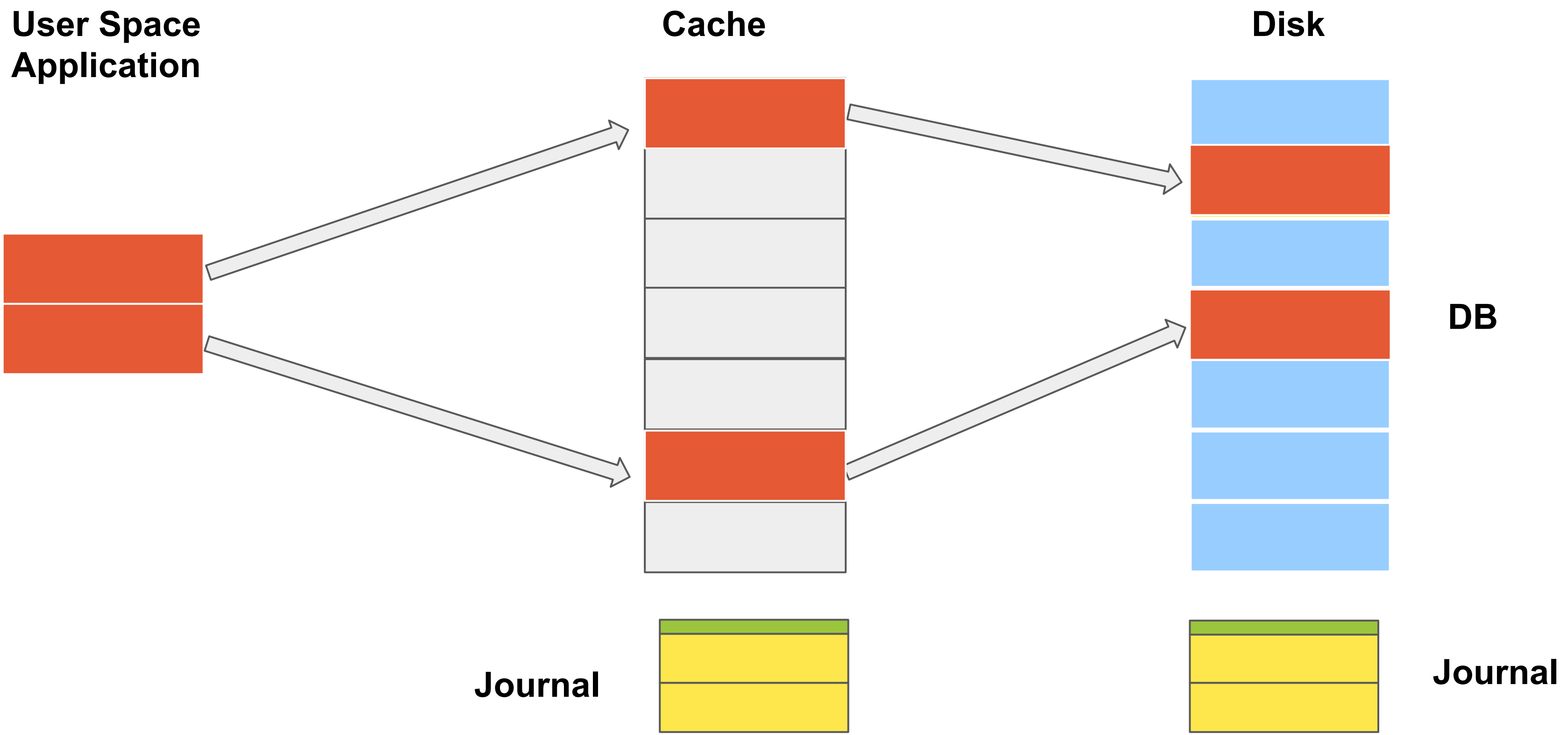

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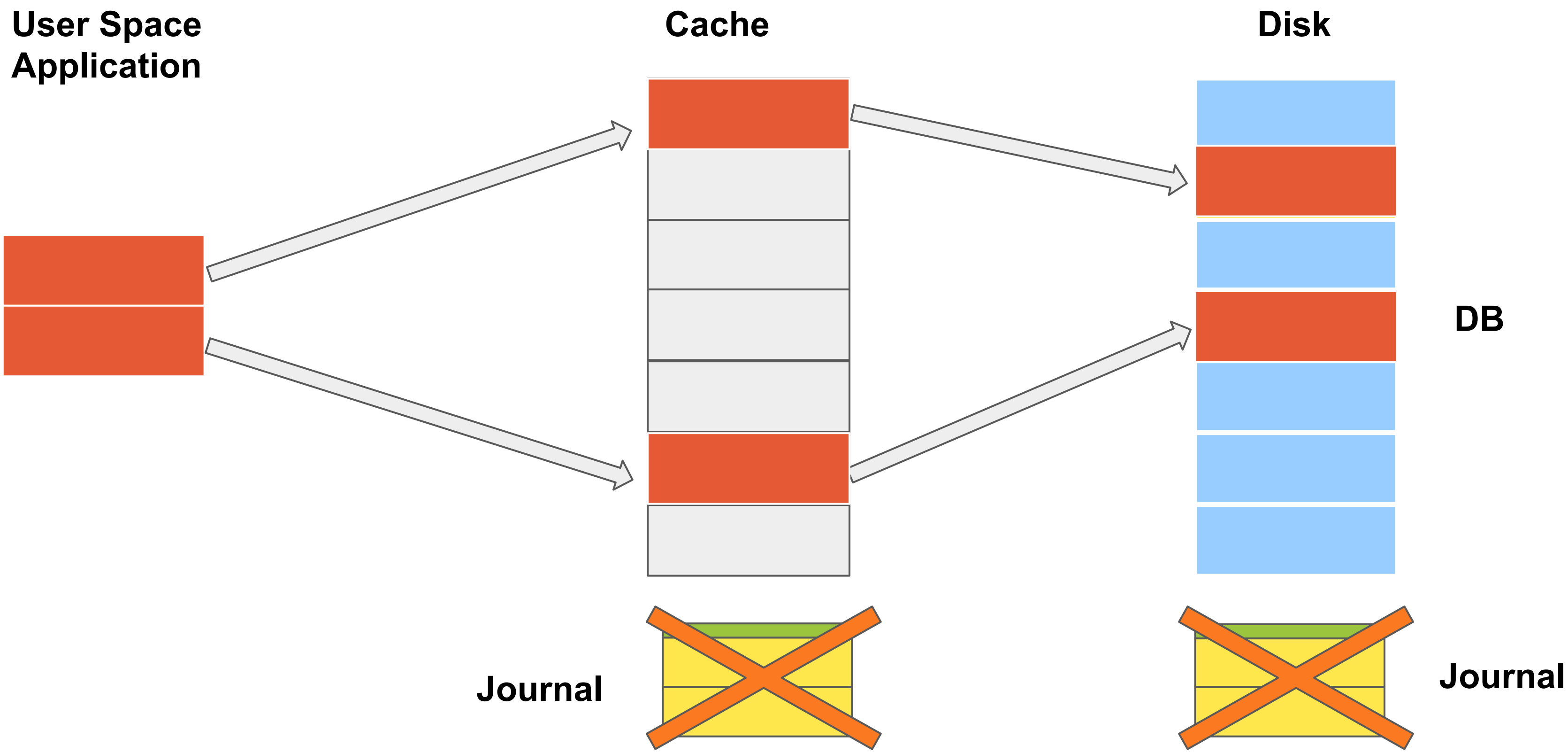

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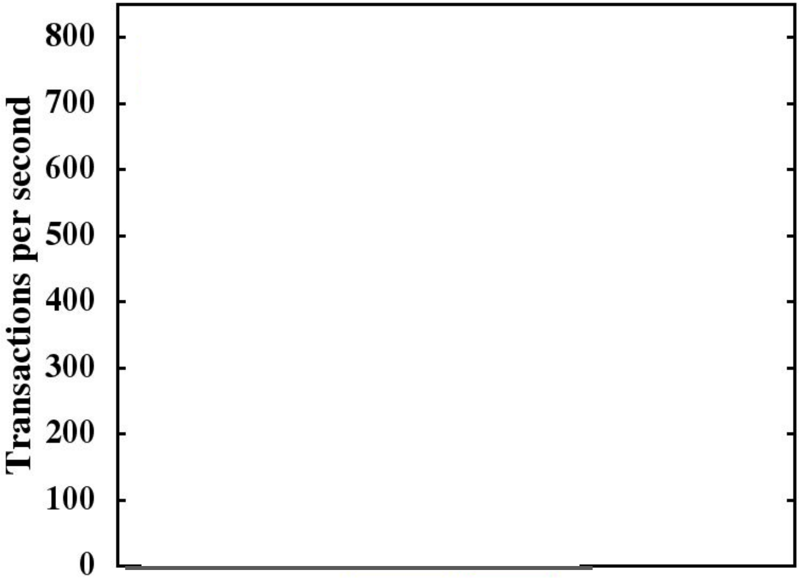
Motivation : A Case Study of SQLite

Benchmarking SQLite is tricky - It’s performance varies greatly based on configuration parameters.



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- ➢ **Workload: 1 trial = ** 30K transactions (10 K inserts, followed by updates and deletes of 10K)

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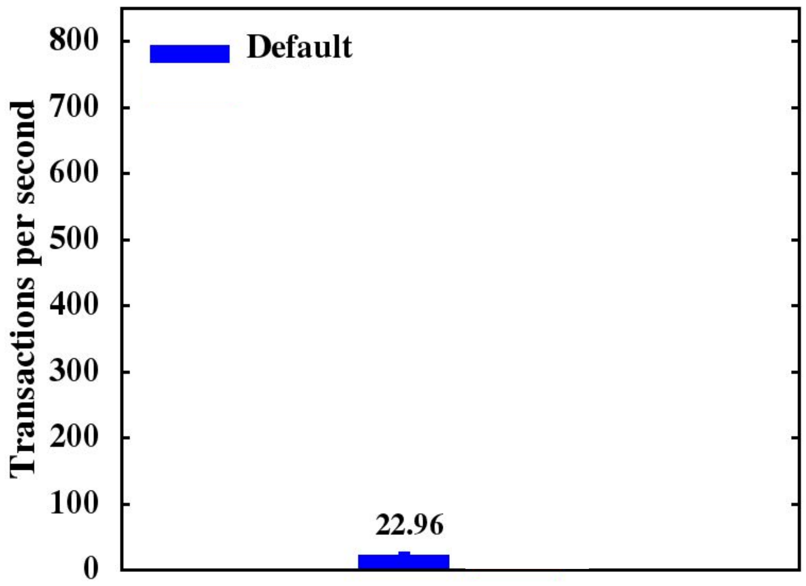

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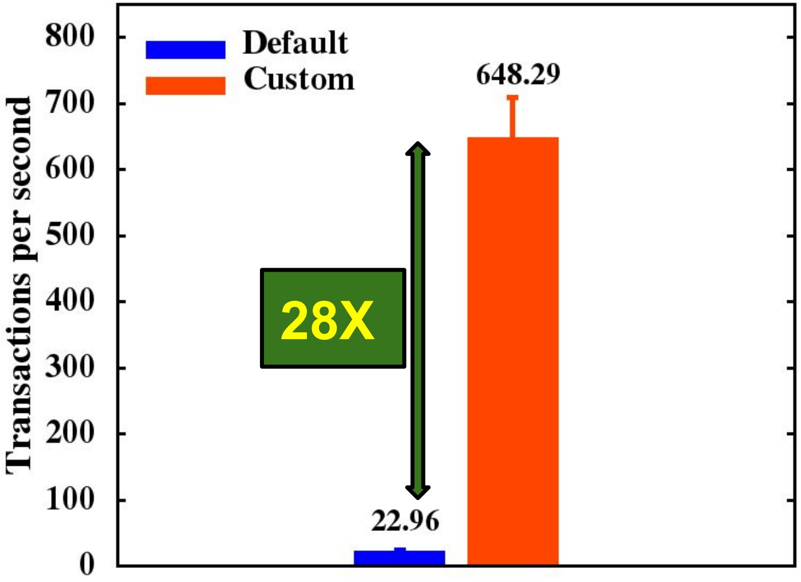

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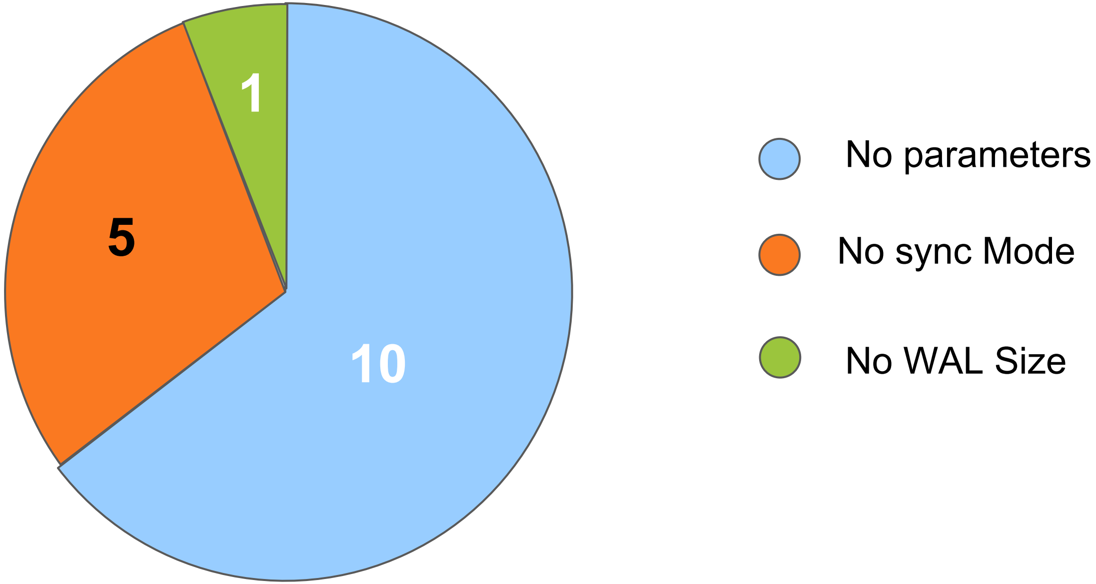
Are we reporting it right?

Incomplete specification of benchmarking results

- 16 papers from the past couple of years, used SQLite to evaluate performance.



NONE of them reported all the parameters required to meaningfully compare results.

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Inconsistency in existing benchmarking tools

Tool	Default TPS	Custom TPS	Papers that use
MobiBench	20	57	7
RL Bench	30	-	4
AndroBench	29	150	3

- Results between the tools differ by **50%** in their default setting
- Differ by 3X when a single parameter is changed.

Misleading and meaningless to compare, if parameters are not reported!

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Parameters affecting SQLite Performance

1. Filesystem
2. Journaling Mode
3. Pre-population of database
4. Synchronization Mode
5. Journal Size

Hardware Setup for experimentation

- Experiments performed on Samsung Galaxy Nexus S on 32GB internal storage.
- Controlled experimental setup : Vary one parameter, while keeping all others constant.

Workload

- 1 trial = 3000 transactions (1000 inserts, followed by 1000 updates and 1000 deletes)
- Database prepopulated with 100K rows.
- Results reported as throughput (transactions/sec)
- Default Configuration :
  - DELETE journal mode
  - FULL synchronization mode
  - Ext4 filesystem in ordered mode.

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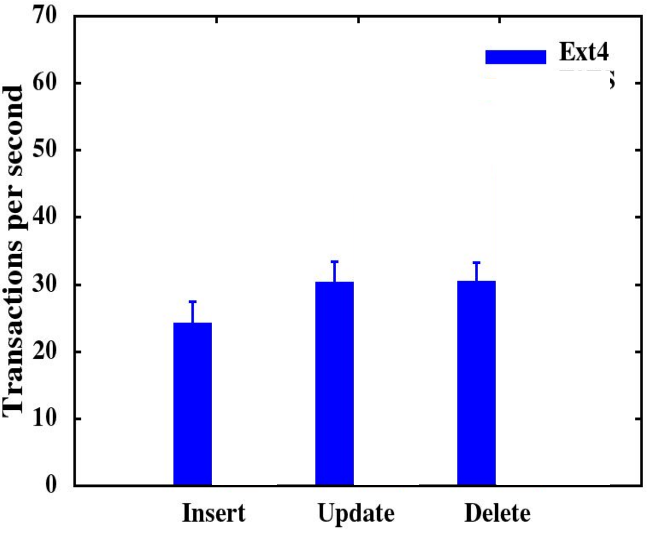
1. Filesystem

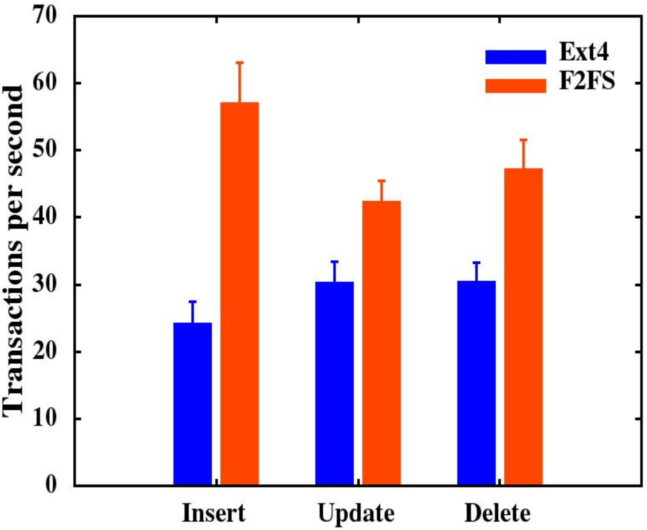
- Application writes are transformed into block level operations by filesystem.

1. Filesystem



DELETE - Normal

1. Filesystem



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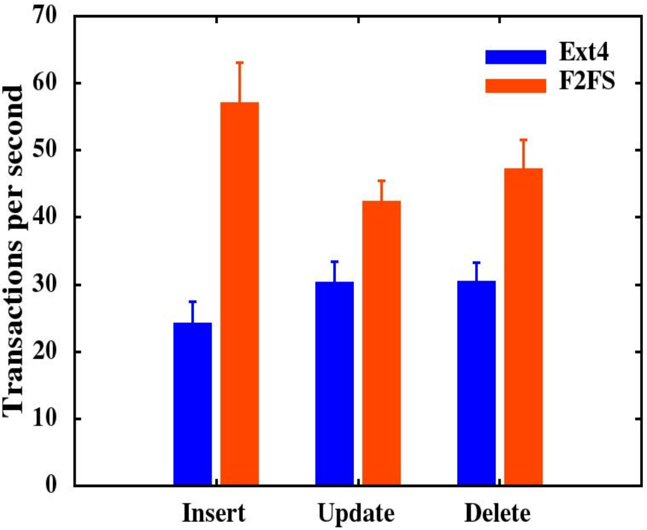

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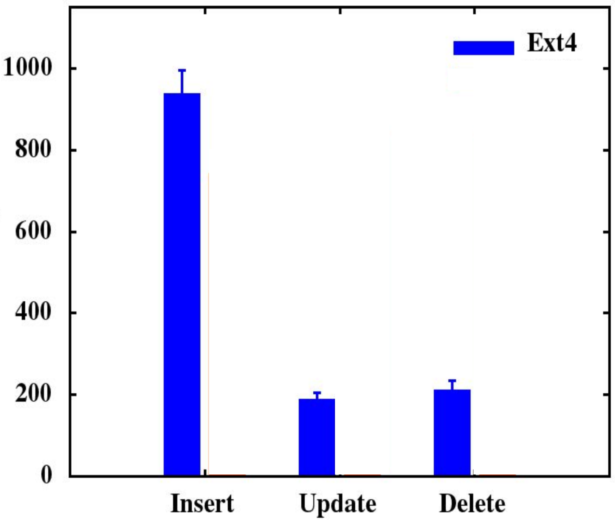

WAL - Normal

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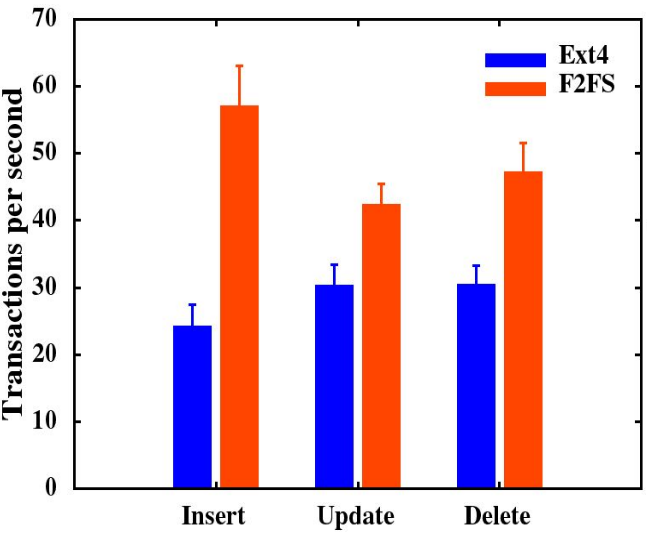

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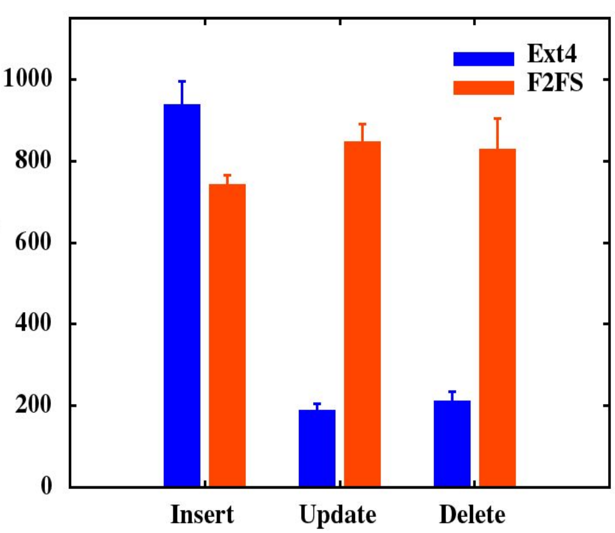

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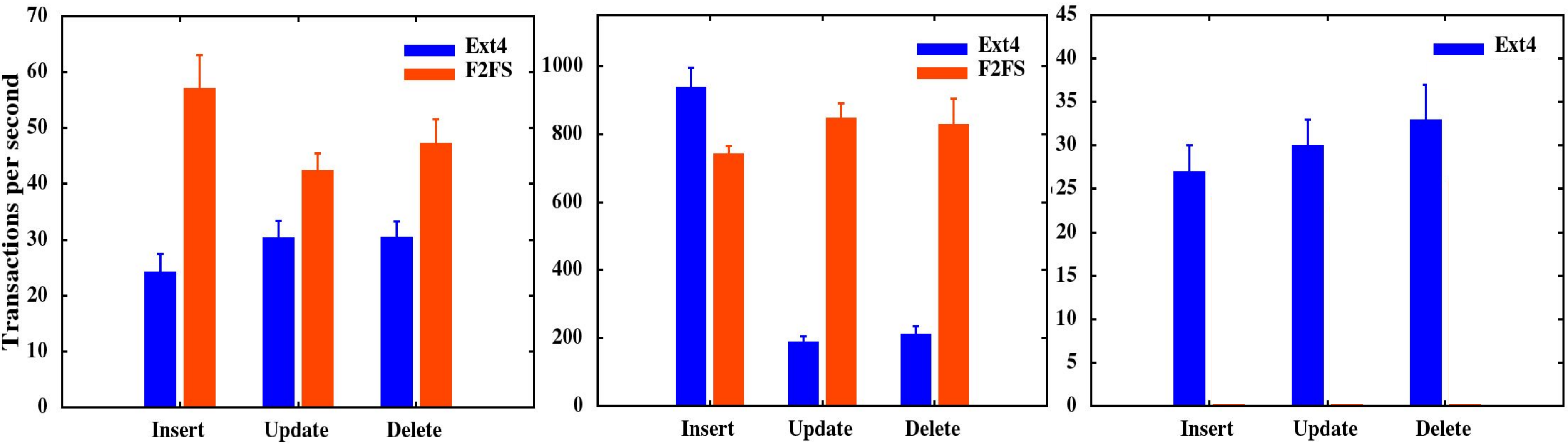
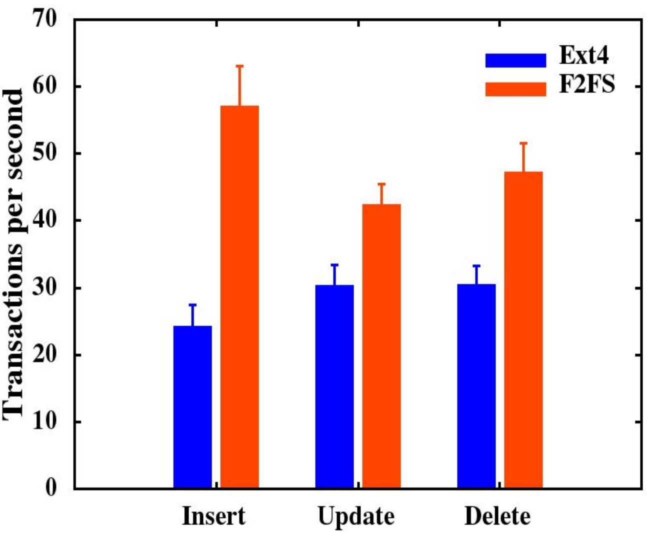


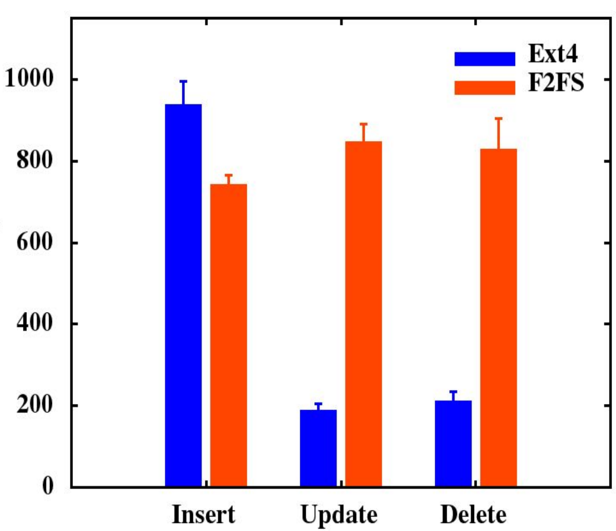
DELETE - Normal | WAL - Normal | DELETE - FULL

1. Filesystem

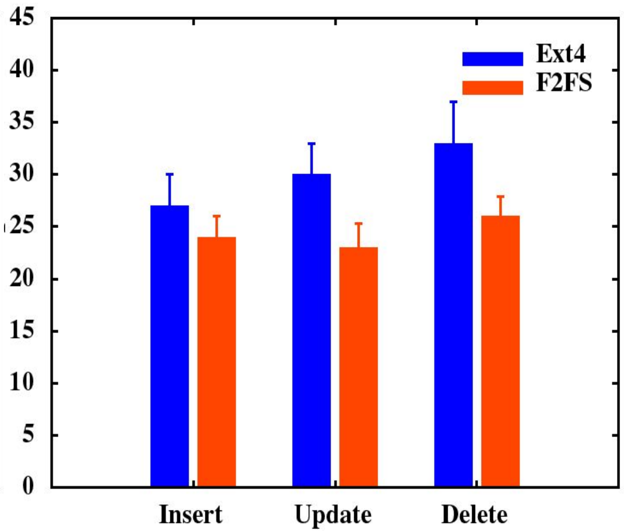
- Depending on the parameters chosen, we can show either one performing better.
- F2fs paper evaluates only WAL mode : claims better performance than ext4.



DELETE - Normal



WAL - Normal



DELETE - FULL

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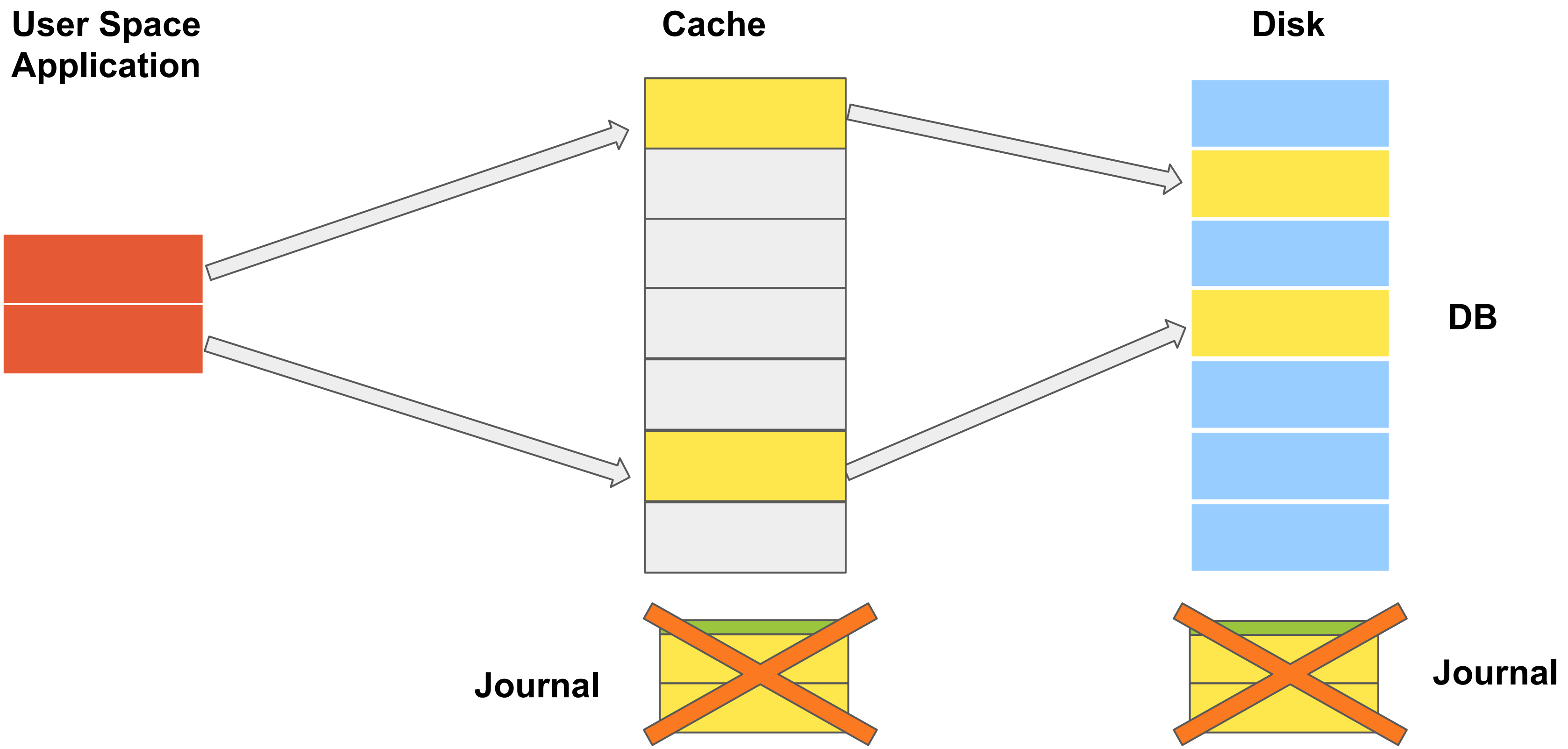
2. Journaling mode

- Defines the type of SQLite journal used.
    - DELETE : Default mode
        - Uses traditional rollback journaling mechanism: contents of the database is written on to the journal and the changes are written to the database file directly.

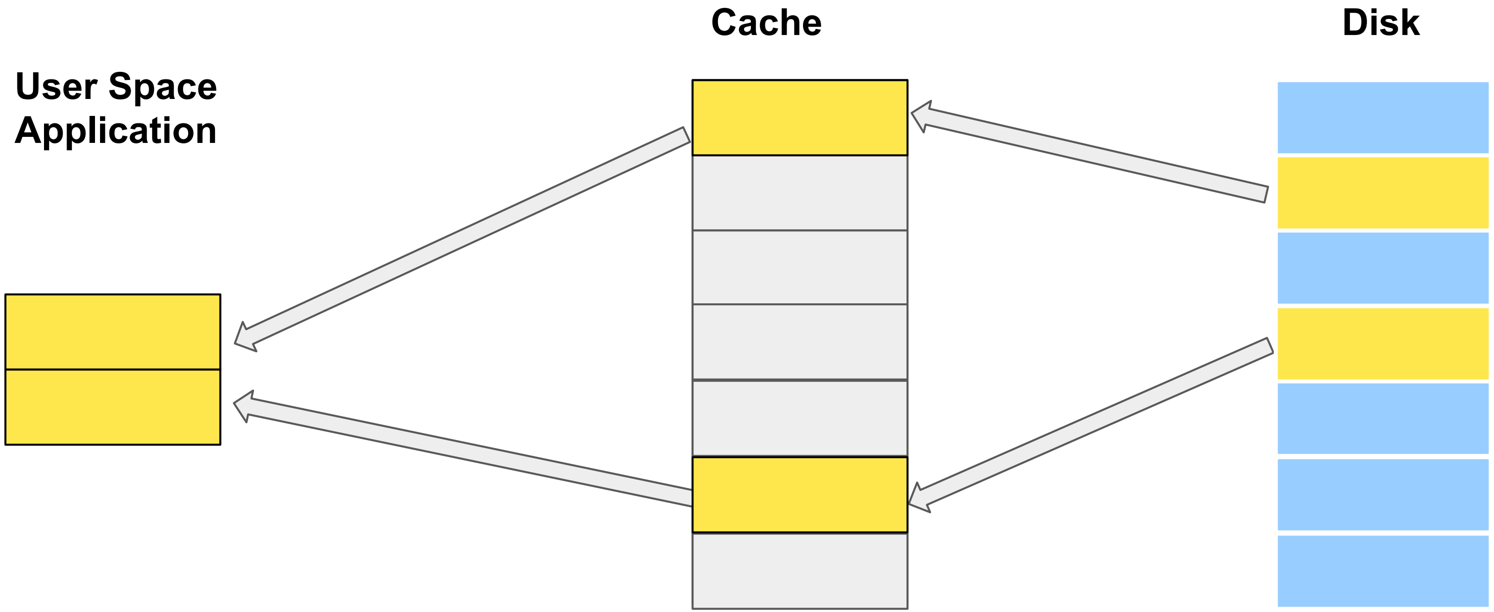
DELETE Journal mode revisited



2. Journaling mode

- Defines the type of SQLite journal used.
  - DELETE : Default mode
    - Uses traditional rollback journaling mechanism: contents of the database is written on to the journal and the changes are written to the database file directly.
  - WAL :
    - Write-ahead log, in which the changes to the database are written to the journal and is committed to the database when user explicitly triggers it.

WAL journal mode



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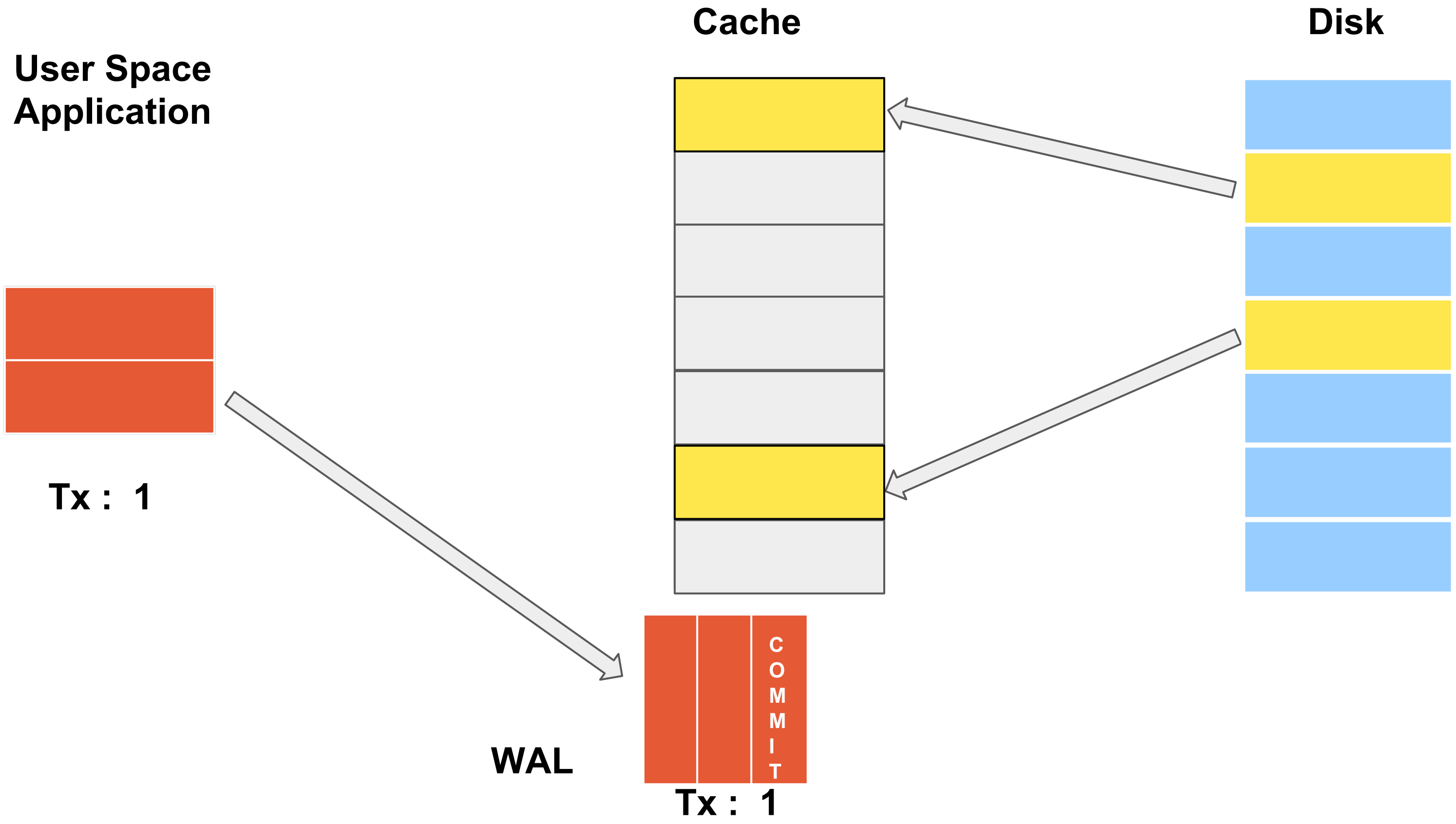

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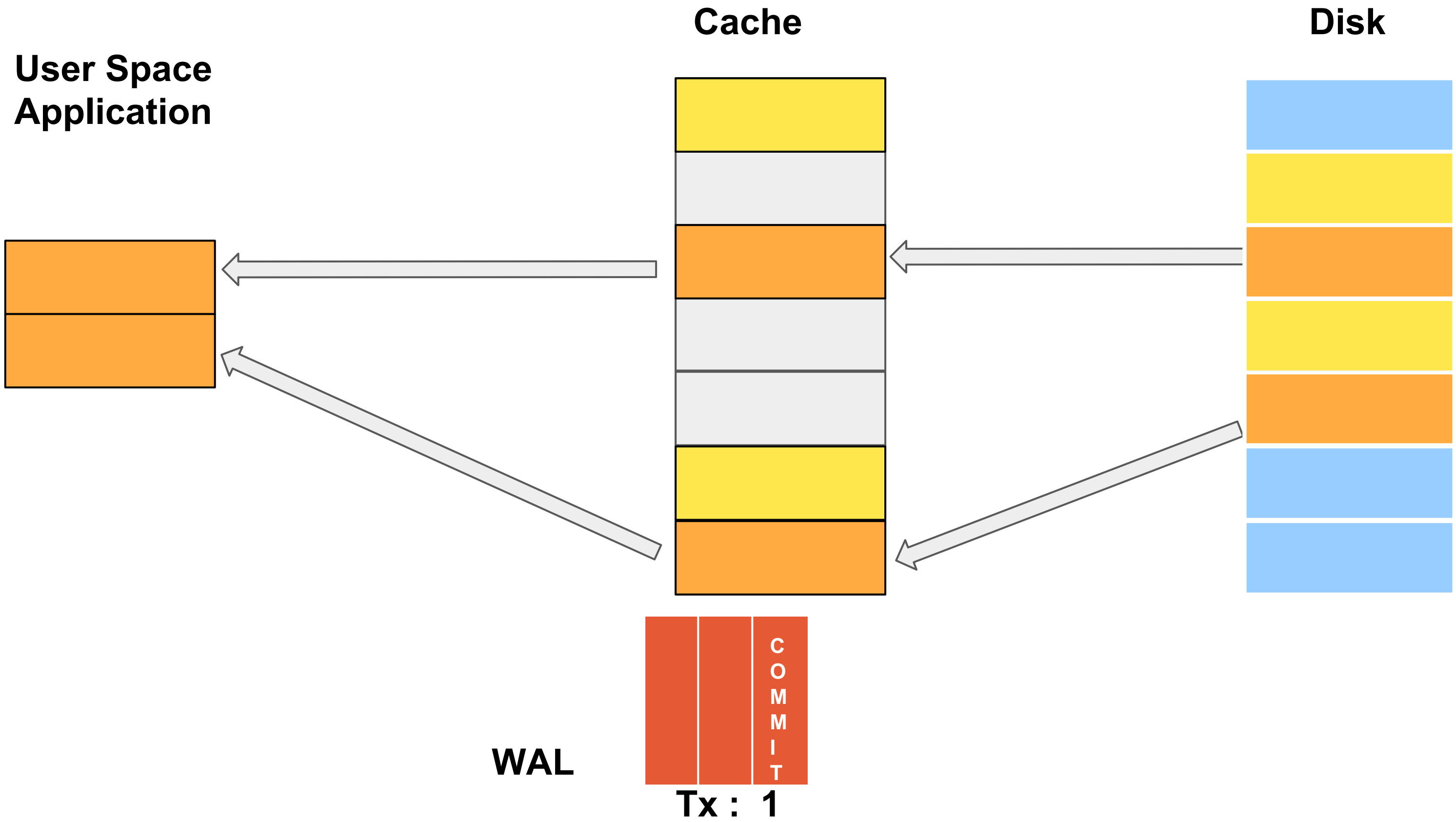

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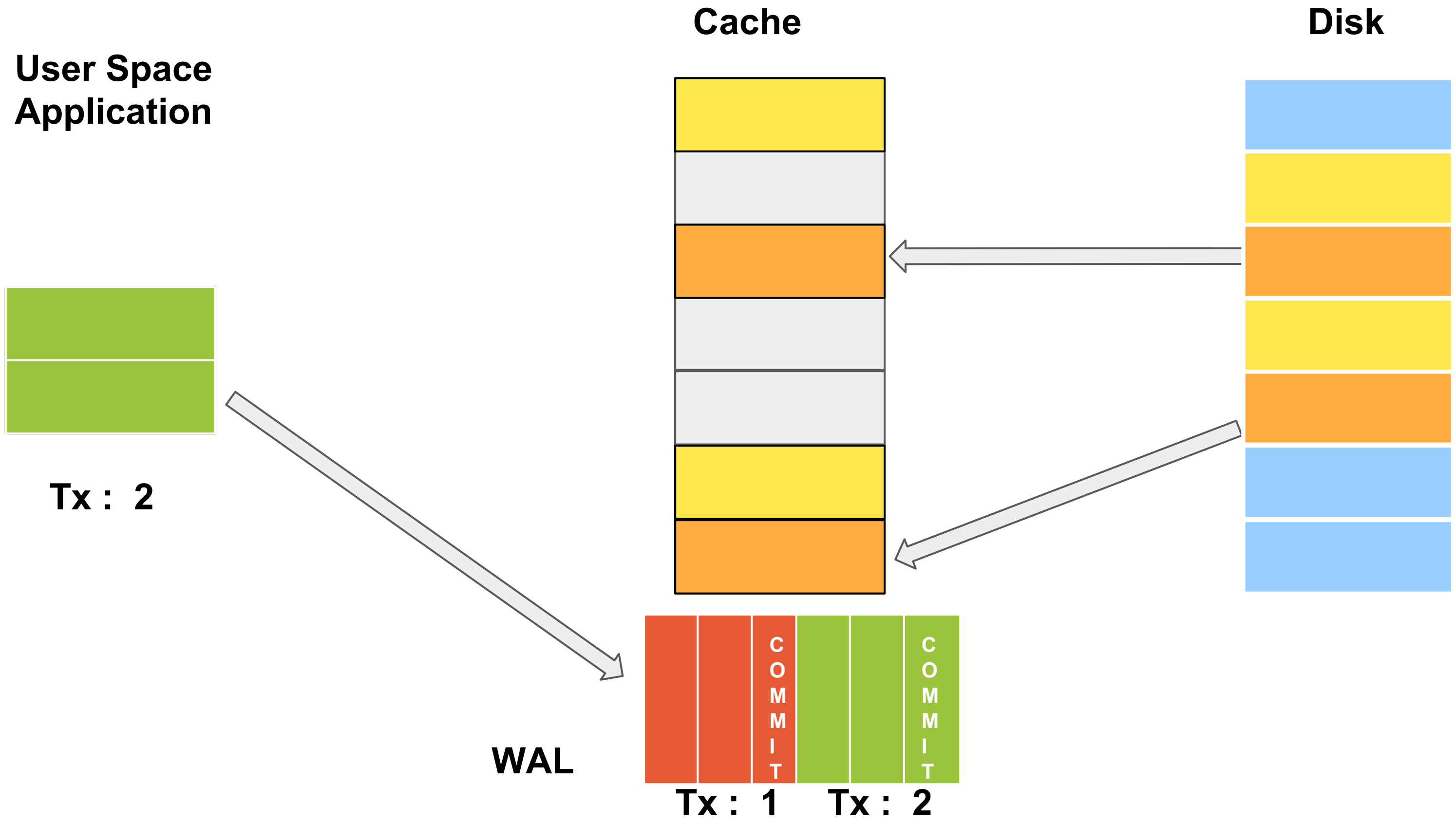
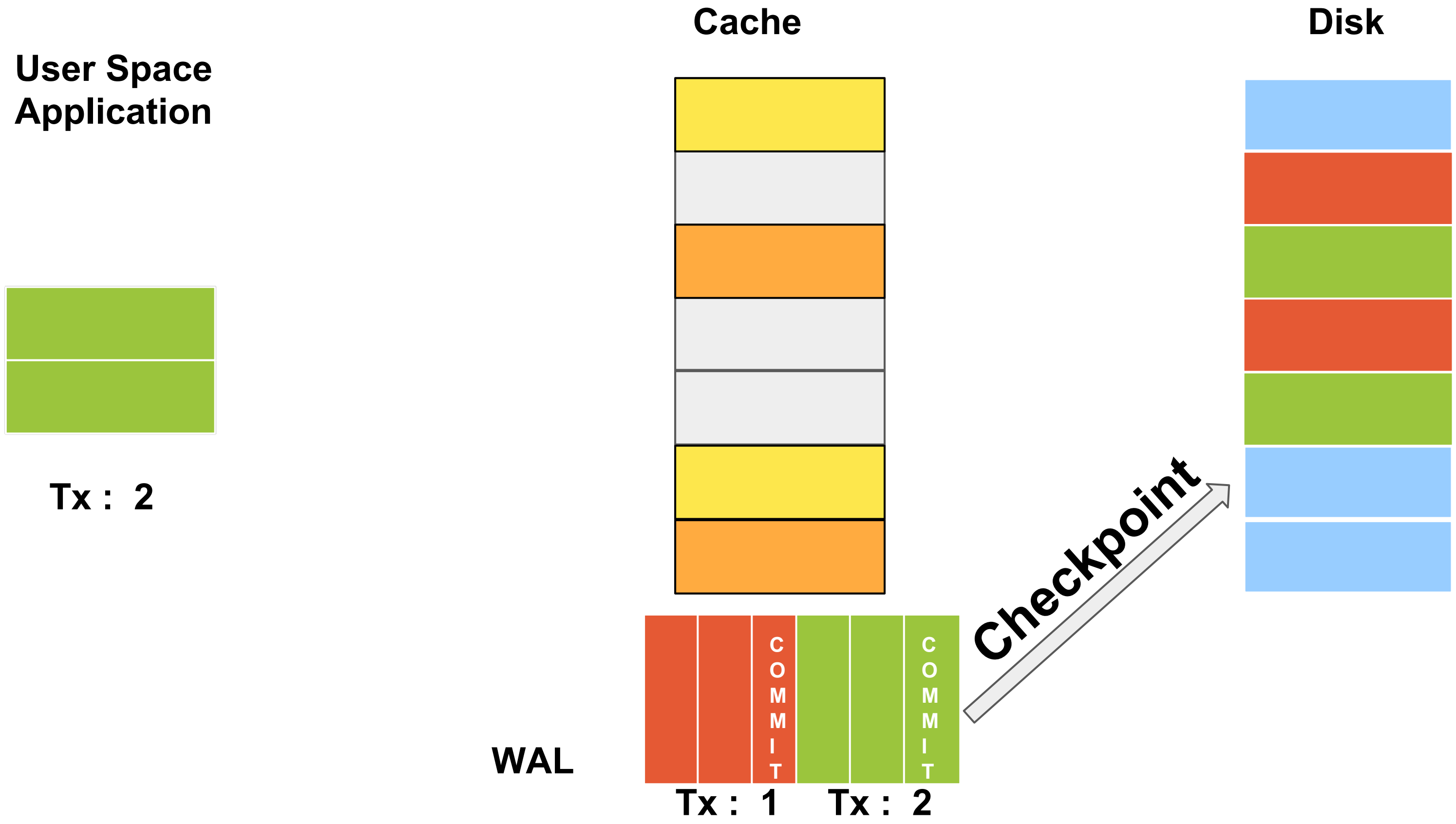


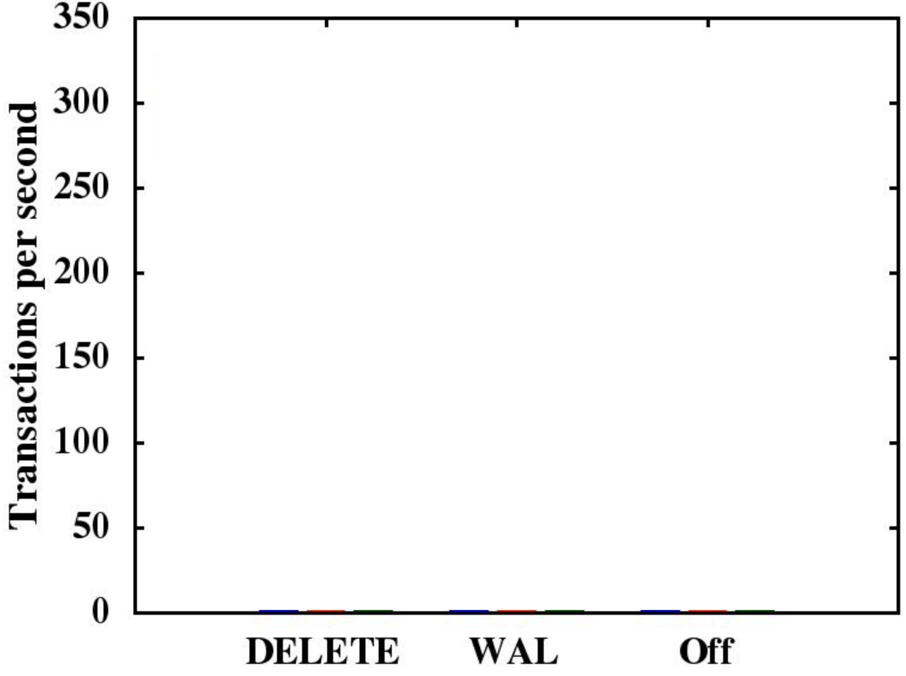
WAL journal mode - checkpointing



2. Journaling mode

- OFF:
  - No Rollback journal
  - Likely corruption on crash

2. Journaling mode



- X-axis : Journaling mode
- Y-axis : Results reported in transactions/sec

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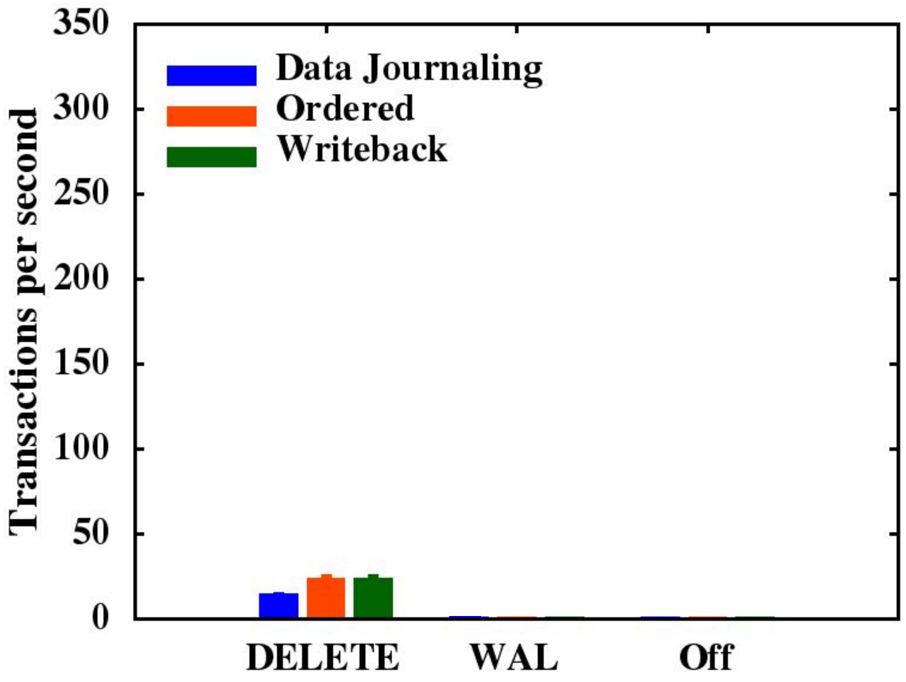
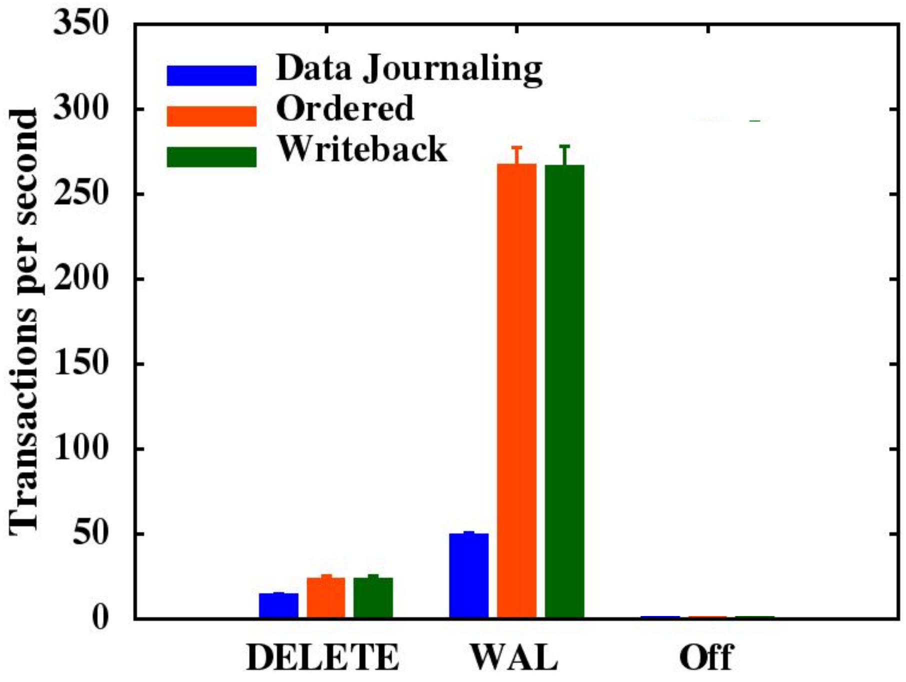


- DELETE :

  Max TPS of 30 achieved

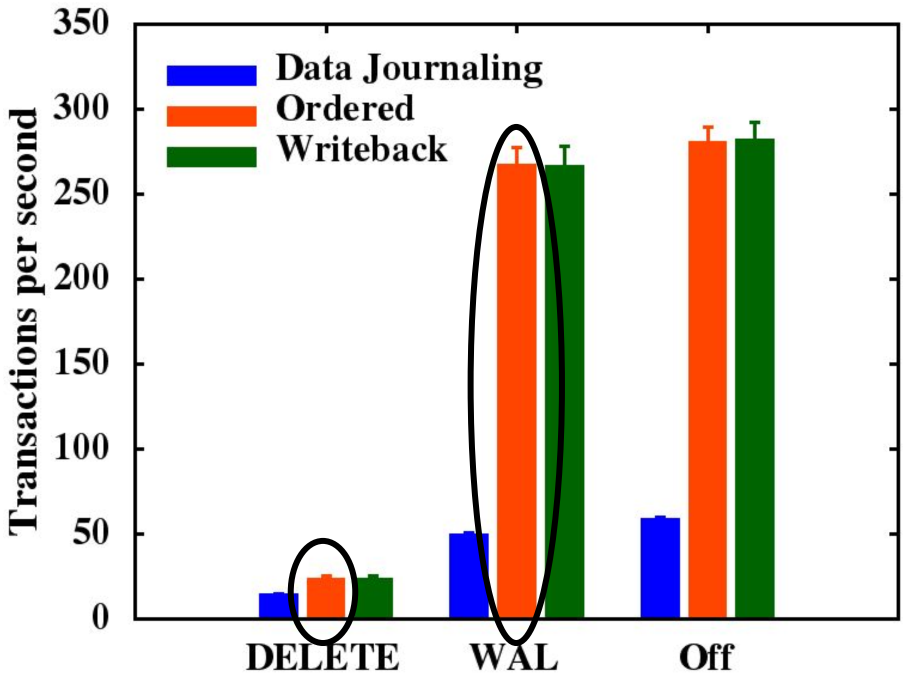
2. Journaling mode



- WAL :

  Max TPS of 270 achieved

2. Journaling mode



- WAL 10X better than DELETE
- Journal deleted after each commit in DELETE mode.
- For 1000 SQLite inserts,
  - WAL : 1000 fsync()
  - DELETE : 5000 fsync()

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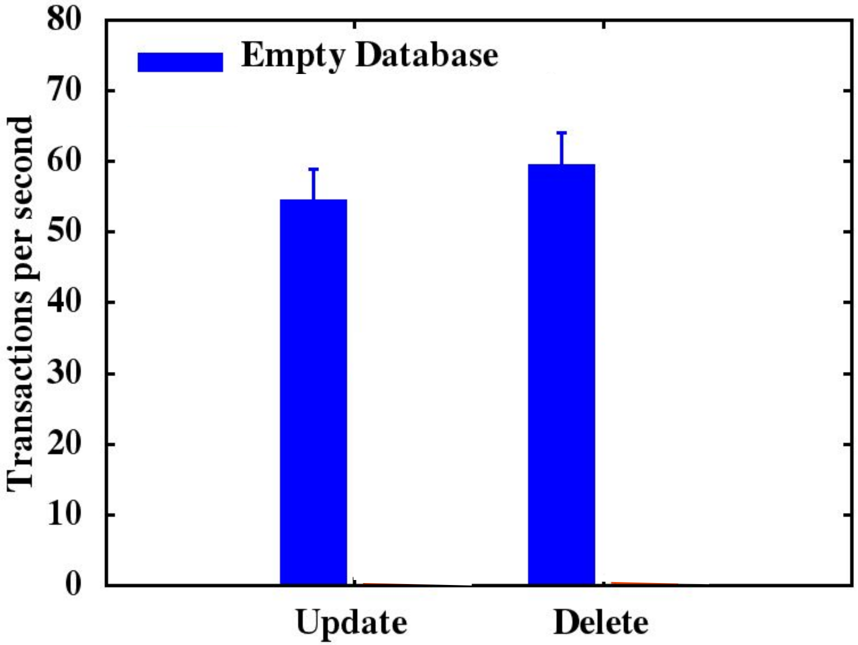
3. Pre-population of database

- Necessary to ensure realistic performance estimates.



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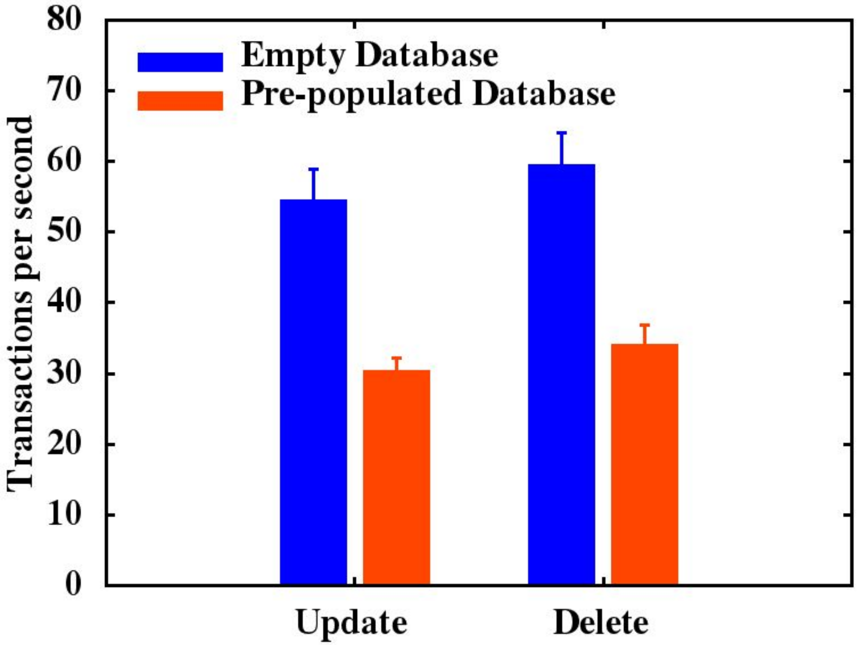

- Almost 2X performance difference
- Benchmarking tools don’t prepopulate. Unrealistic numbers.

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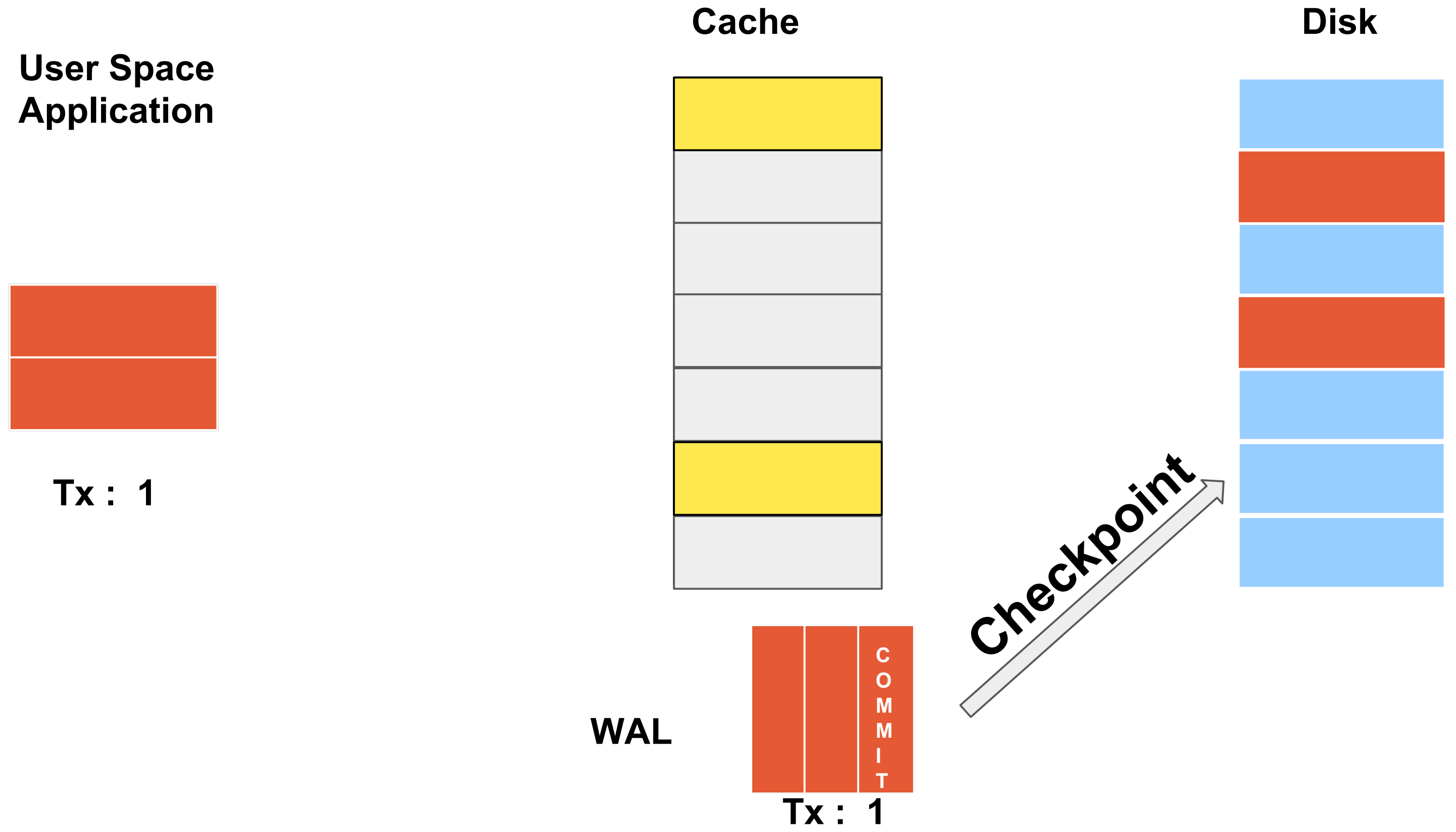
4. Synchronization Mode

- Controls the frequency of fsync() issued by SQLite library.
    - **FULL :**
        - Writes to database(calls fsync()) on each commit.

FULL Synchronization in WAL



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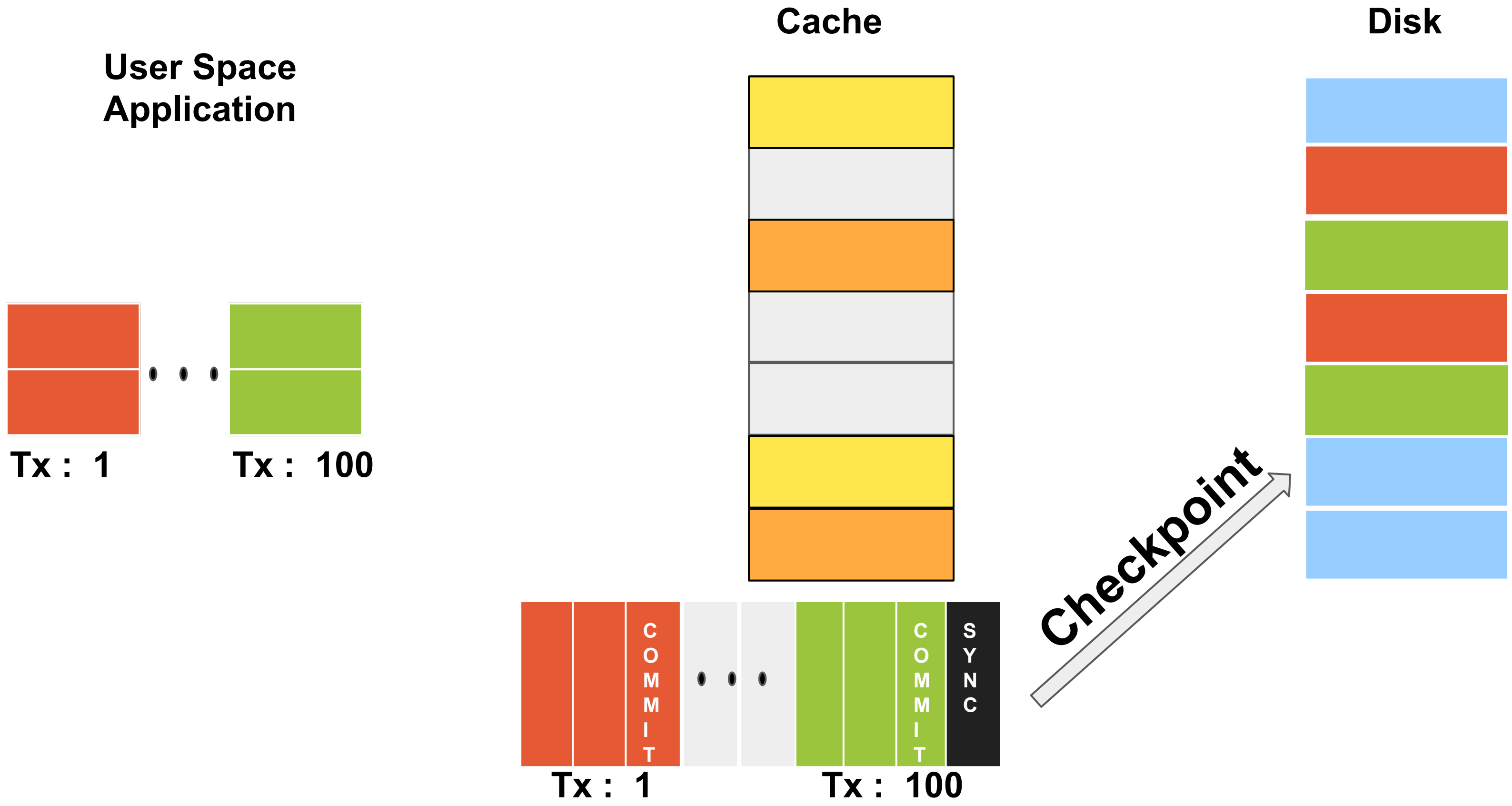
- Controls the frequency of fsync() issued by SQLite library.
  - **FULL :**
    - Writes to database(calls fsync()) on each commit.
  - **NORMAL:**
    - Writes to log on each commit.

NORMAL Synchronization in WAL



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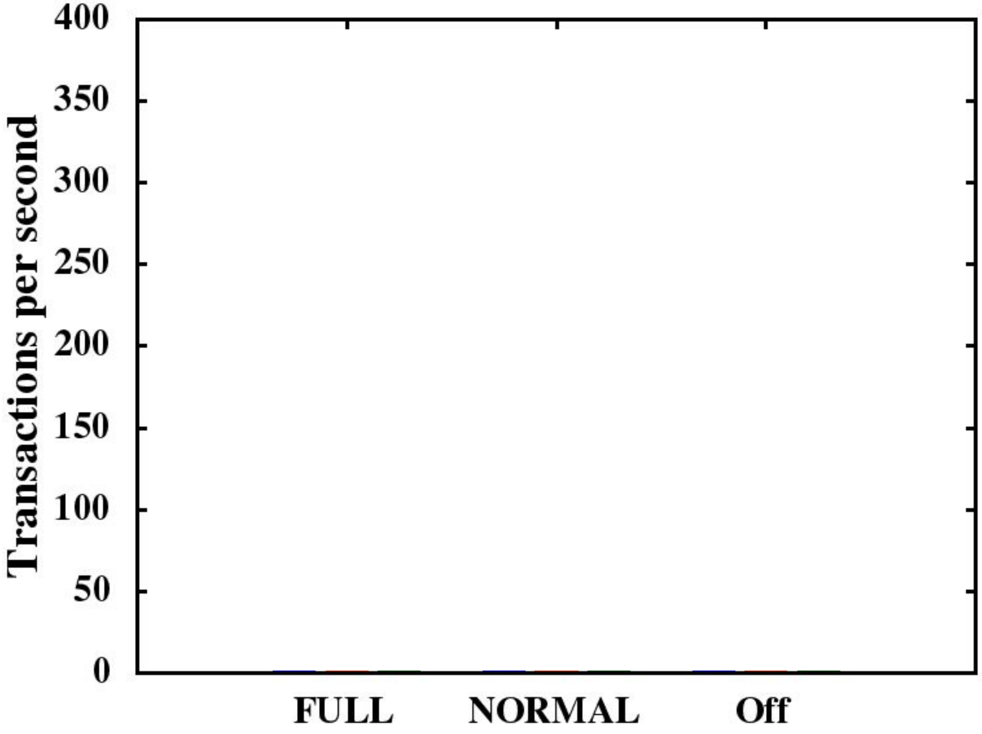
- Controls the frequency of fsync() issued by SQLite library.
  - **<u>FULL :</u>**
    - Writes to database(calls fsync()) on each commit.
  - **<u>NORMAL:</u>**
    - Writes to log on each commit.
  - **<u>OFF:</u>**
    - Consistency mechanism left to the OS.

4. Synchronization Mode



- X-axis : Synchronization mode
- Y-axis : Results reported in transactions/sec

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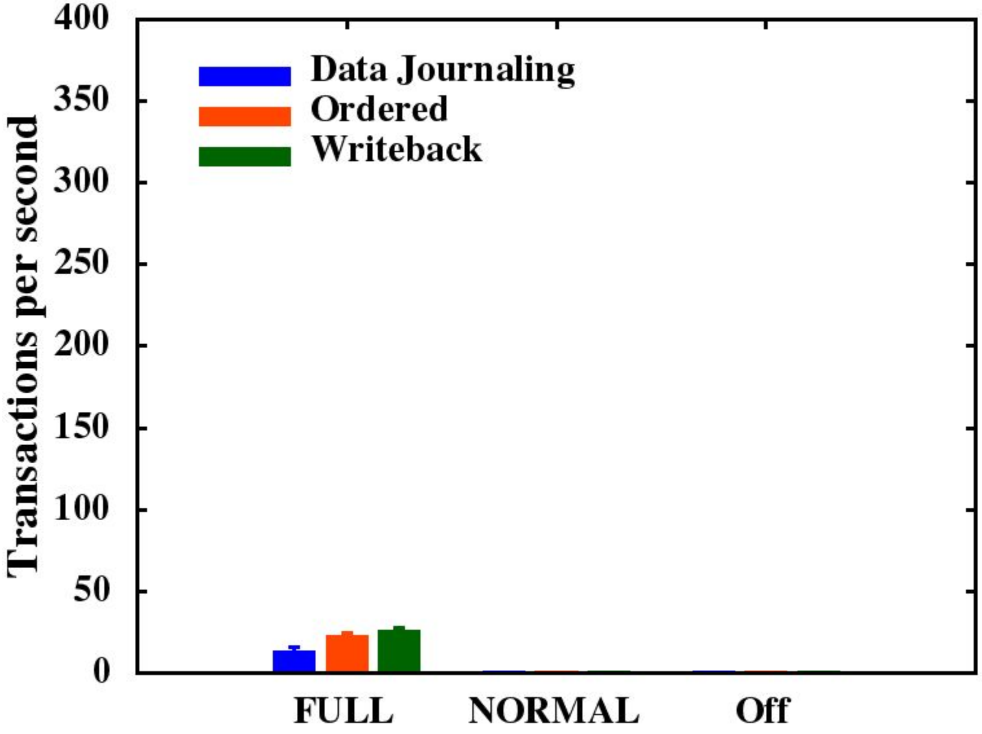

- FULL :

  Max TPS : 30

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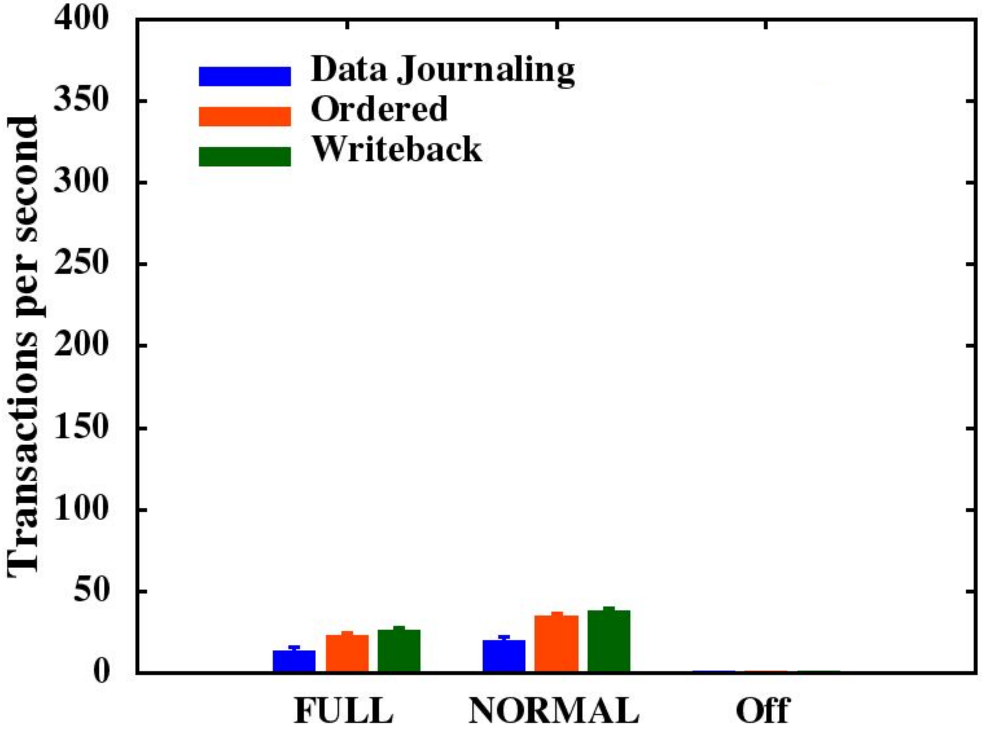

- NORMAL :

  Max TPS : 45

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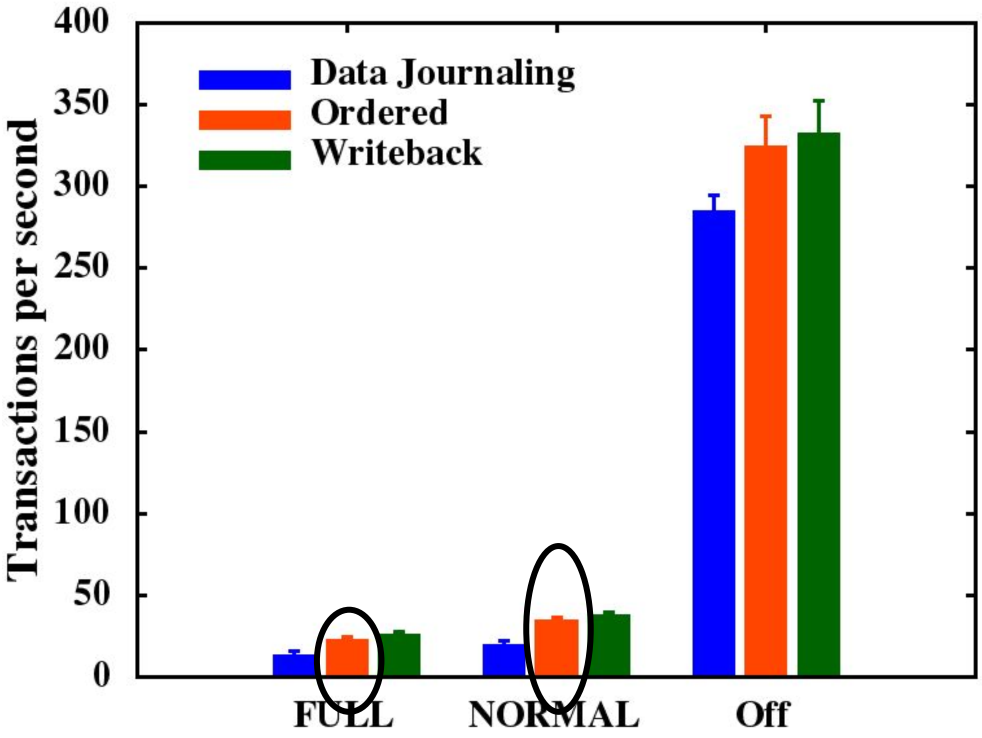

- NORMAL : 1.5X better than FULL .
- To strike balance between durability and performance, use WAL+NORMAL

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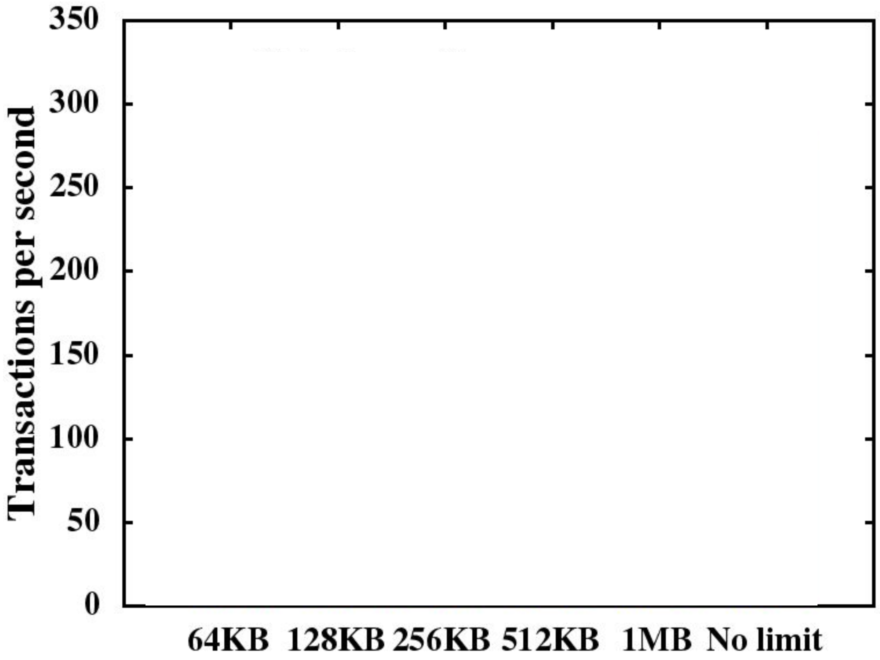
5. Journal Size

- In WAL mode, journal can grow unbounded
- Potentially affects read performance.



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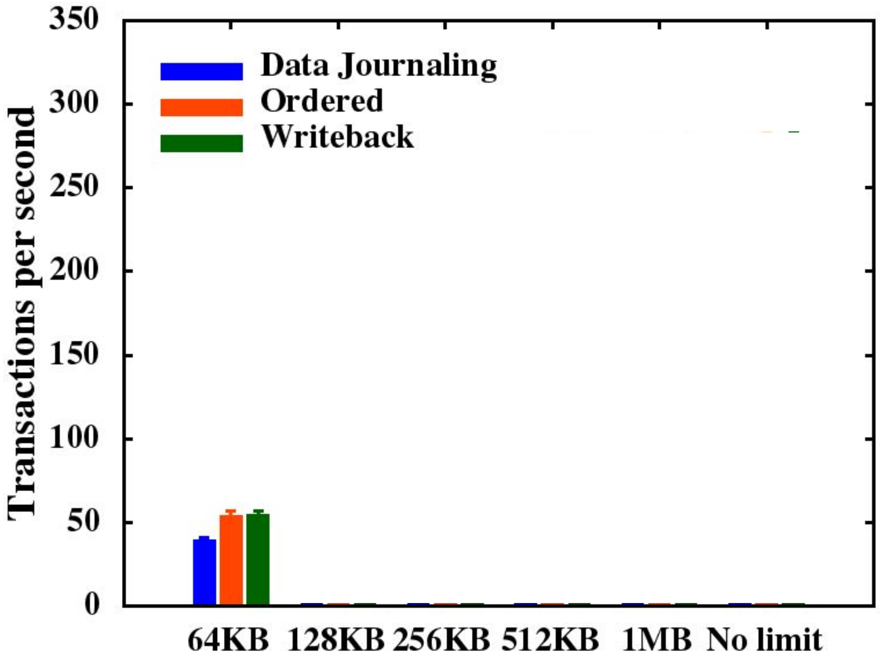

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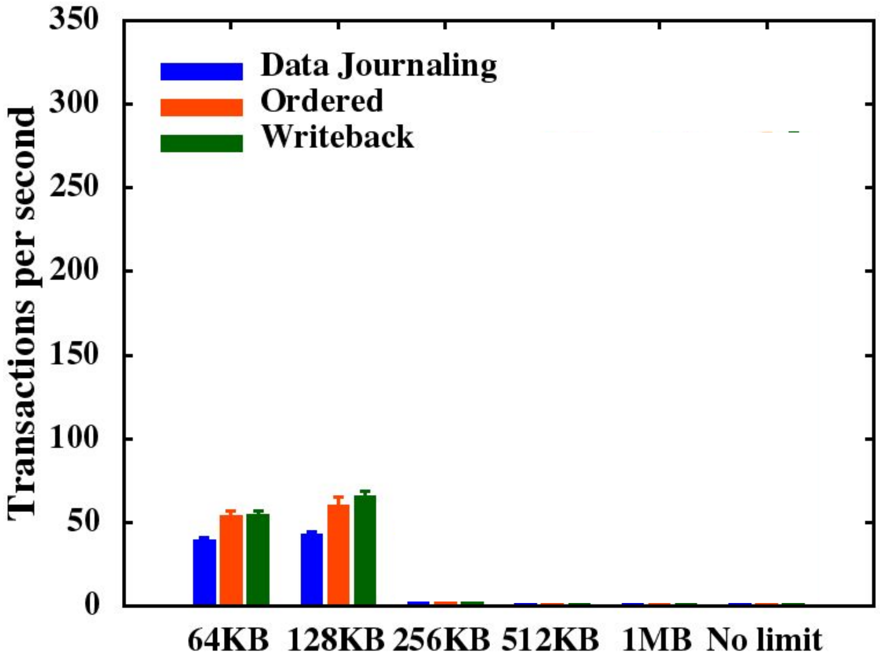

- Performance improves with increase in journal size

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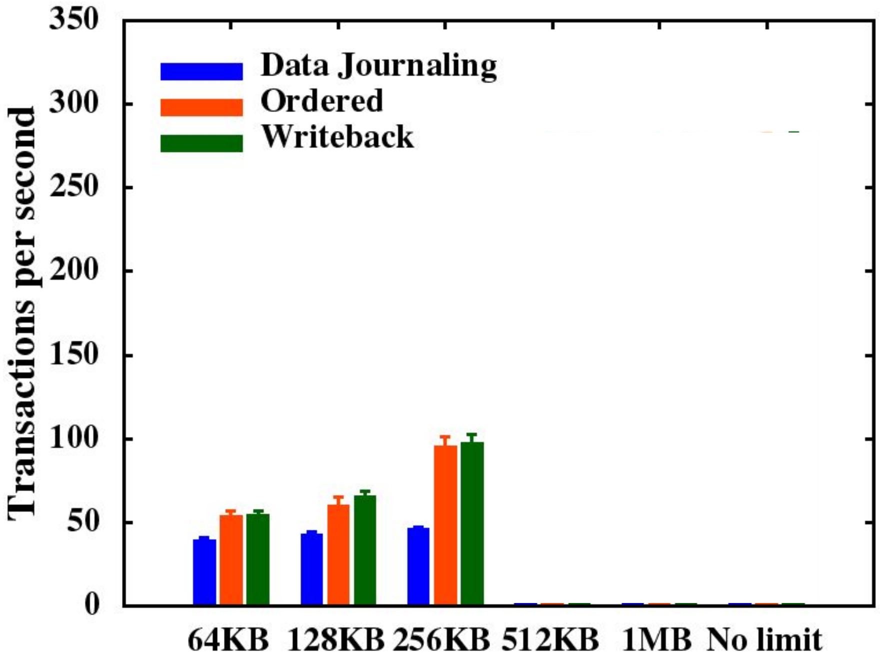

- Performance improves with increase in journal size
- When WAL is full - triggers checkpoint.
- Smaller WAL => more checkpointing

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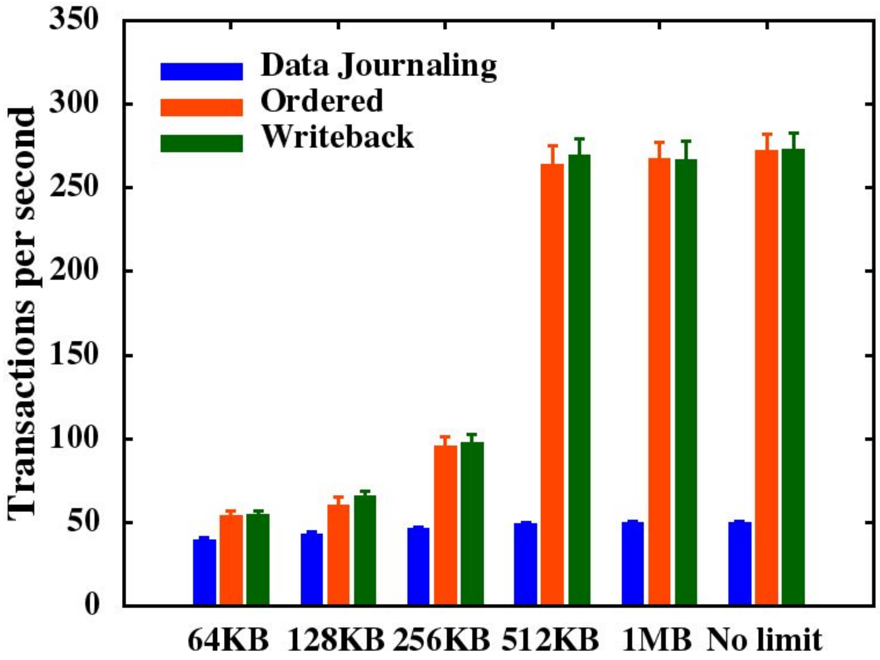

- Performance improves with increase in journal size
- When WAL is full - triggers checkpoint.
- Smaller WAL => more checkpointing
- Saturates beyond a point

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Conclusion

- The Systems community has discussed in the past, how tricky benchmarking can be.
- But in practice, we have shown that industrial benchmarking tools are **inconsistent**, and academic reporting of results is **incomplete.**
- **Draw attention to:**
  - Developers and researchers must understand the impact of various parameters on SQLite performance.
  - To ensure repeatable and comparable results, reporting configuration parameters is vital.

THANK YOU..

Questions ?

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BACKUP SLIDES

Hardware Setup for experimentation

CPU	**Dual Core 1.2GHz Cortex A9**
Memory	**32GB internal, 1GB RAM**
Android	**6.0.1(cyanogenmod 13)**
Kernel	**3.0.101 (F2FS enabled)**
Battery	**3.7V, 1850mAh**

- Experiments performed on Samsung Galaxy Nexus S
- Controlled experimental setup : Vary one parameter, while keeping all others constant.