LDT: Lightweight Dirty Tracking of Memory Pages for x86 Systems

IRS 2023

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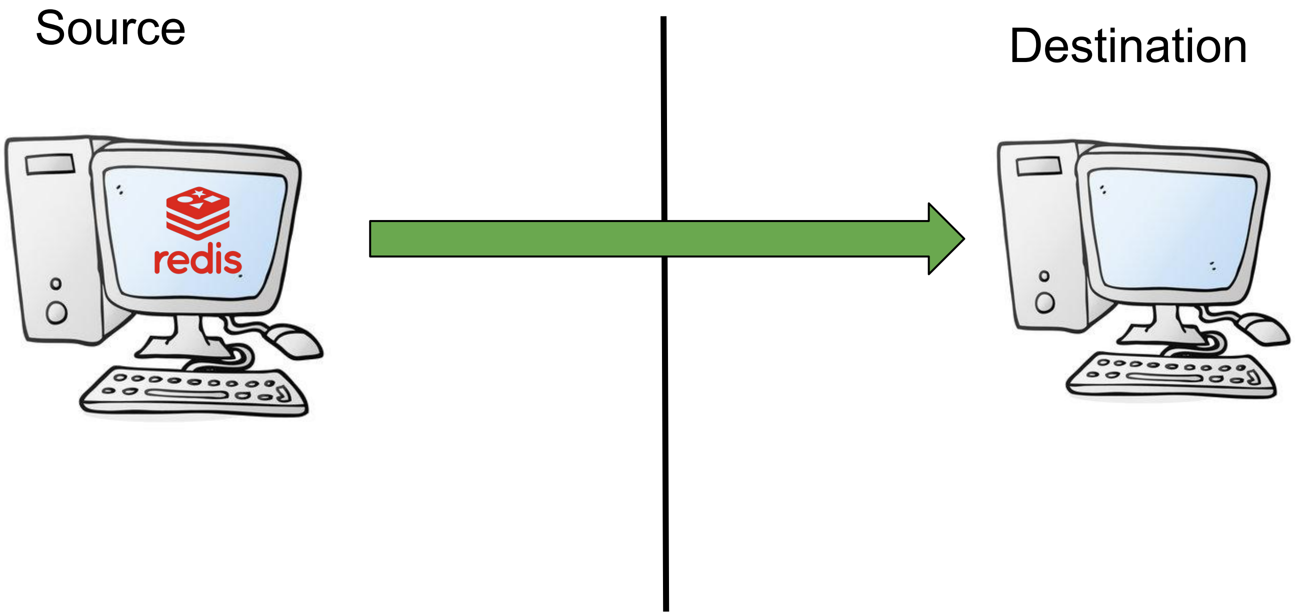
Process Migration



Ref: google images

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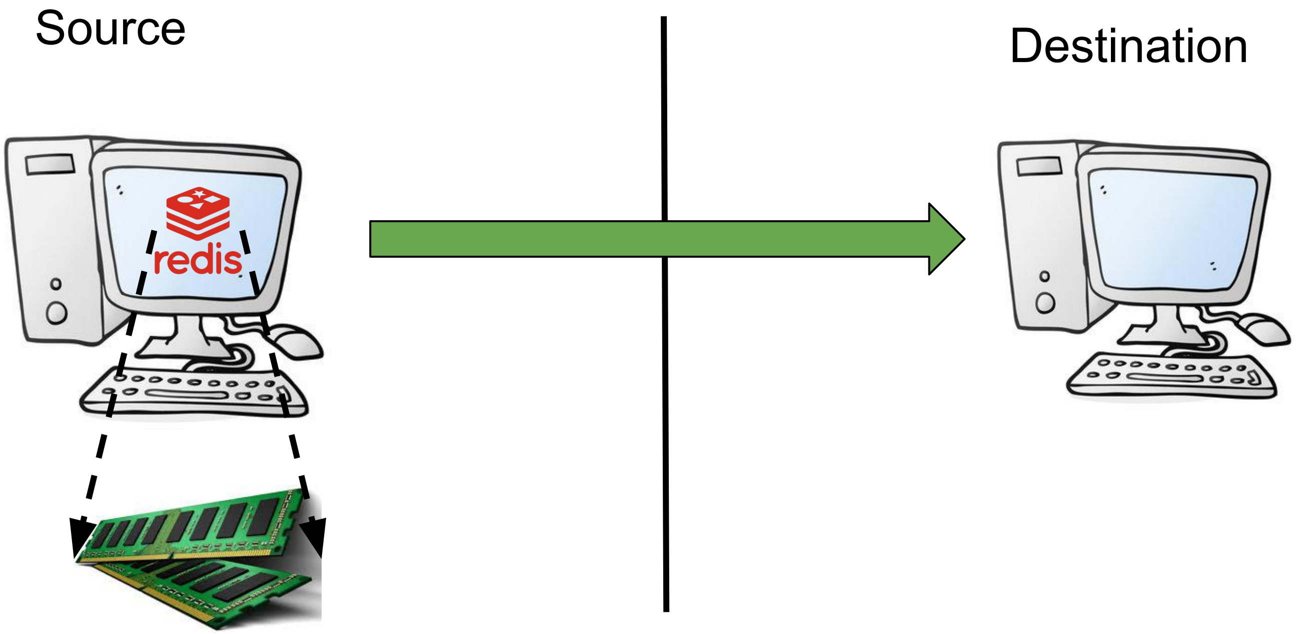

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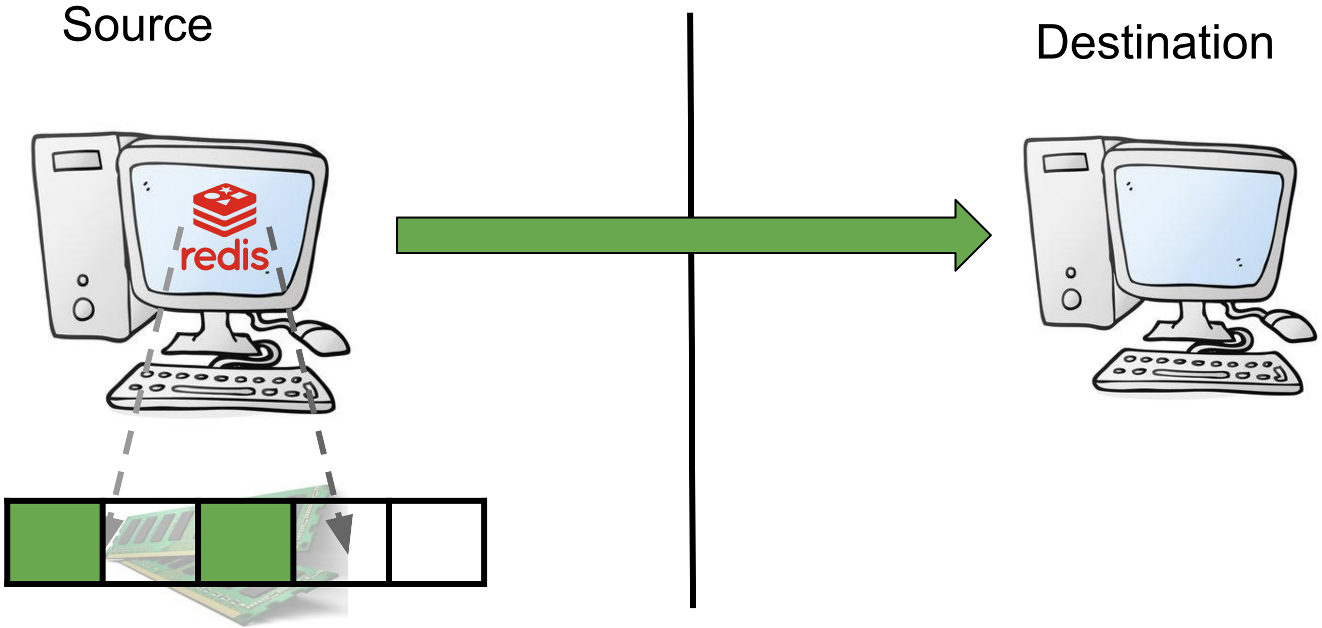

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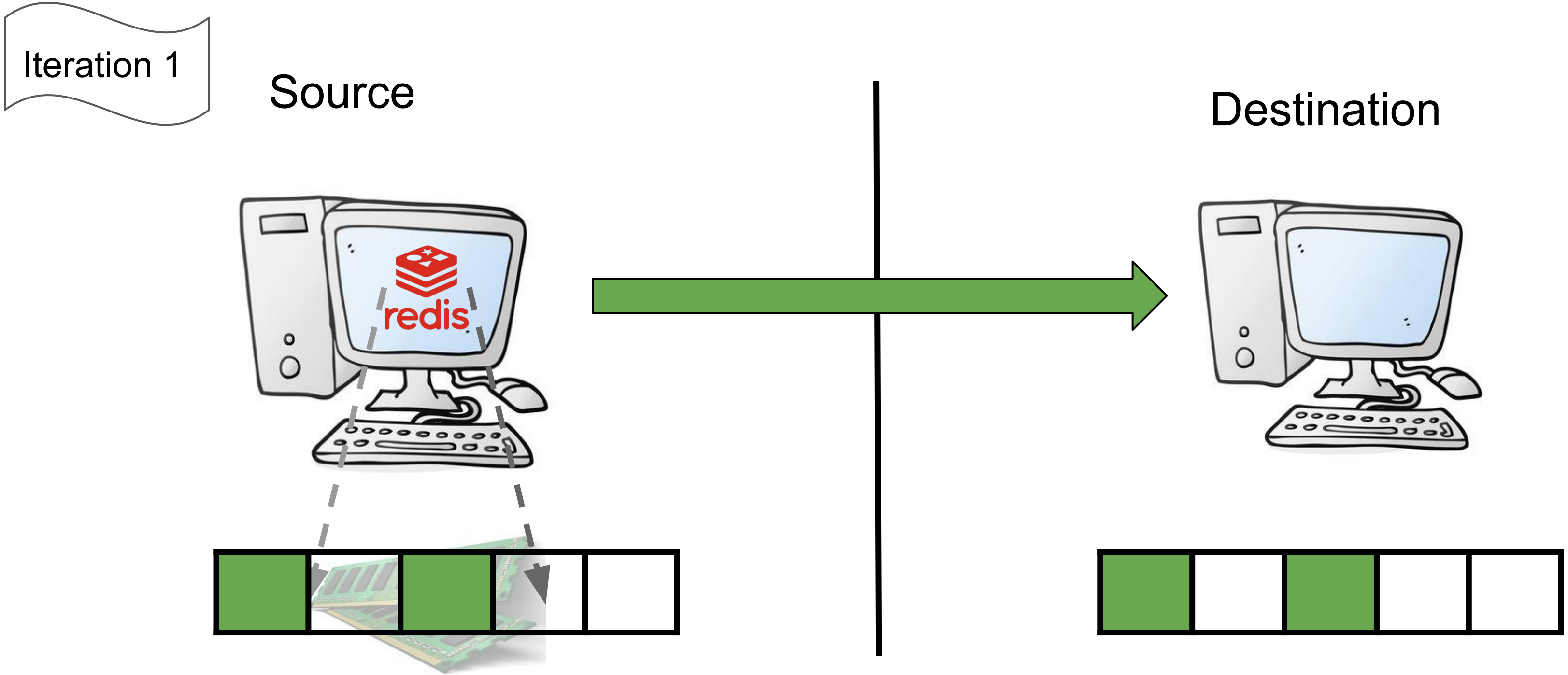

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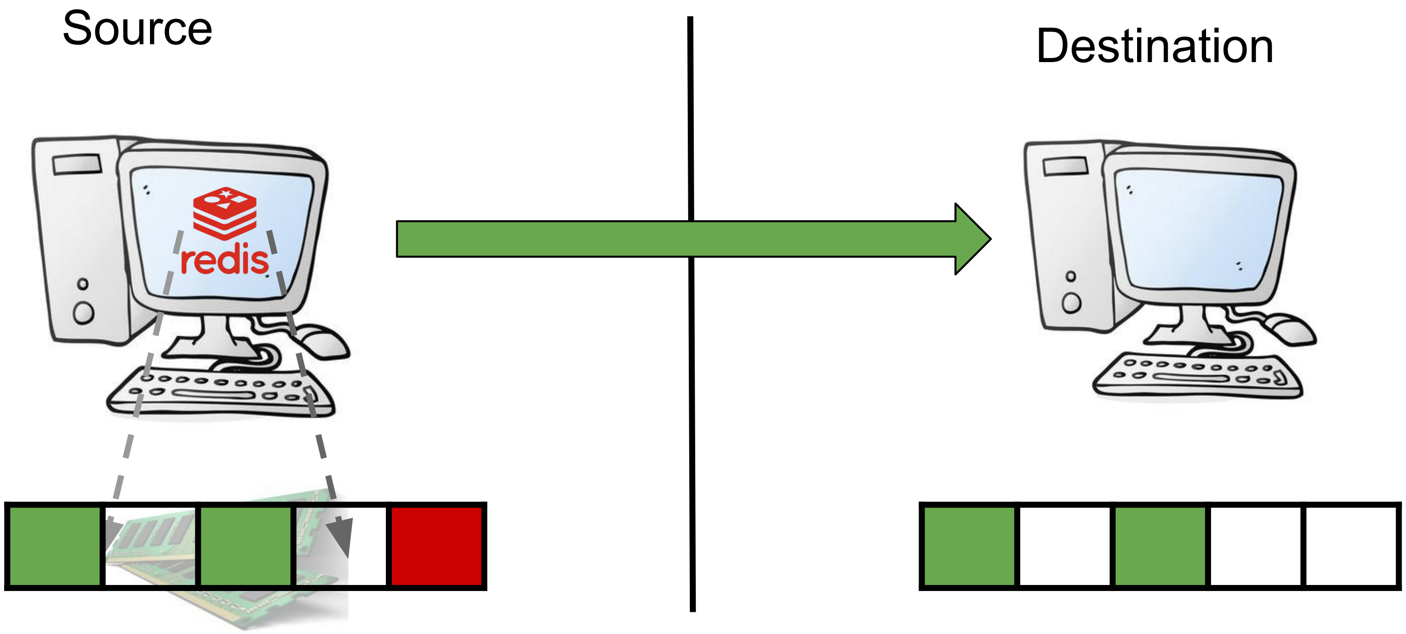

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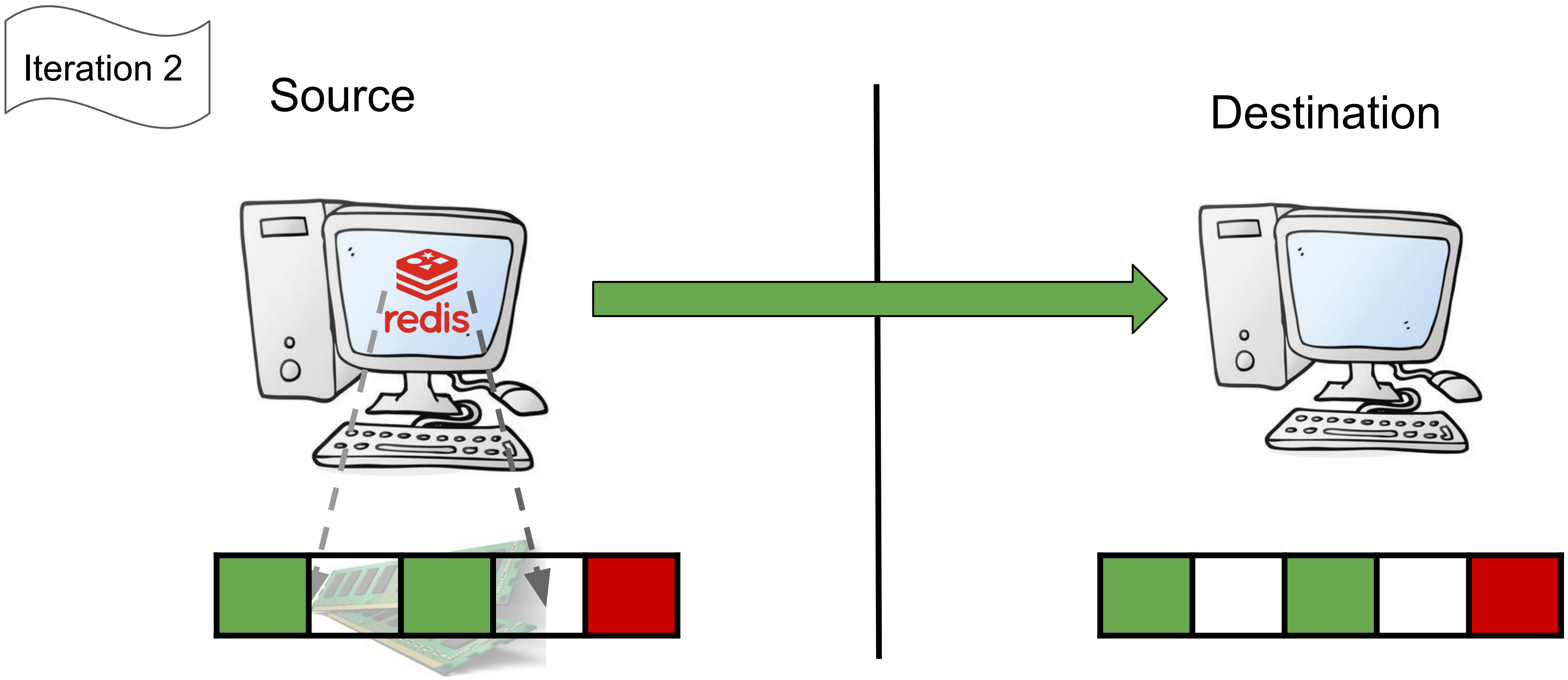

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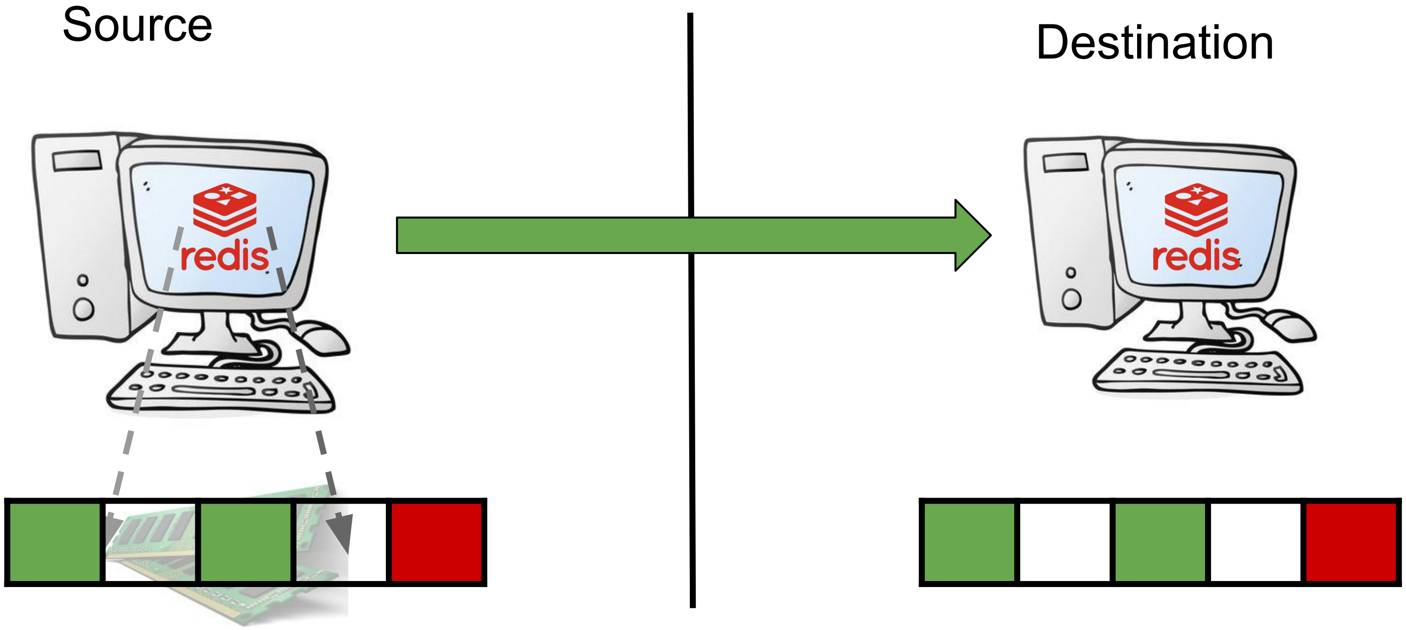

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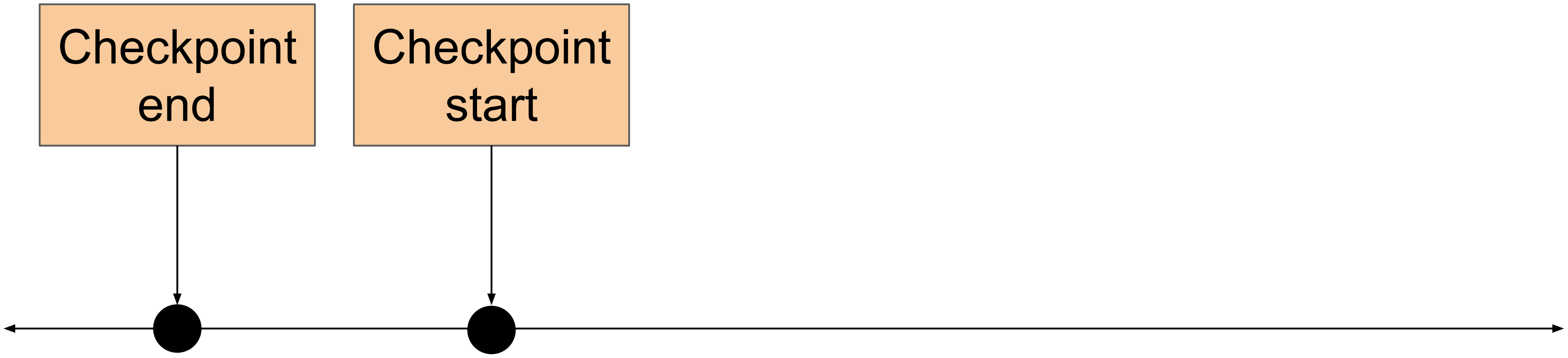
Incremental Checkpointing



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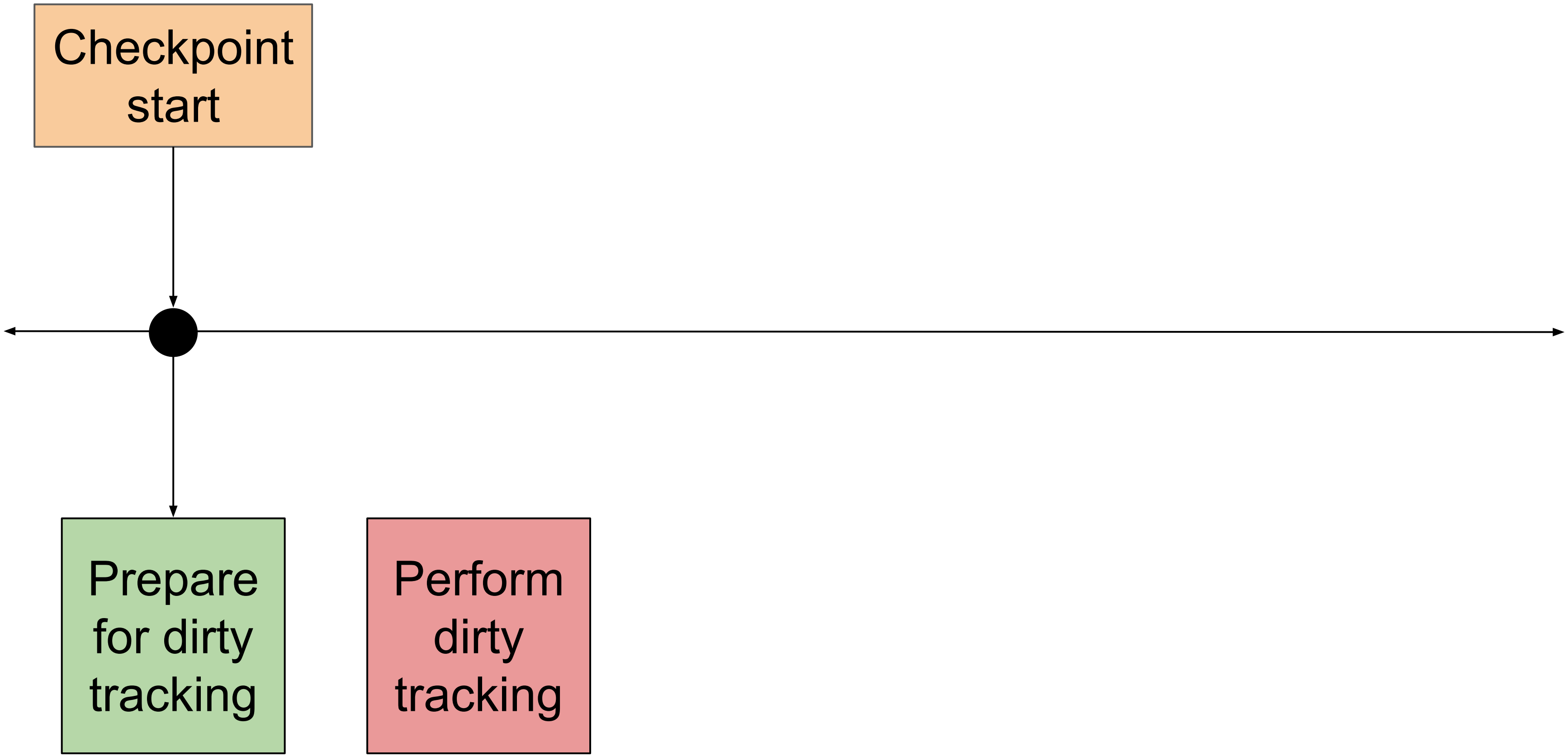

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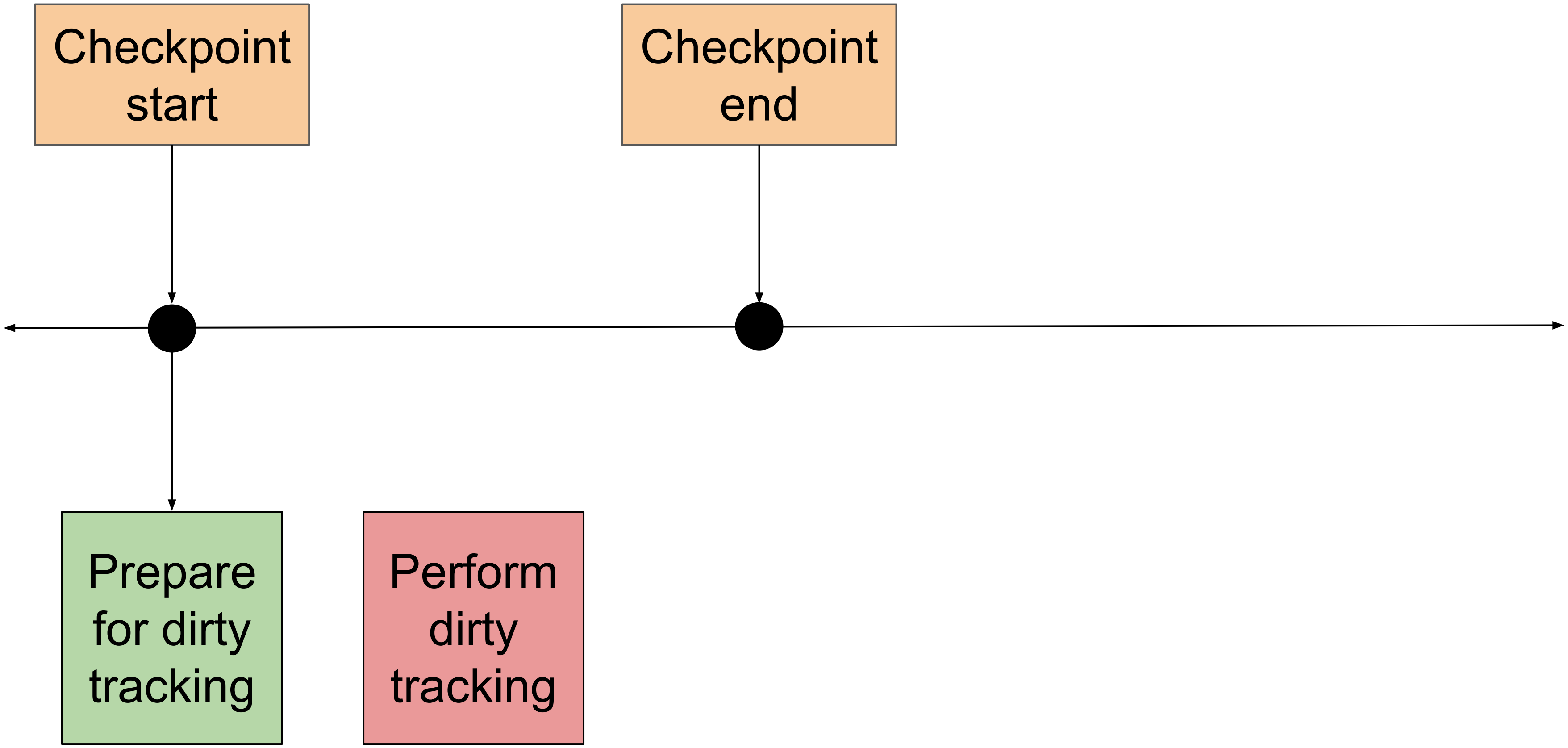

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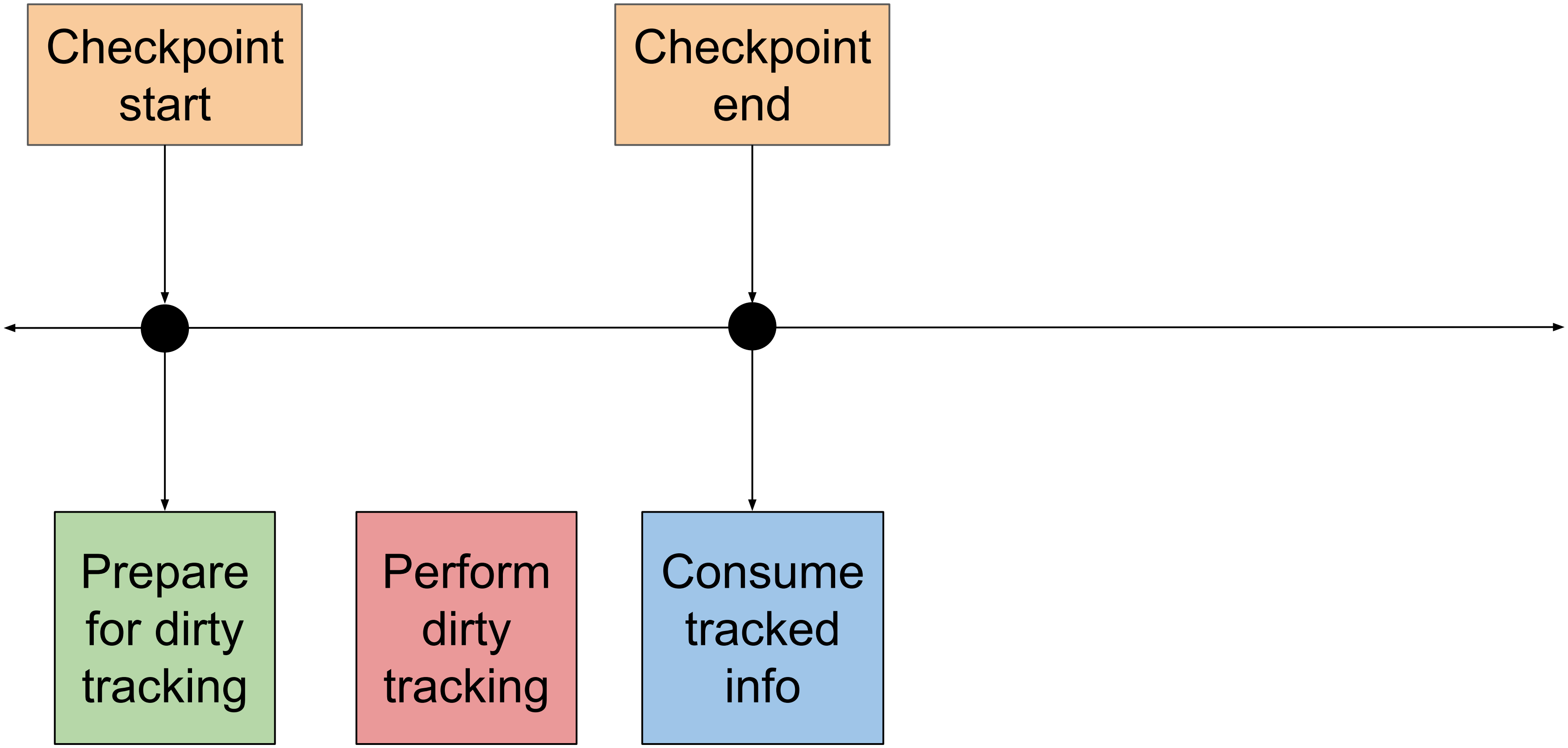

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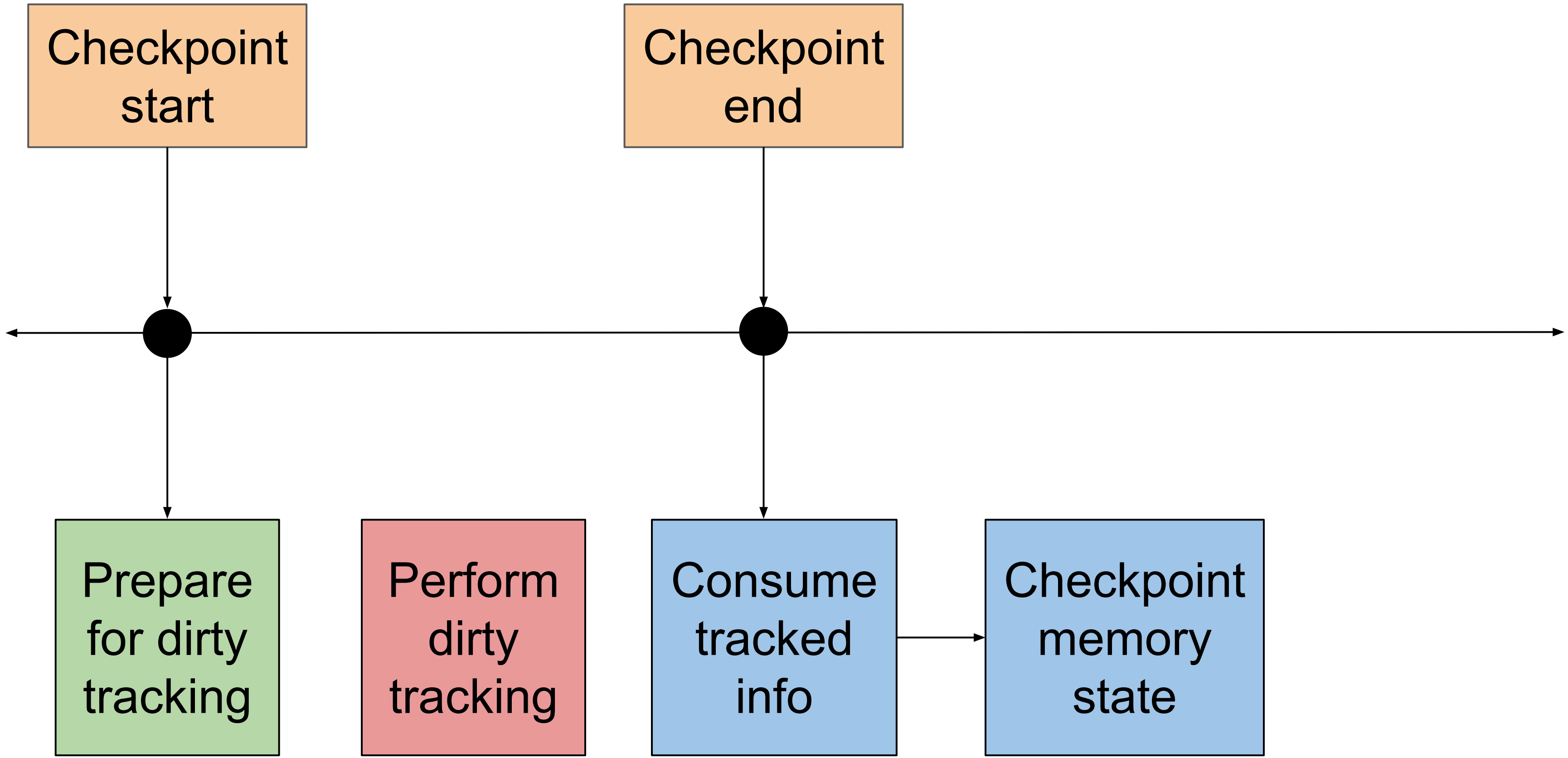

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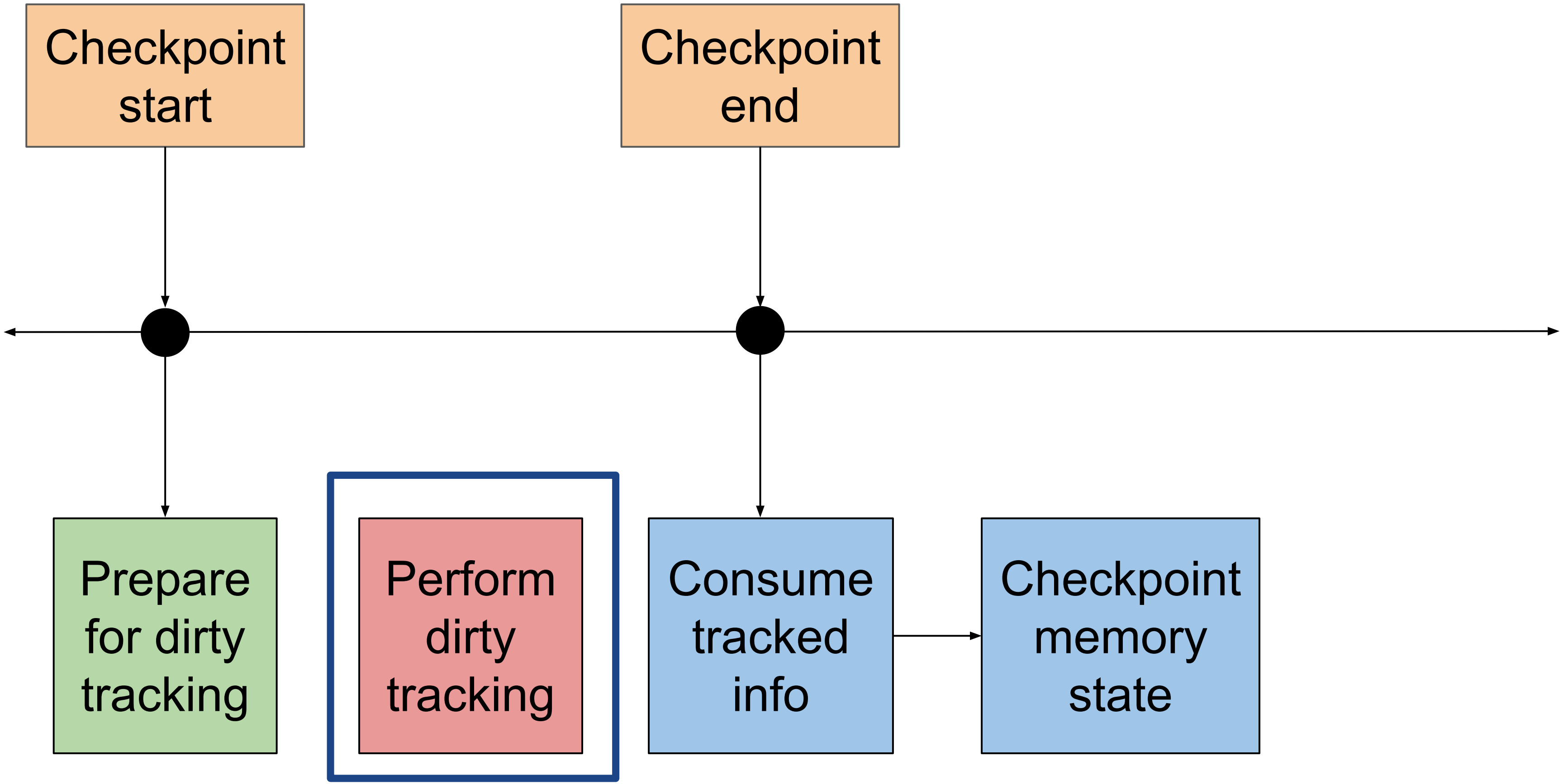
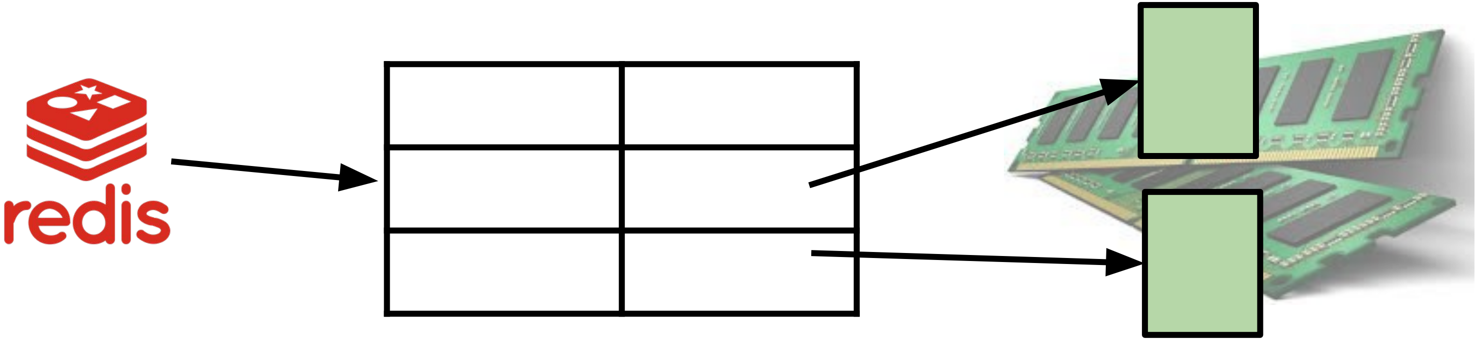


State of the Art: Dirty Tracking with write faults



Translation Table

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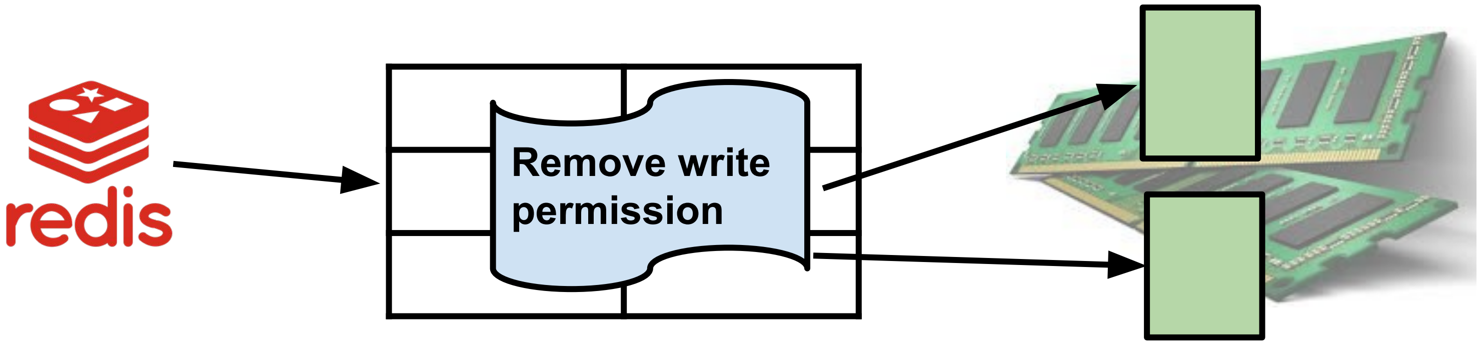

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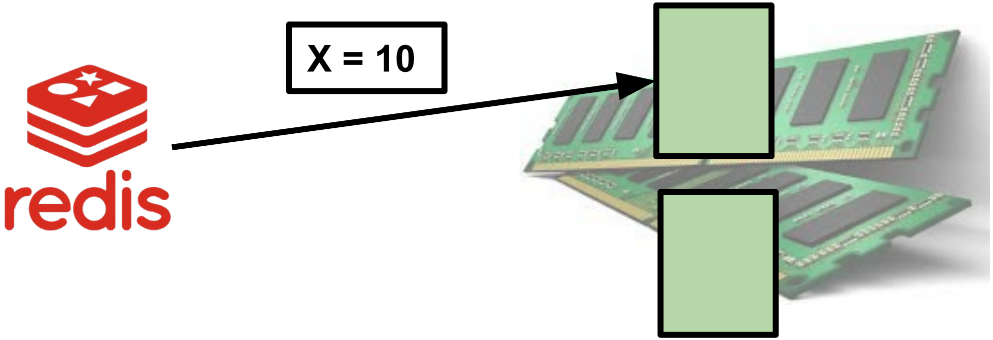

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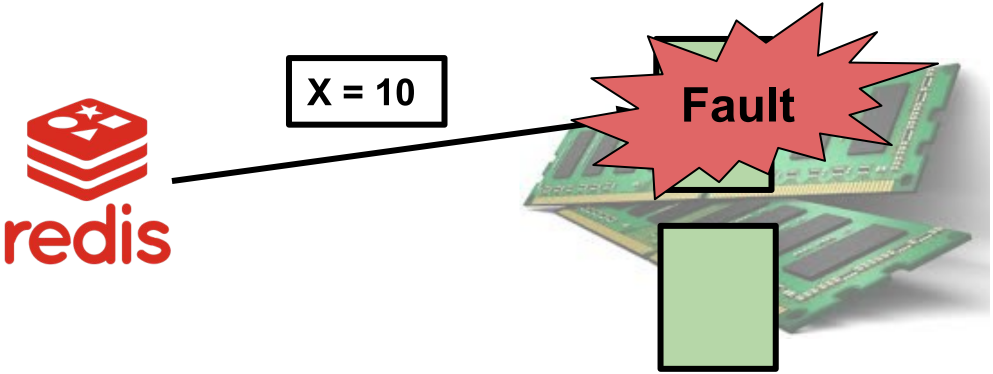

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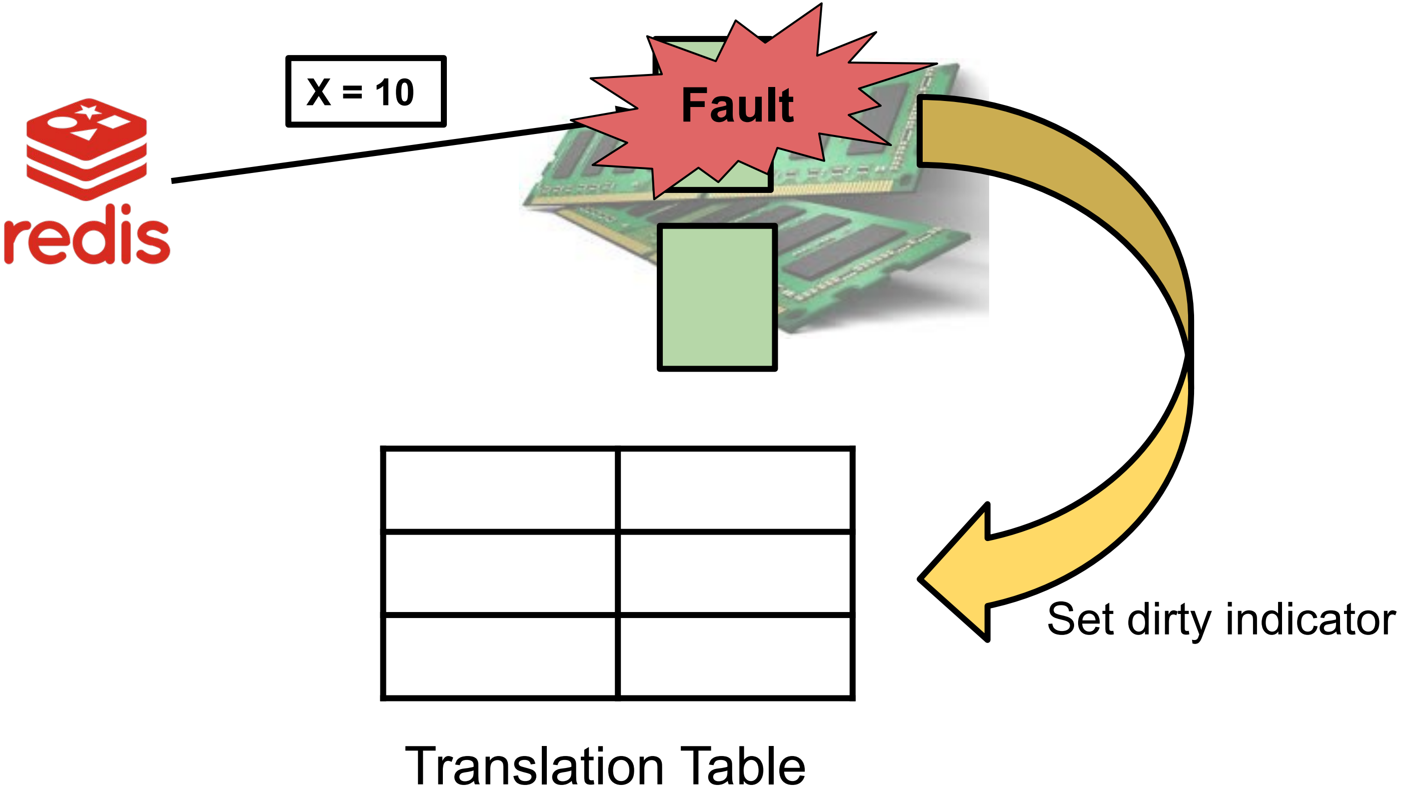

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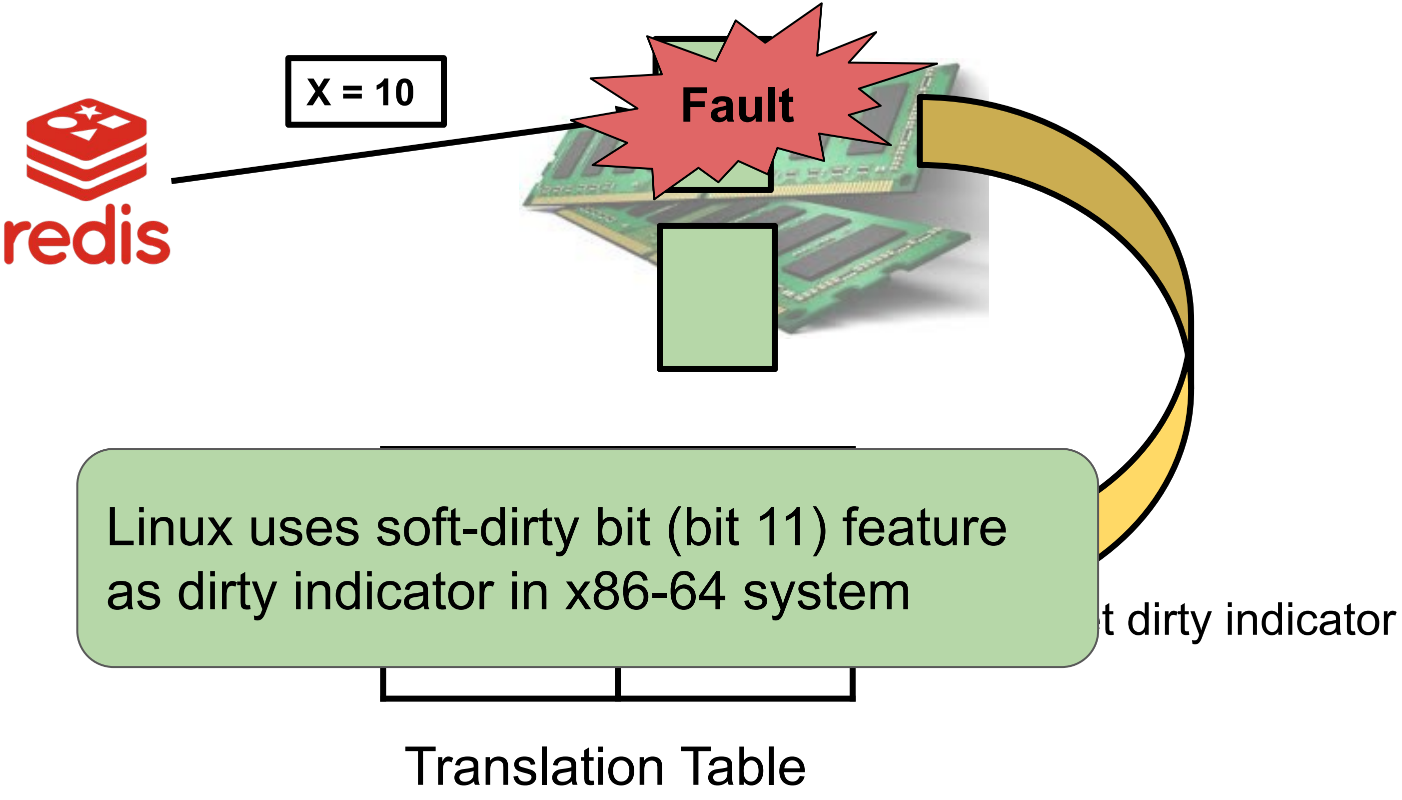
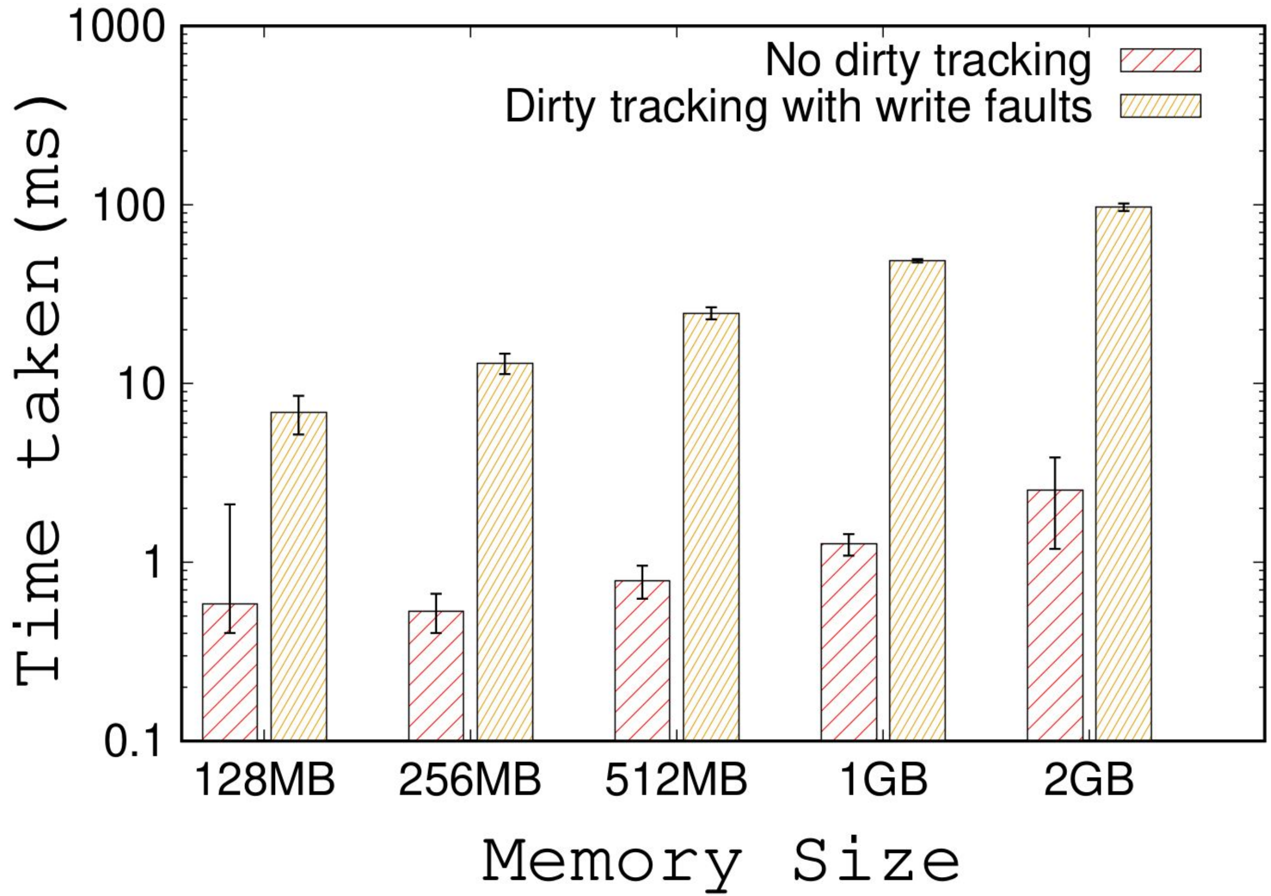


Linux uses soft-dirty bit (bit 11) feature as dirty indicator in x86-64 system

Ref: google images

Dirty Tracking with write faults overhead



- Workload with different working set sizes where 1 byte of each page is written

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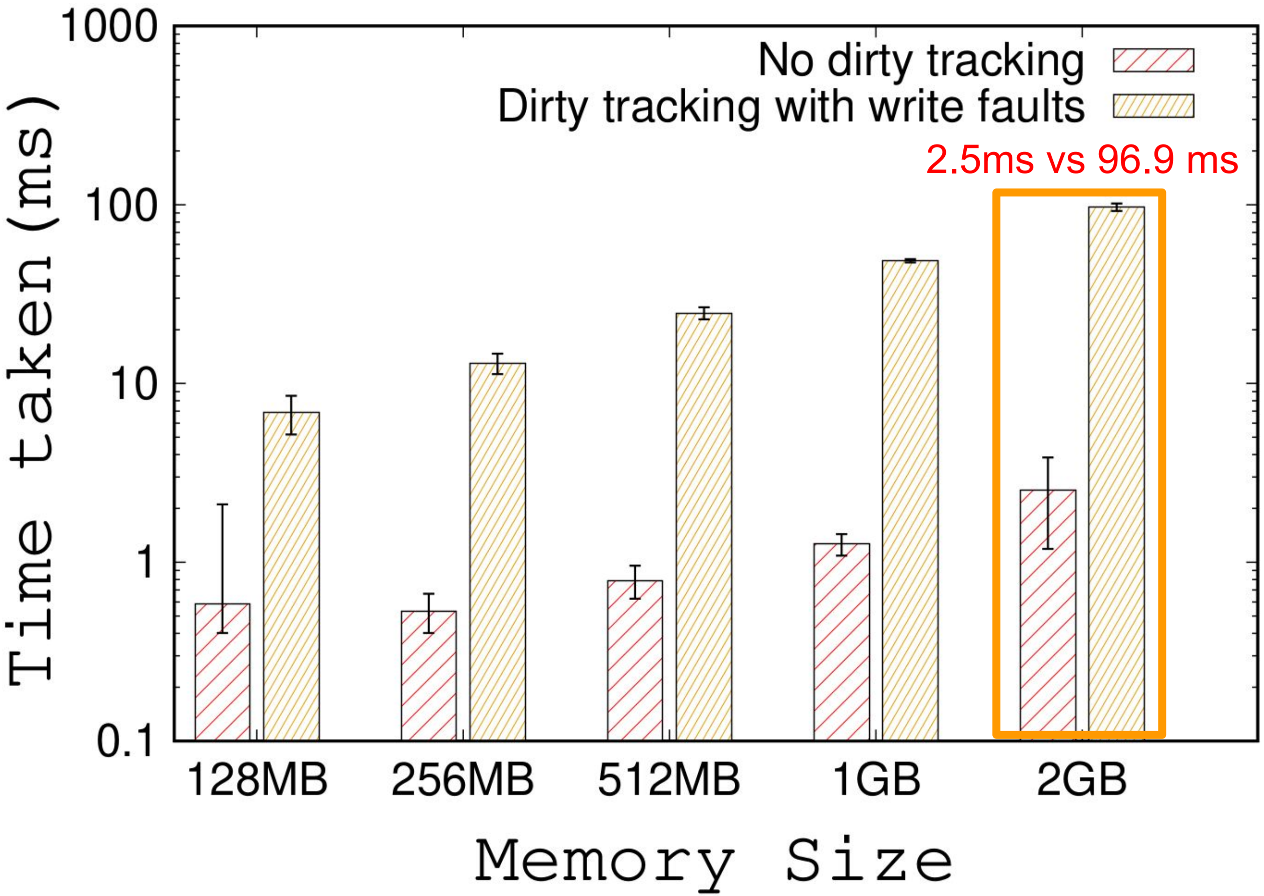
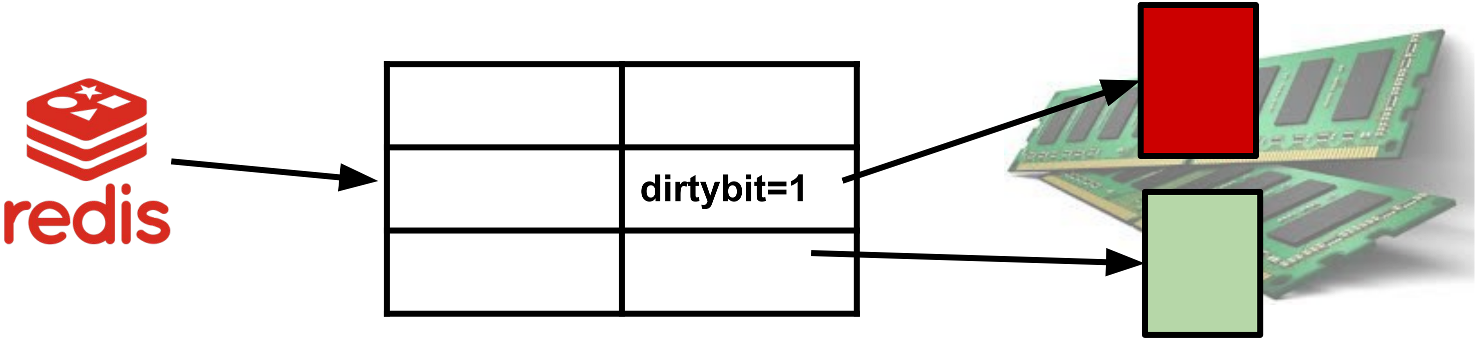


- Workload with different working set sizes where 1 byte of each page is written

- Time taken to write for each working set size is many times more in case of dirty tracking with write faults

Can we use an alternative approach with less overhead for dirty tracking?

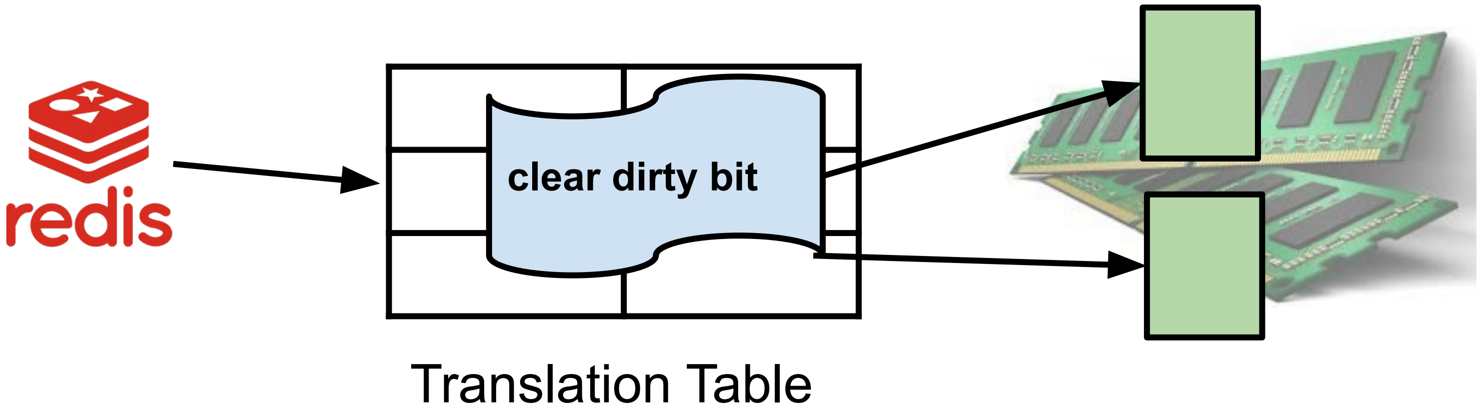
Alternative: Dirty Tracking with Dirty Bit (x86)



Translation Table

Dirty bit is set by hardware if a memory page is modified.

Alternative: Dirty Tracking with Dirty Bit (x86)



At dirty tracking start, clear dirty bit in translation table.

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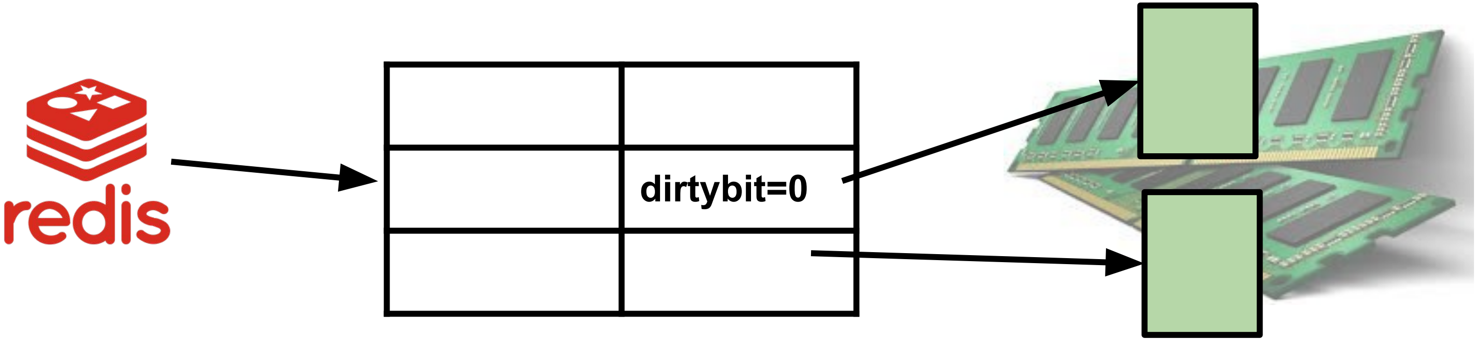

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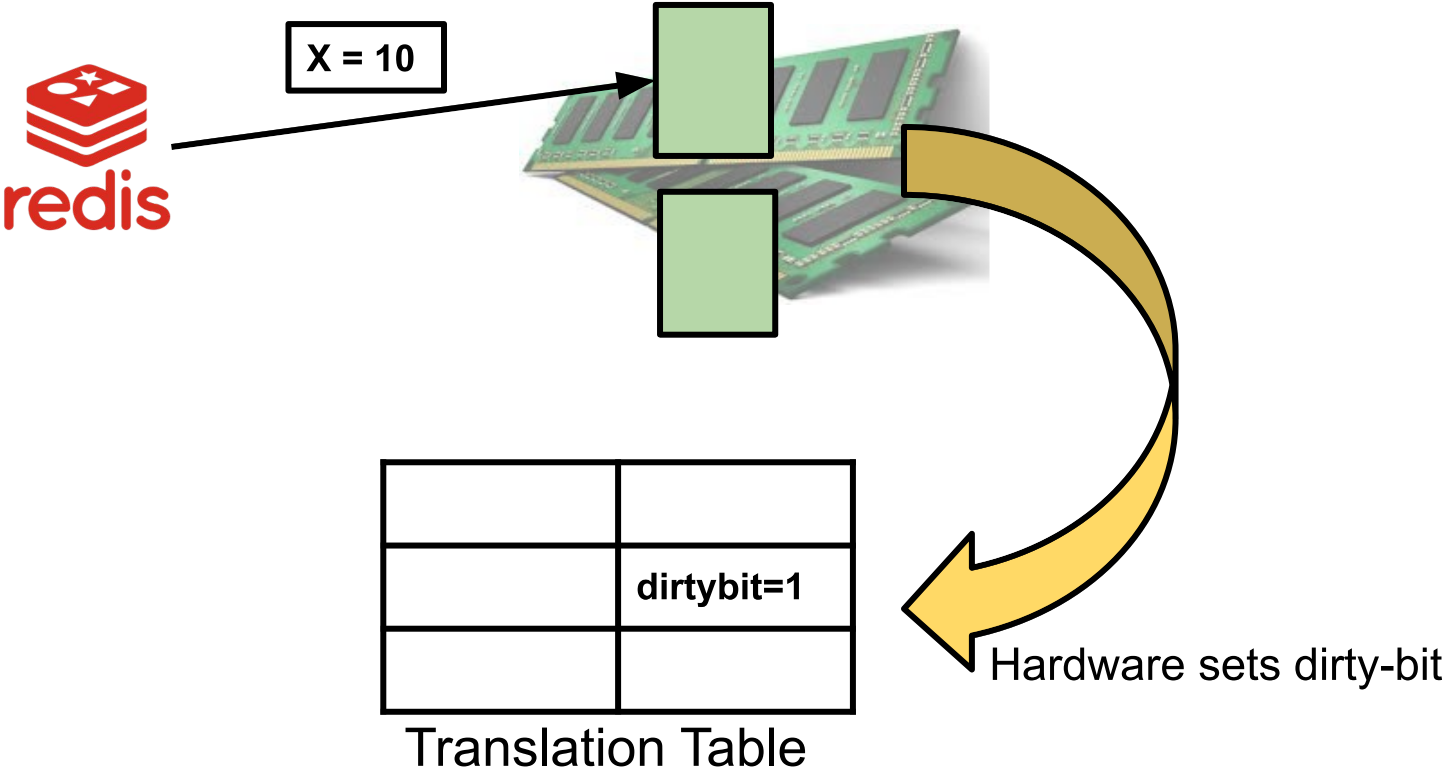

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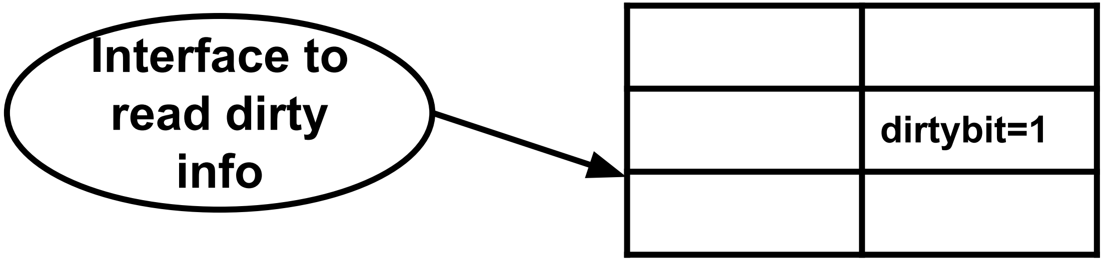
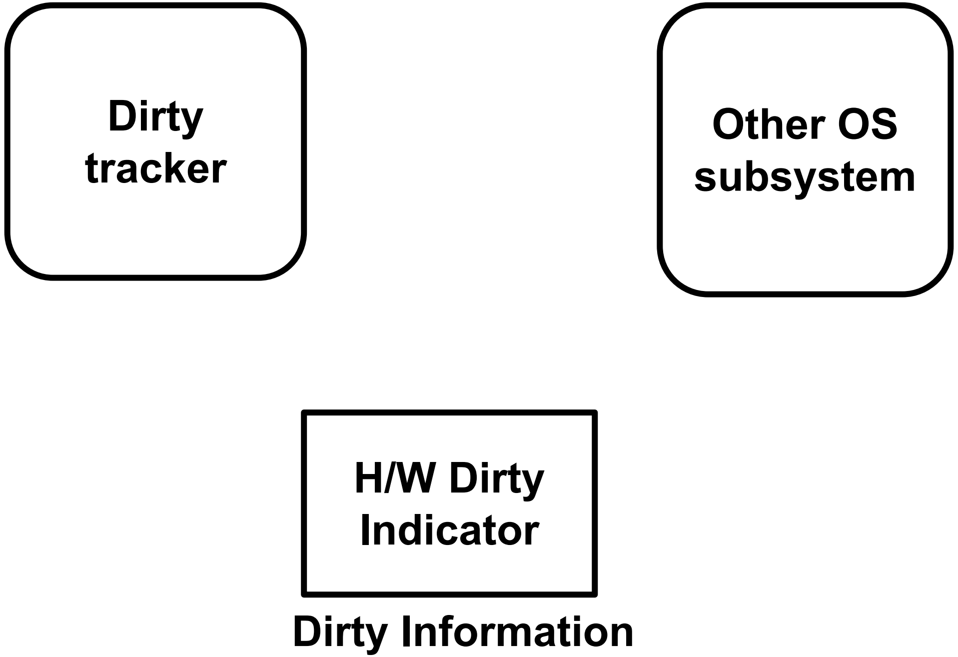


Translation Table

At dirty tracking end, inspect dirty bit in translation table to check page modification.

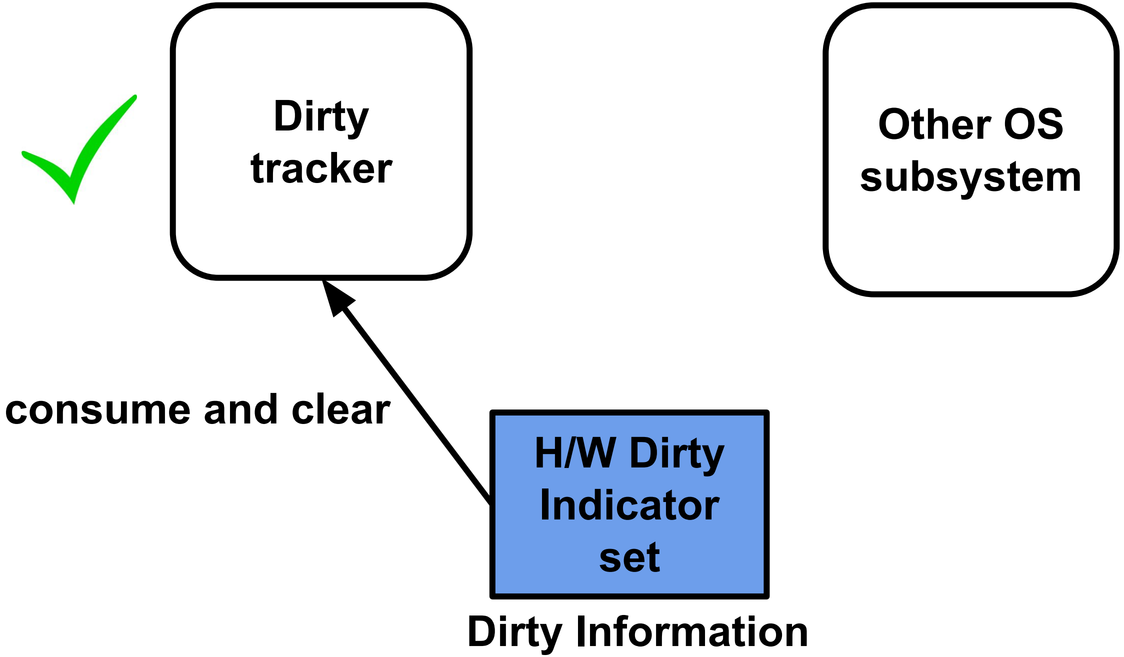
What are the challenges?

Challenge: Interaction with OS subsystems



Challenge: Interaction with OS subsystems

Scenario : 1



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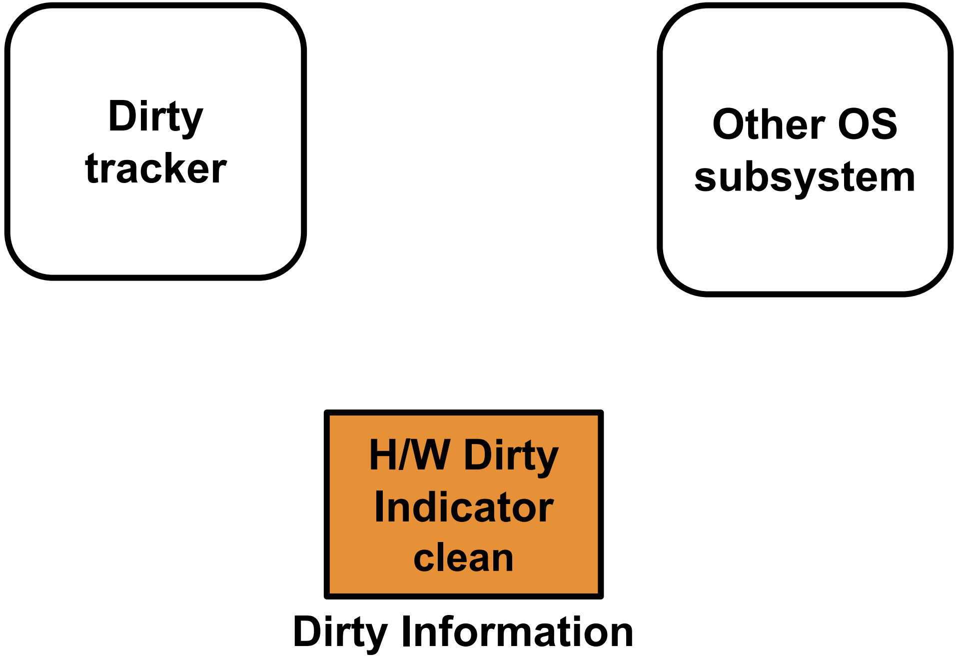

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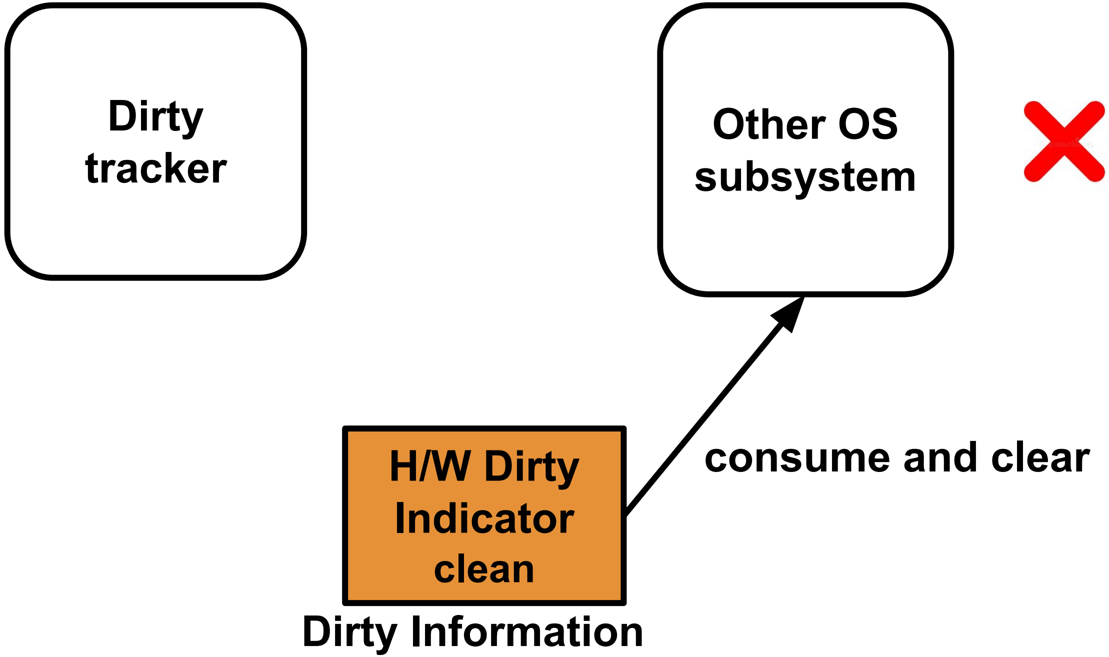

Challenge: Interaction with OS subsystems

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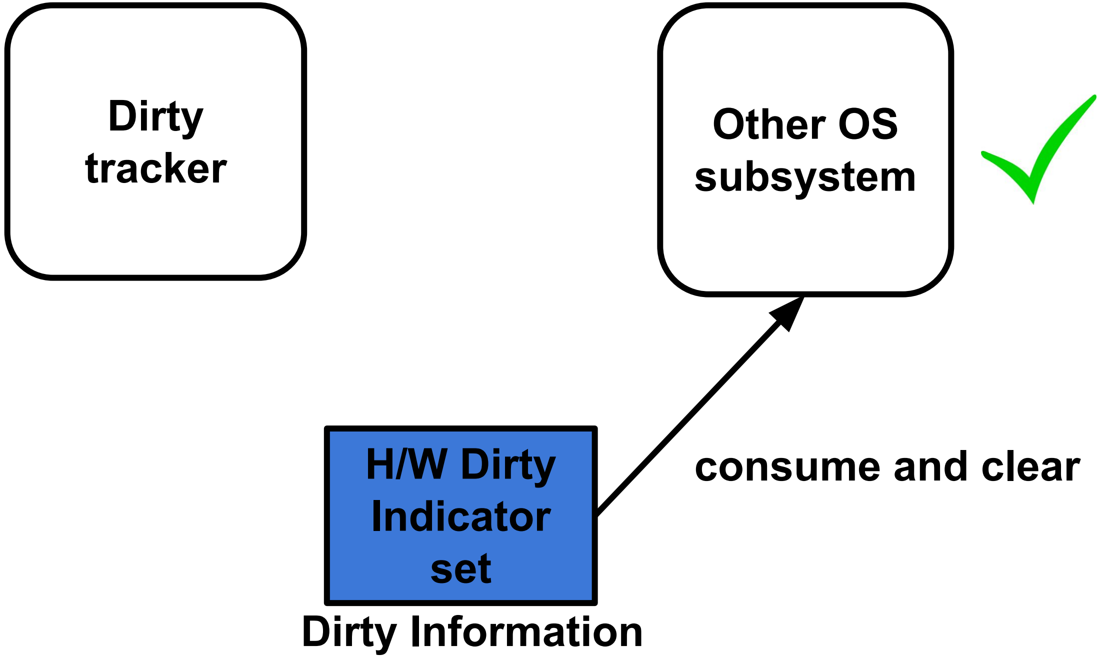

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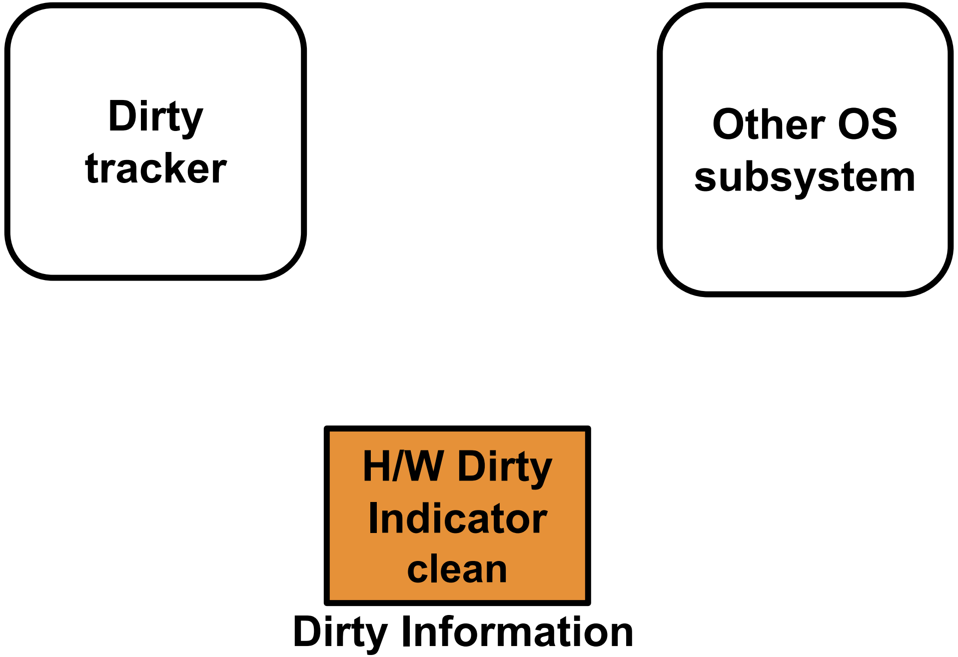

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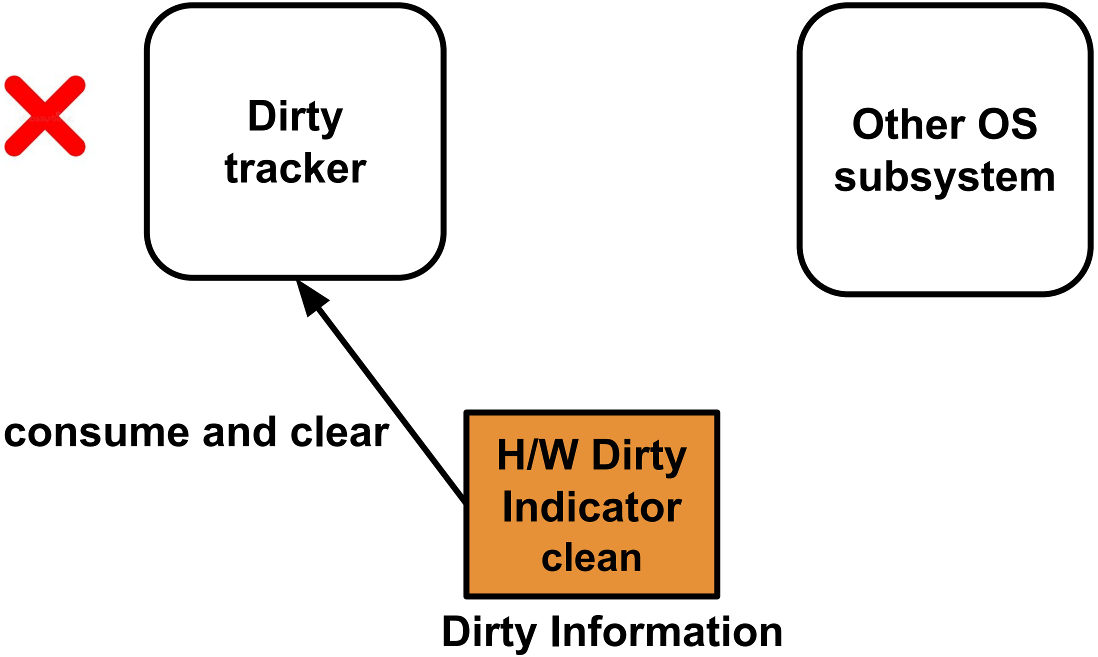

How to overcome the challenges?

LDT: Idea to overcome the challenge

- Translation table entry has unused bits for the software to use.

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- Use 2 unused bits in x86-64 to coordinate with other OS subsystem.
  - Use 1st unused bit to maintain backup of **dirty bit** information for other OS subsystems in case LDT consume and clears.

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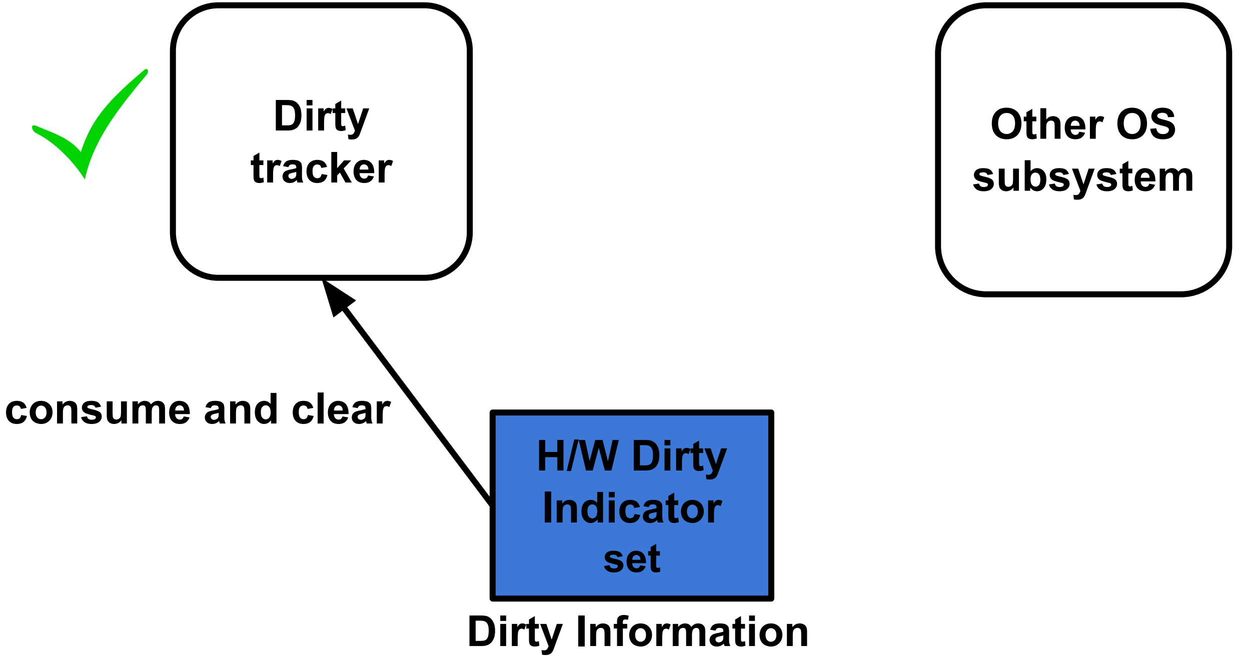
- Use 2 unused bits in x86-64 to coordinate with other OS subsystem.
  - Use 1st unused bit to maintain backup of **dirty bit** information for other OS subsystems in case LDT consume and clears.
  - Use 2nd unused bit to maintain backup of **dirty bit** information for LDT in case other subsystem consume and clears.

LDT: Handle interaction with OS subsystems

Scenario : 1



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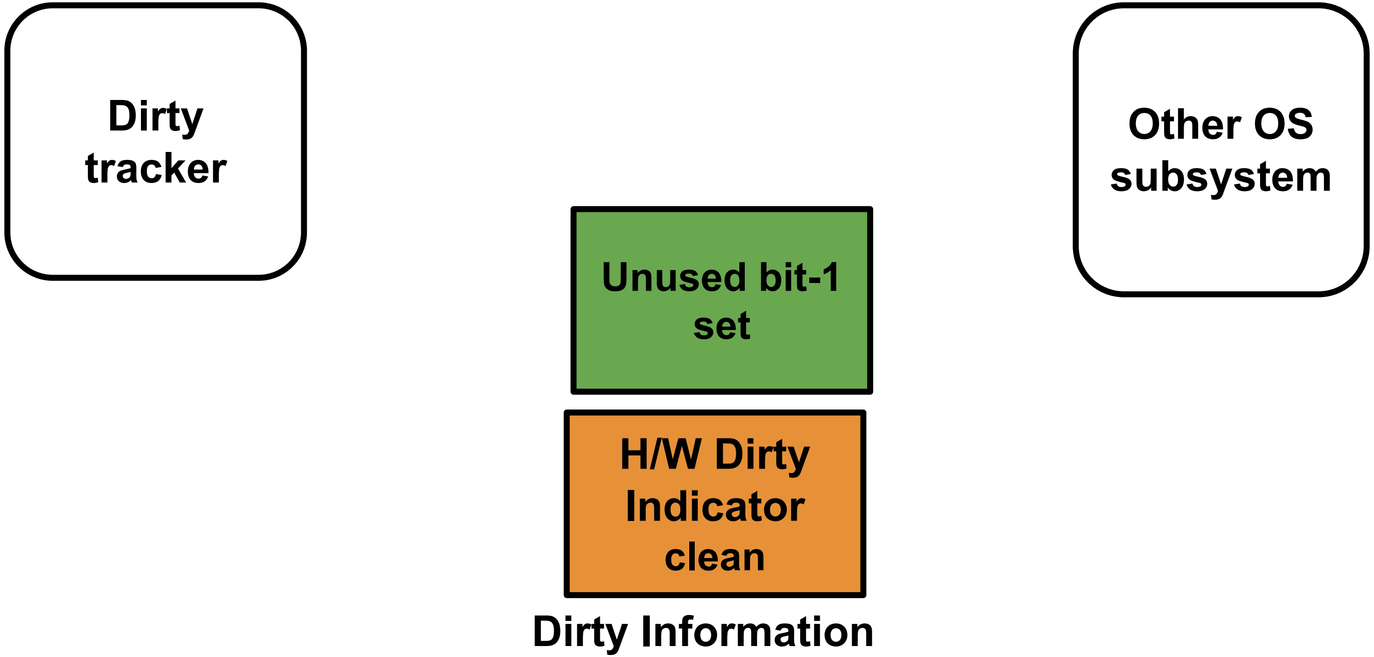

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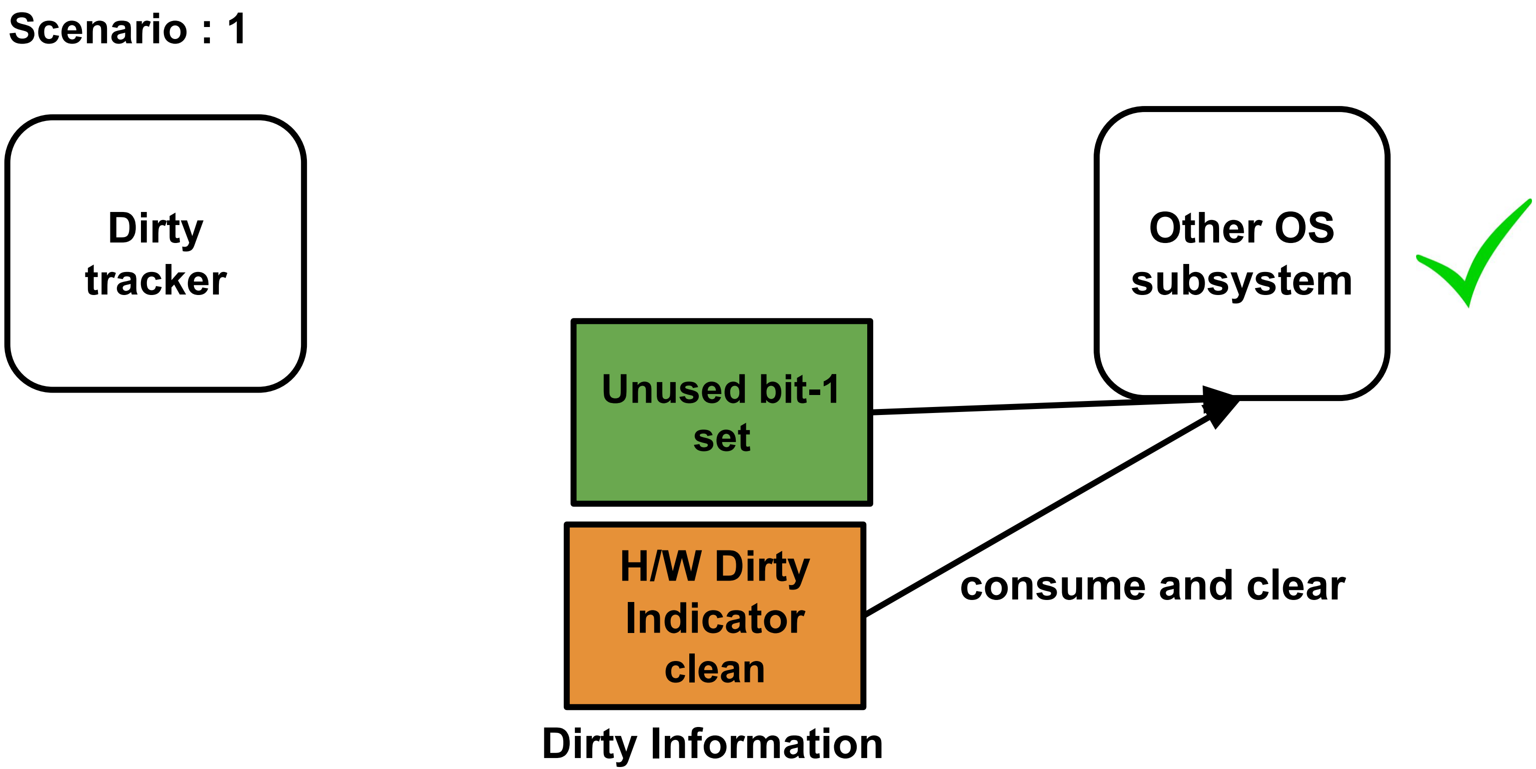

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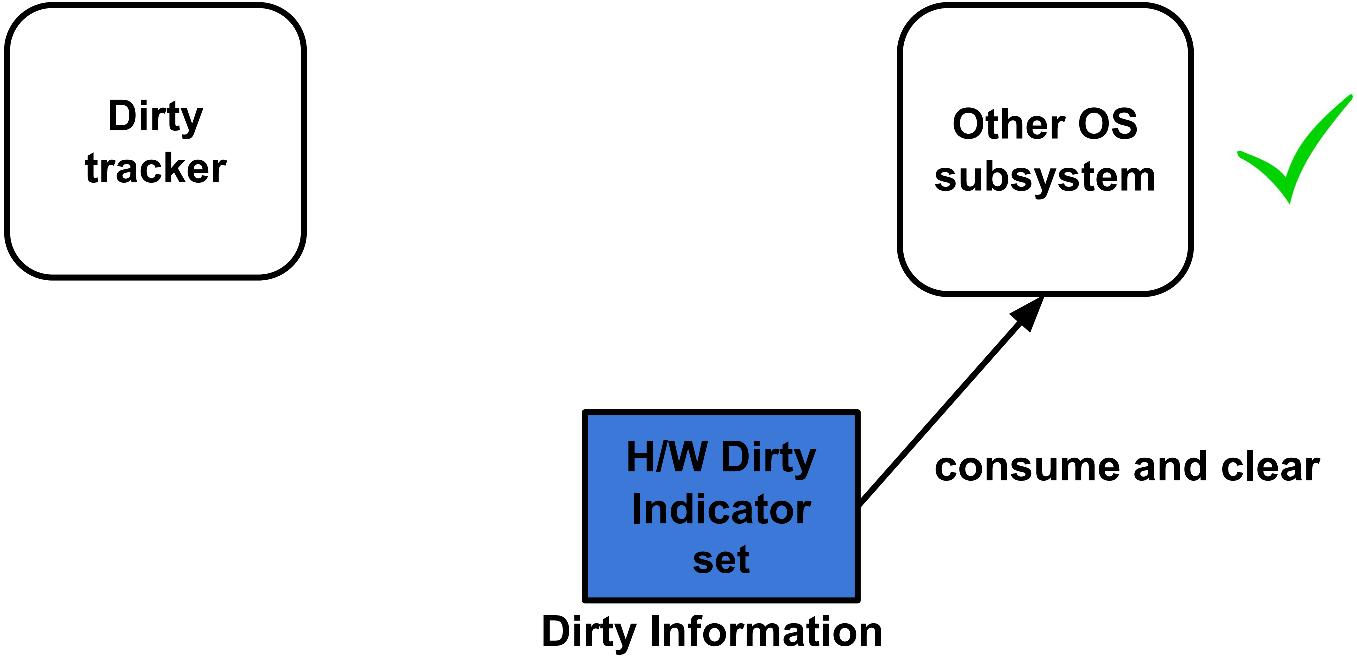

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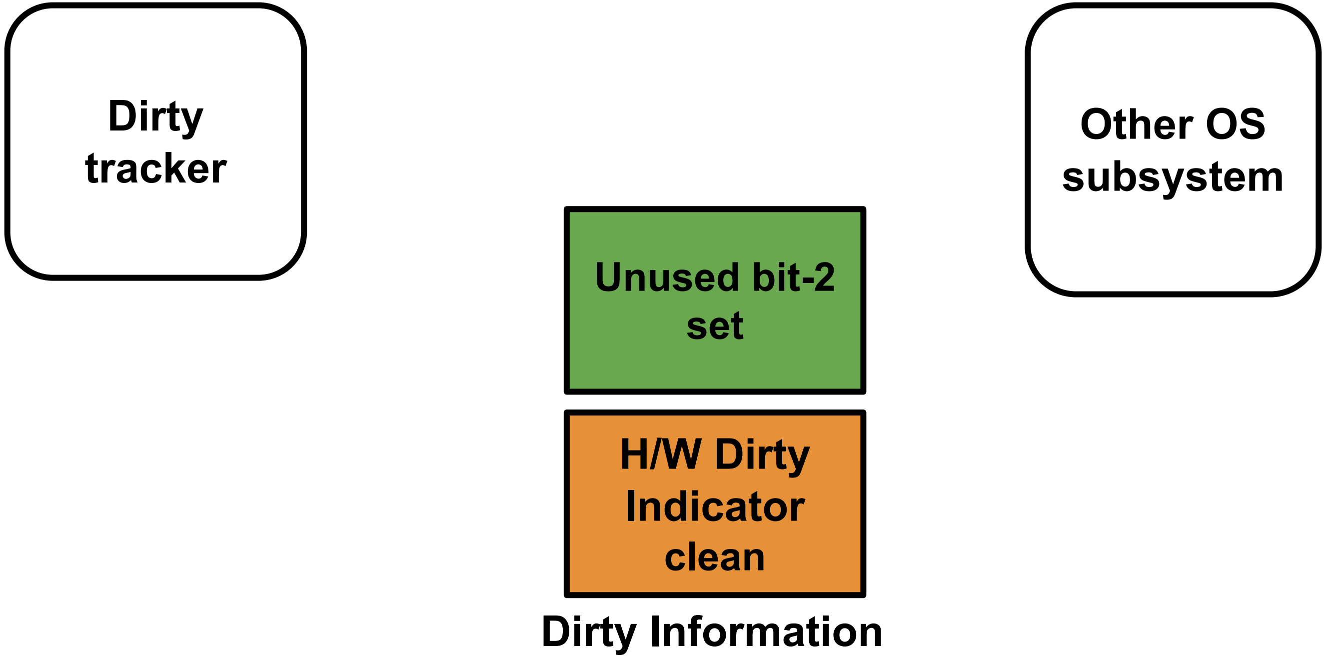

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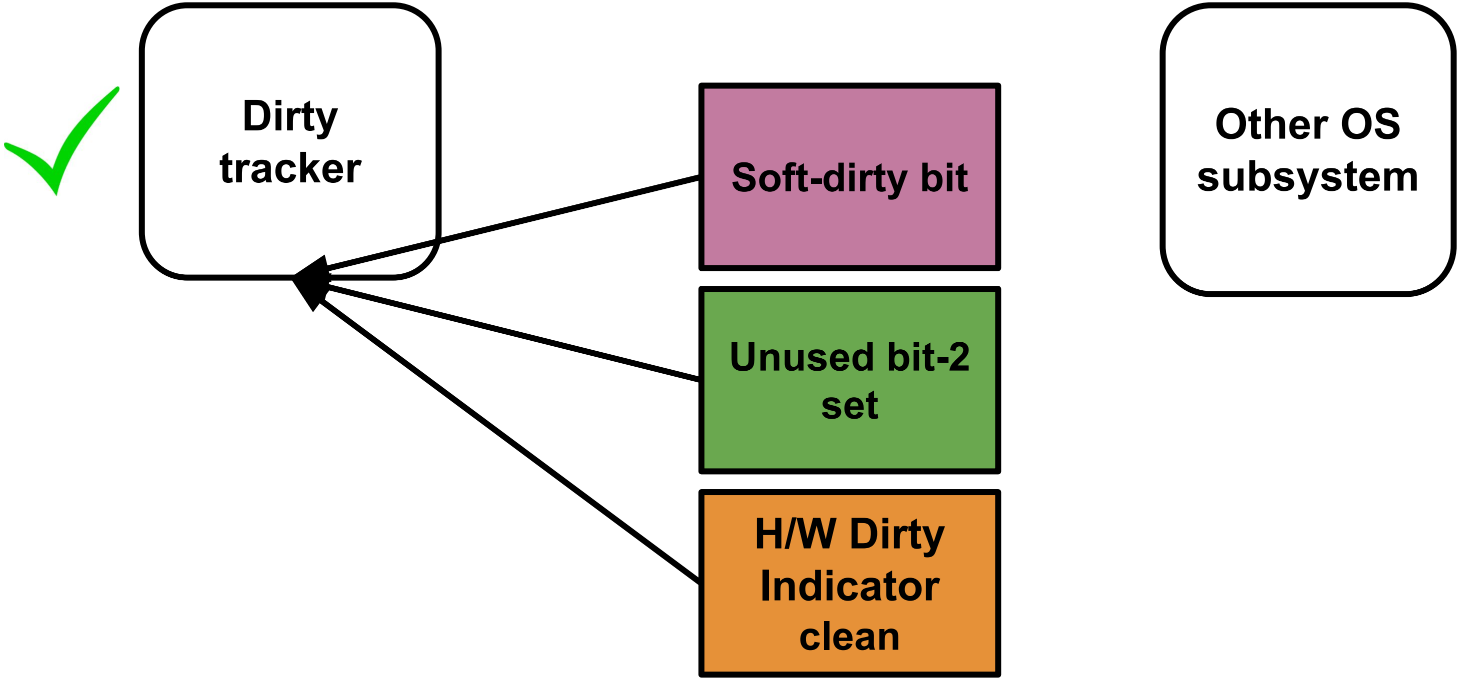


Dirty Information

LDT: Interface to read dirty track information

- Existing dirty tracking interface passes whole translation table entries to userspace.

- LDT dirty tracking interface passes only modified virtual address information to userspace.

We implemented LDT in linux kernel version 5.5.10

LDT Results

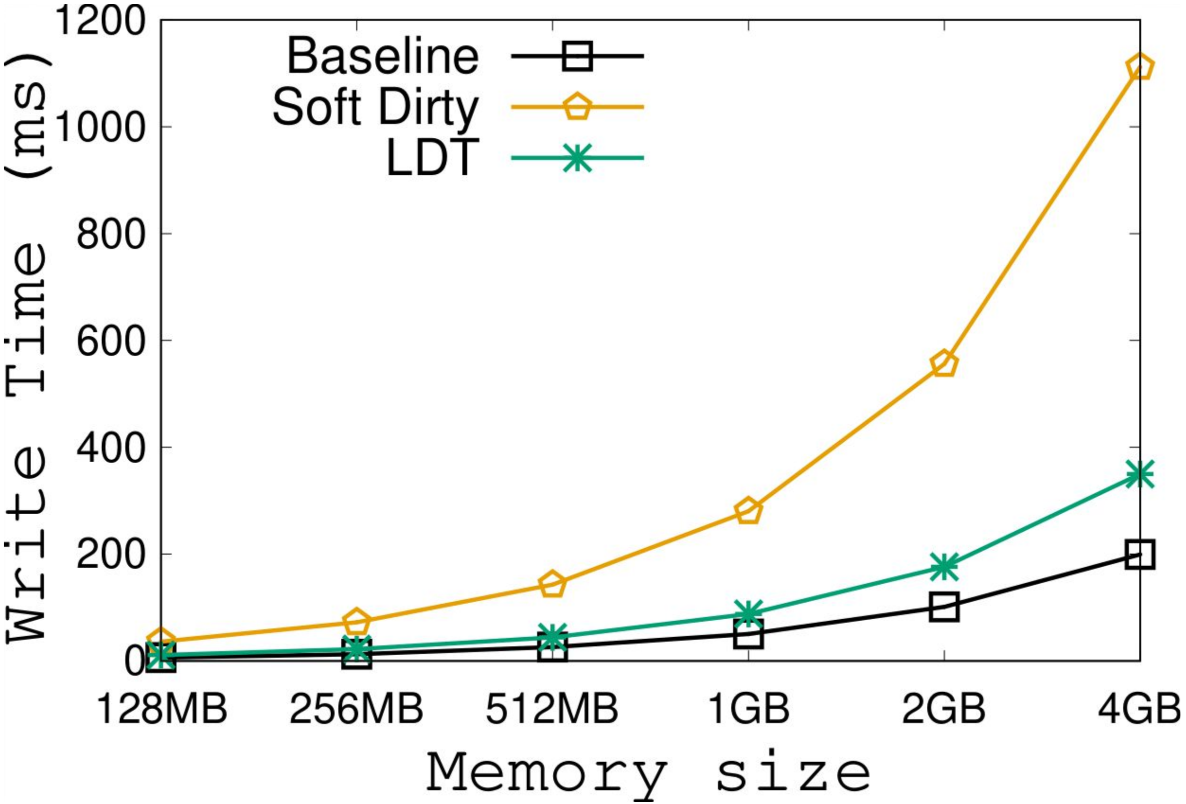
LDT: Correctness checking

- Using micro-benchmarks compared page dirty information given by LDT interface with soft-dirty interface.
- Performed overnight tests with Redis to confirm that LDT is not introducing any kernel issues (assert failures, crashes etc).
- Extreme memory pressure scenarios created using Redis to introduce swapping.
- Performed iterative migration of a container hosting Redis. Docker container is restored correctly and starts serving requests normally after restore.

Evaluation: System Specifications

CPU	Intel i7-4770 CPU @ 3.40GHz
L1-D/I	32 KB (8 way)
L2	256 KB (8 way)
L3	8 MB (16 way)
DRAM	16 GB
Distribution	Ubuntu 18.04.3 LTS
Linux Kernel	5.5.10

Evaluation: Write only scenario



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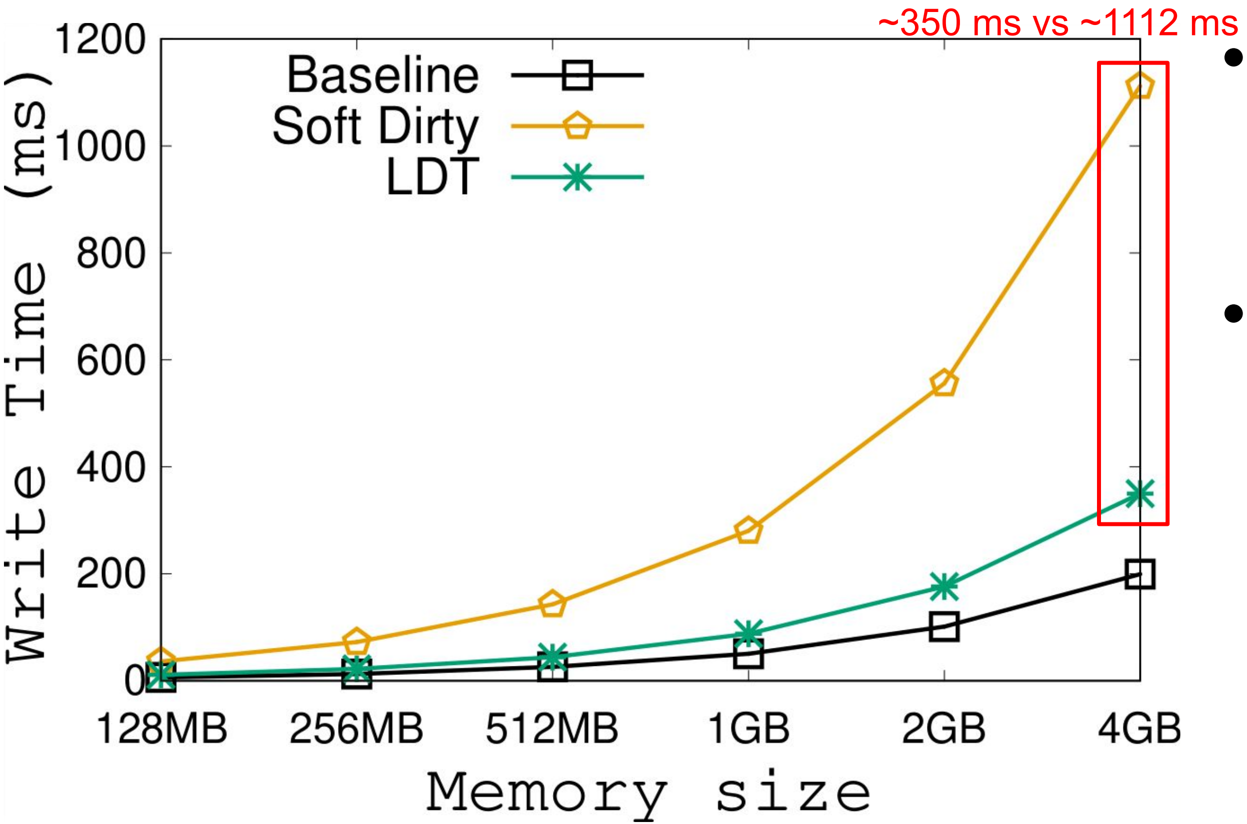

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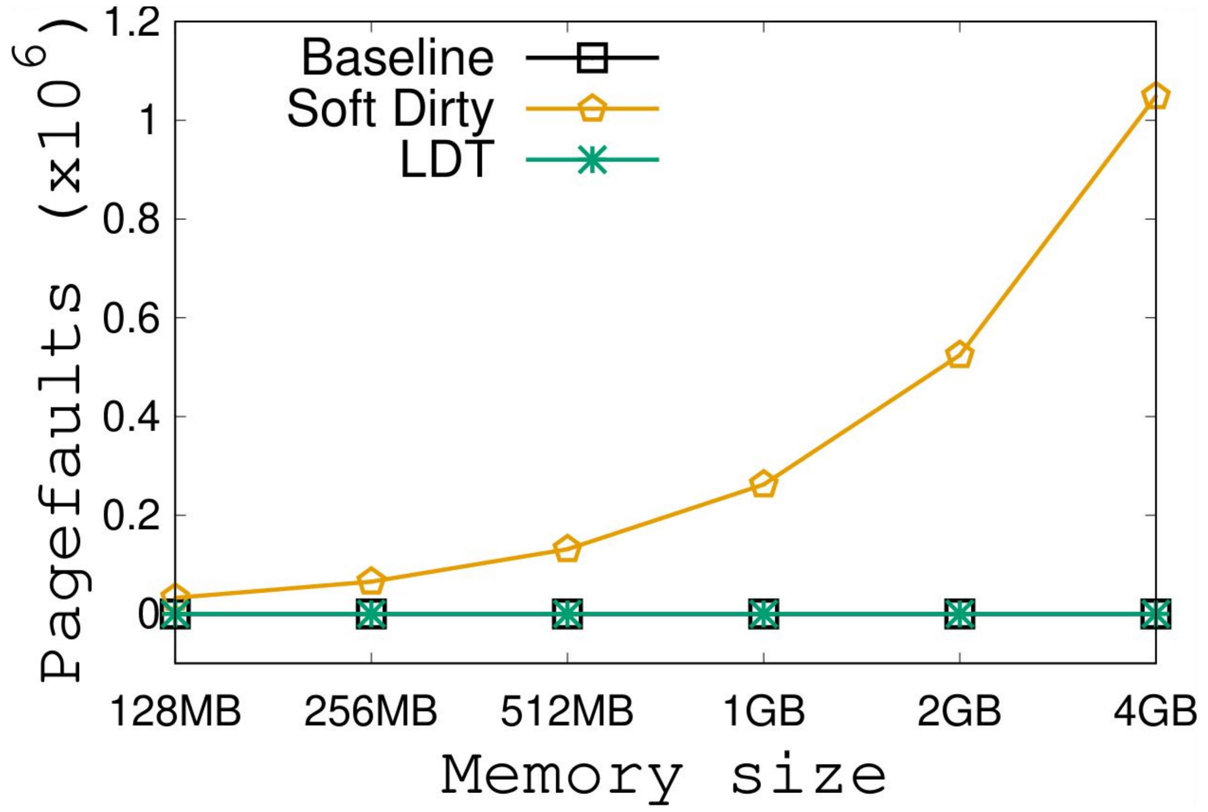

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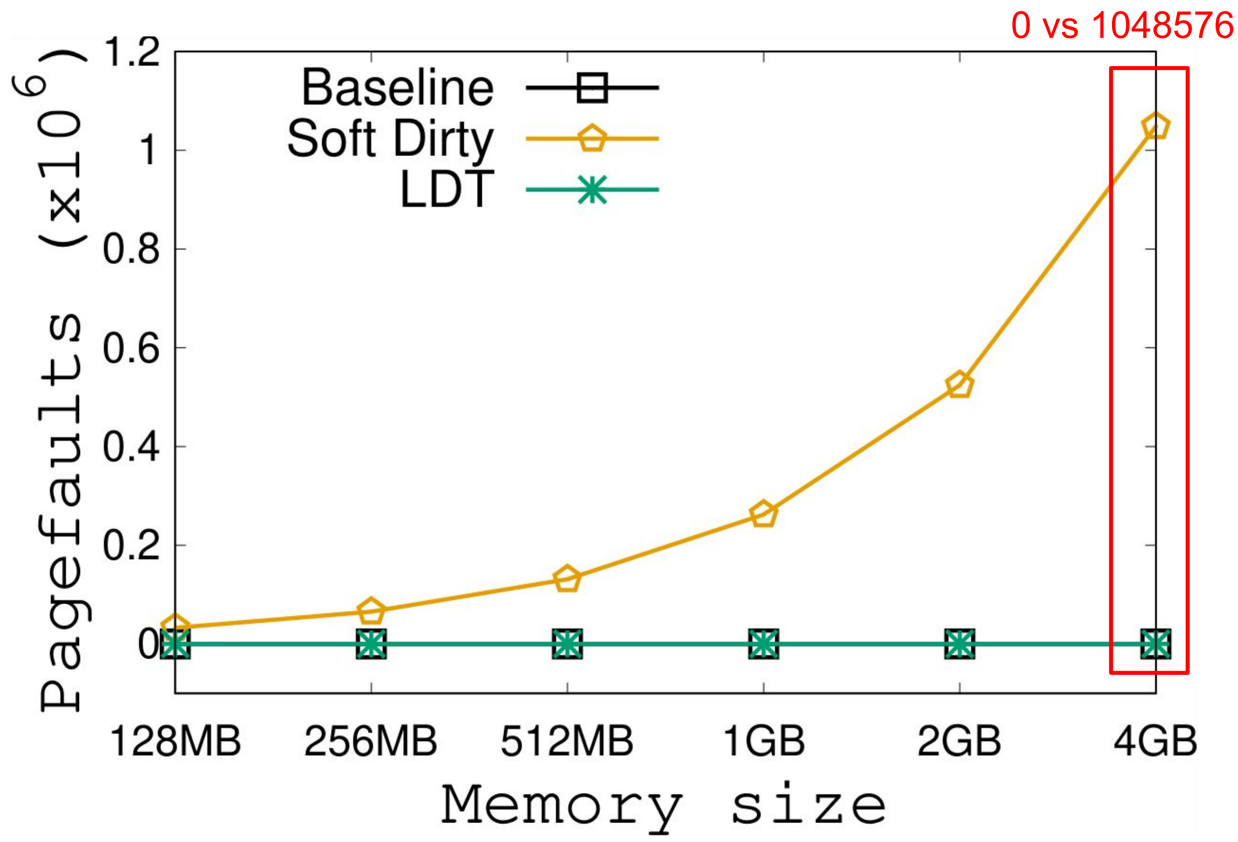

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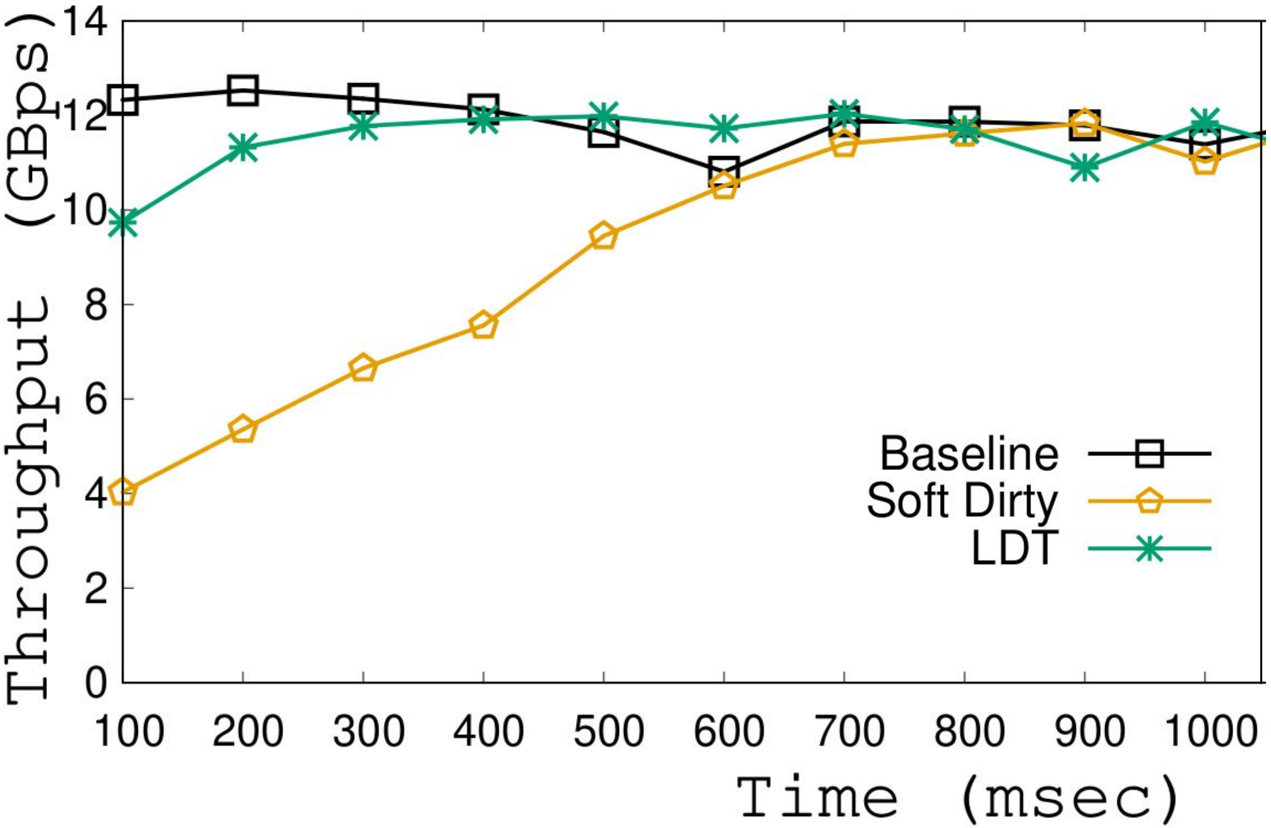

- Under 25% read, 75% write workload, throughput every 100ms

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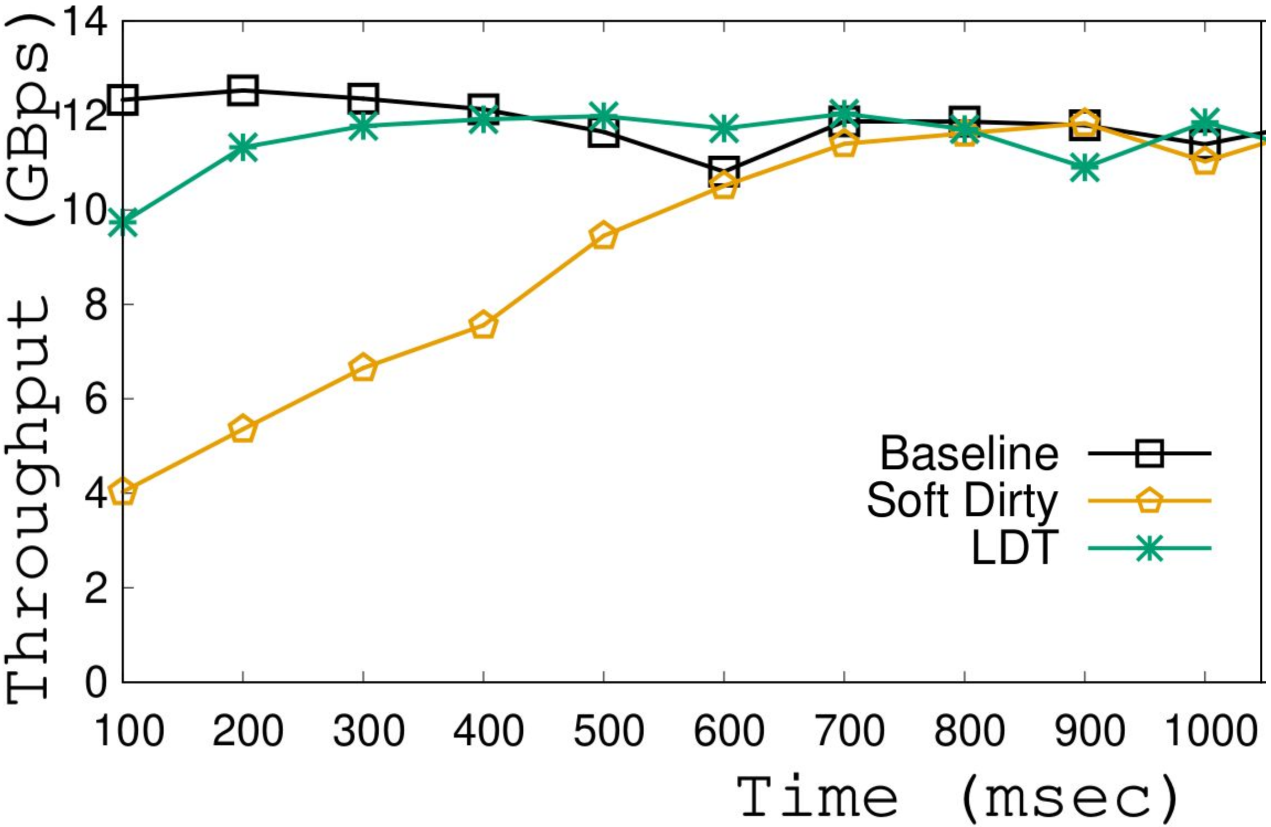

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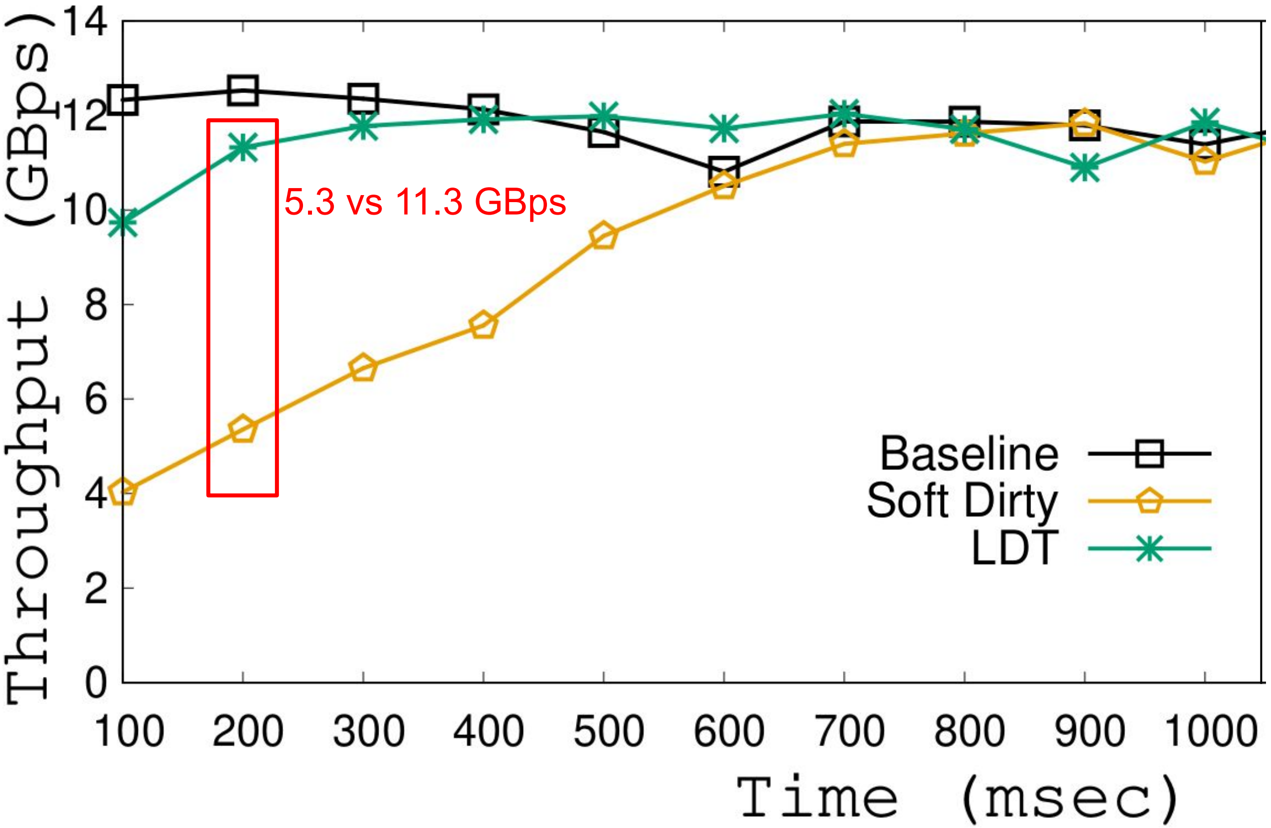

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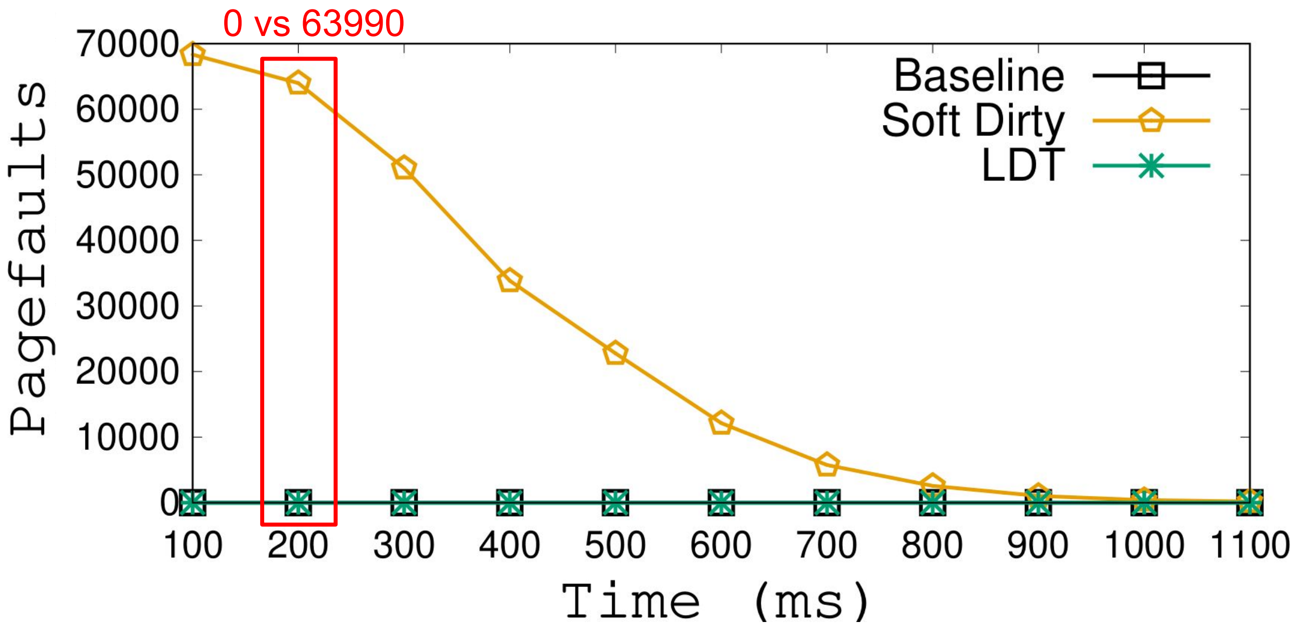

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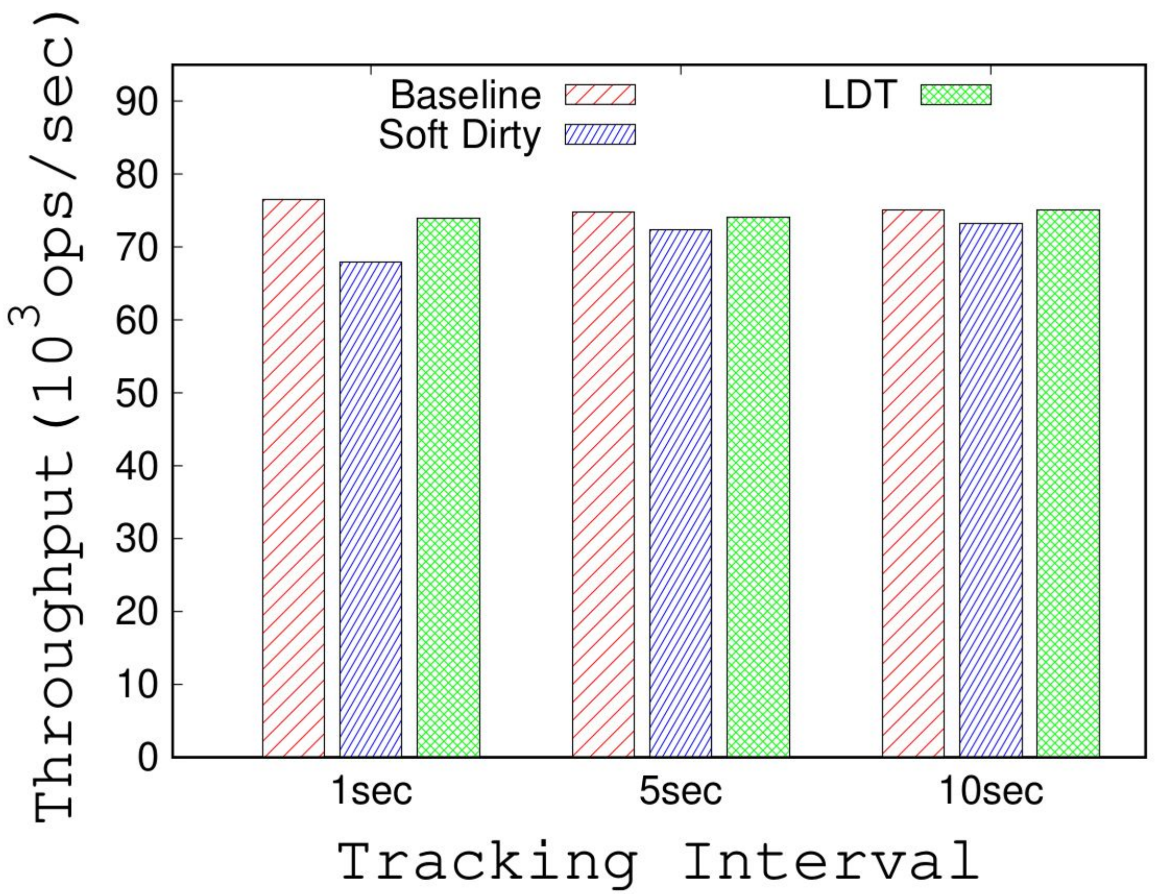

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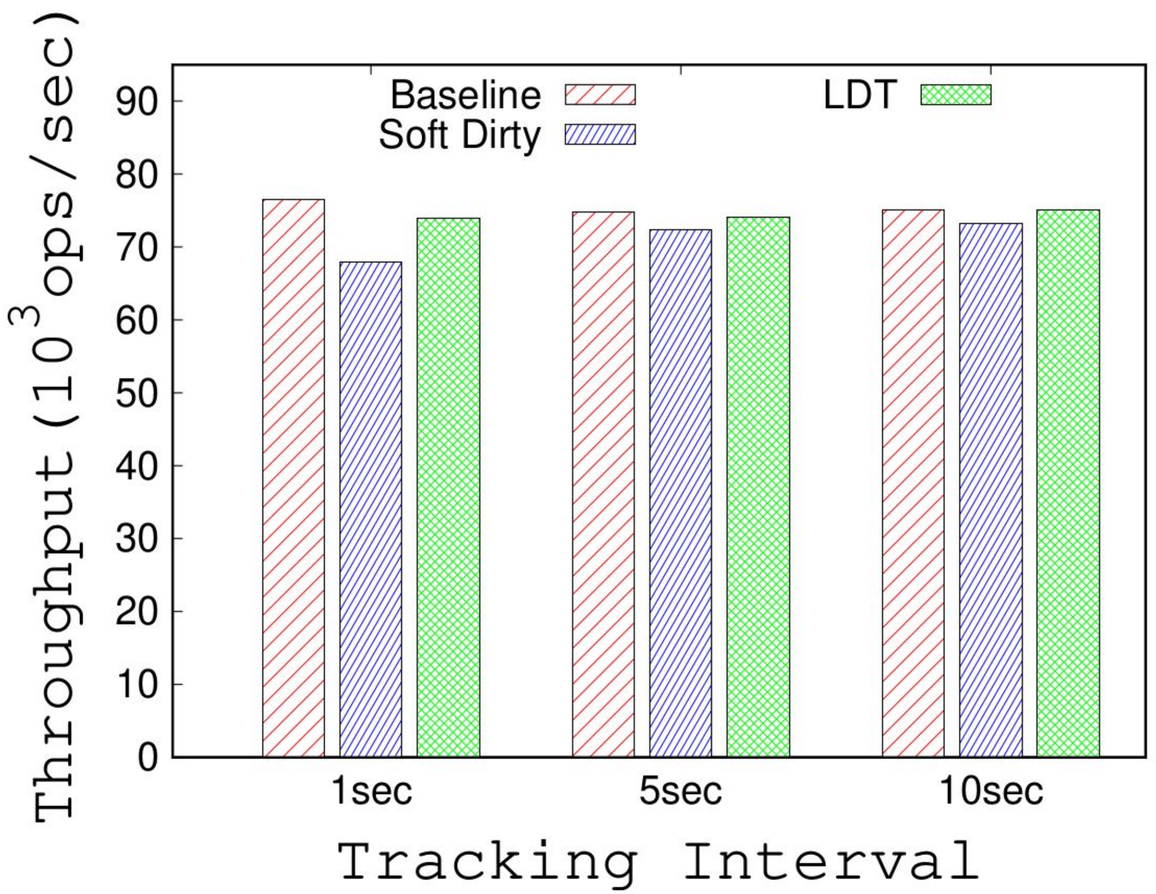

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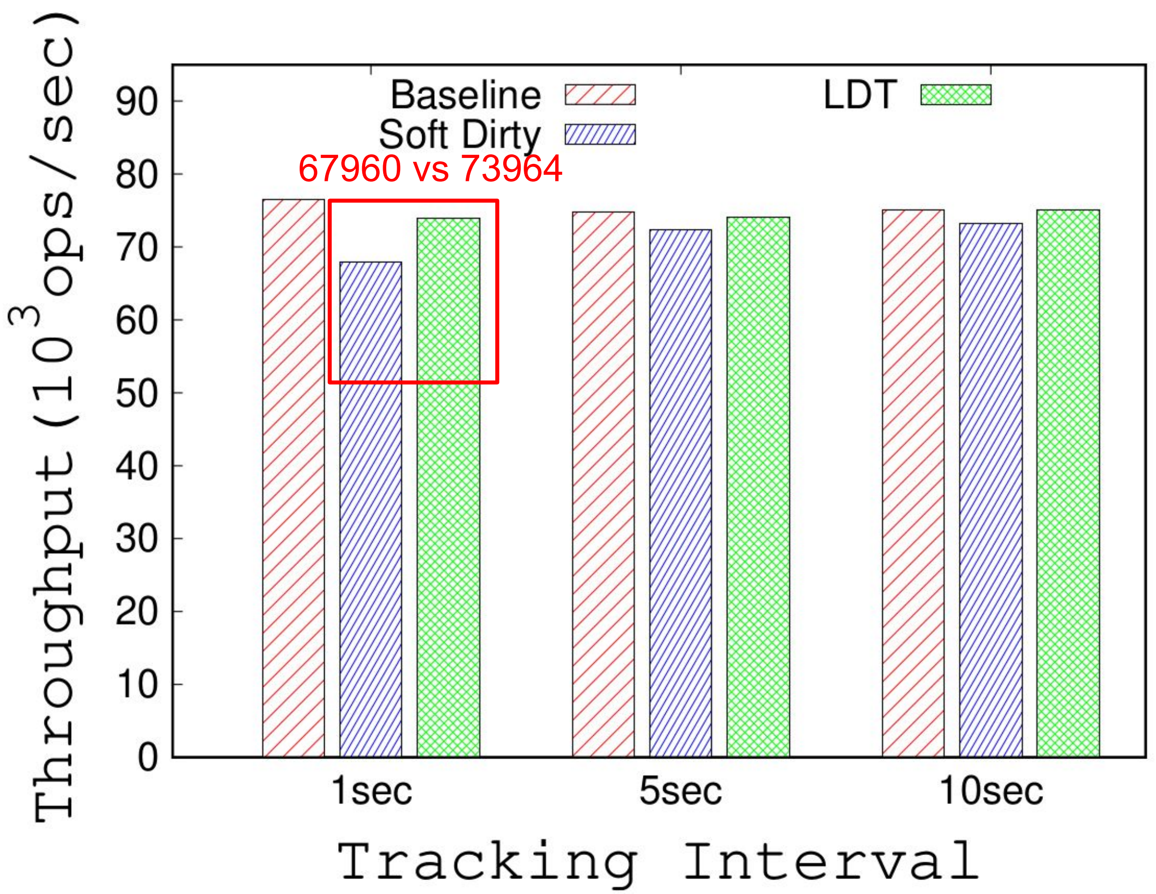

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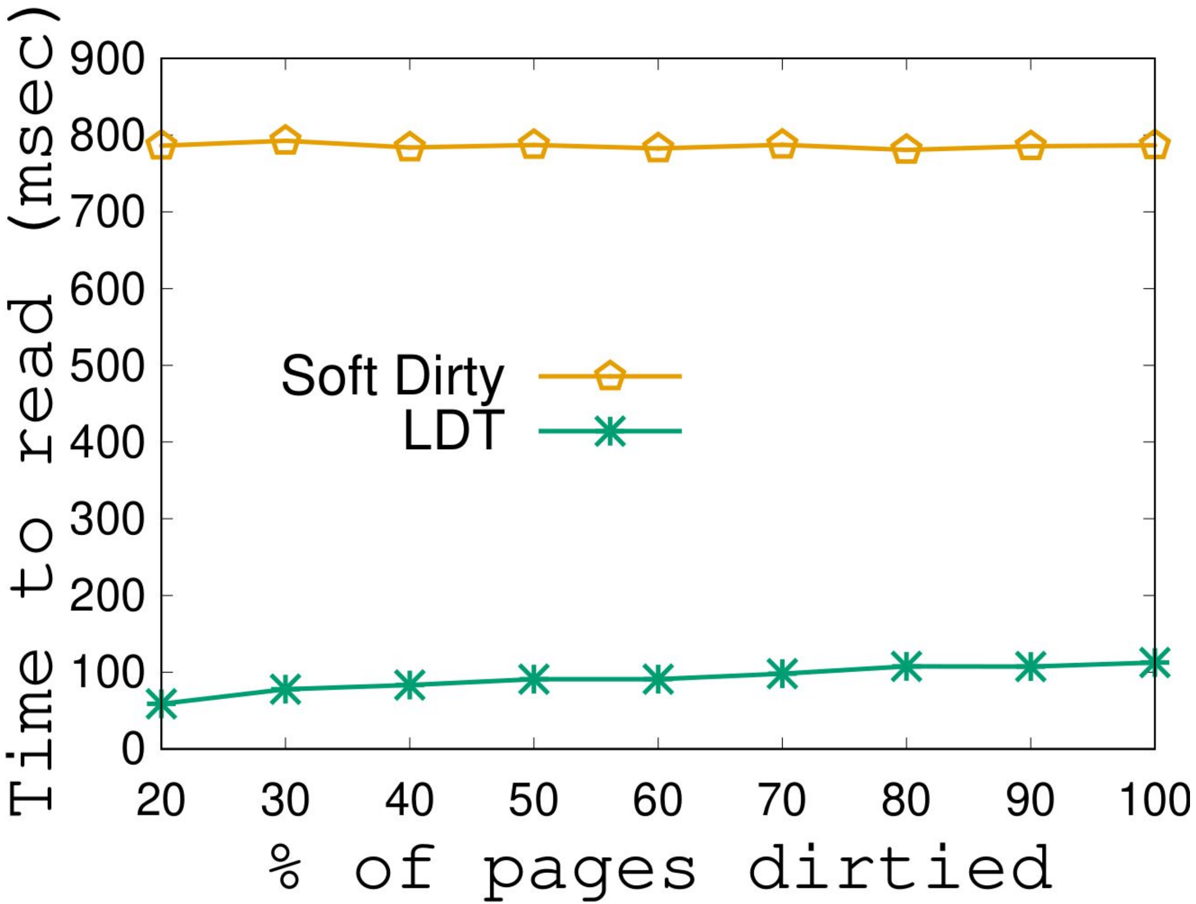
- Baseline gives best throughput, LDT throughput is close to baseline. Soft dirty incurs worse throughput

Evaluation: Time to read dirtied page information



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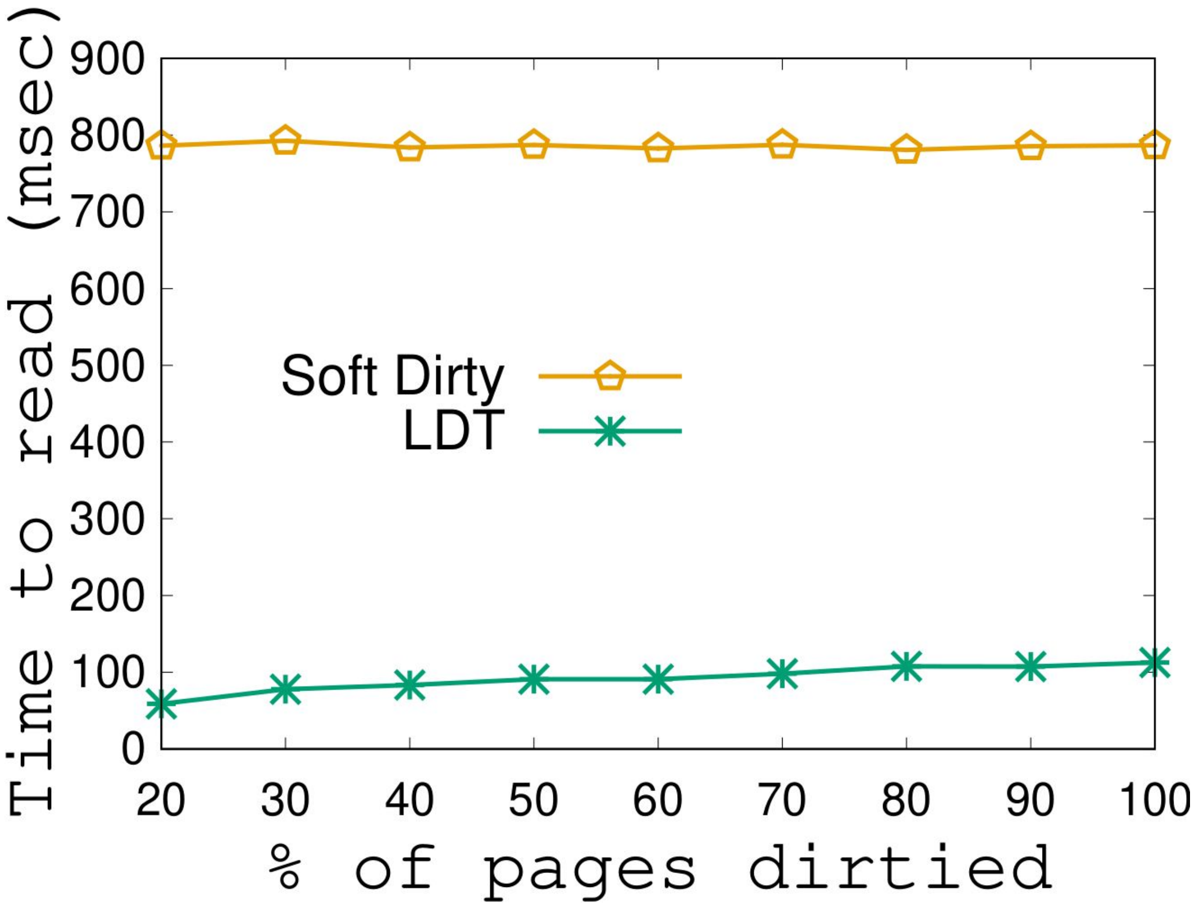

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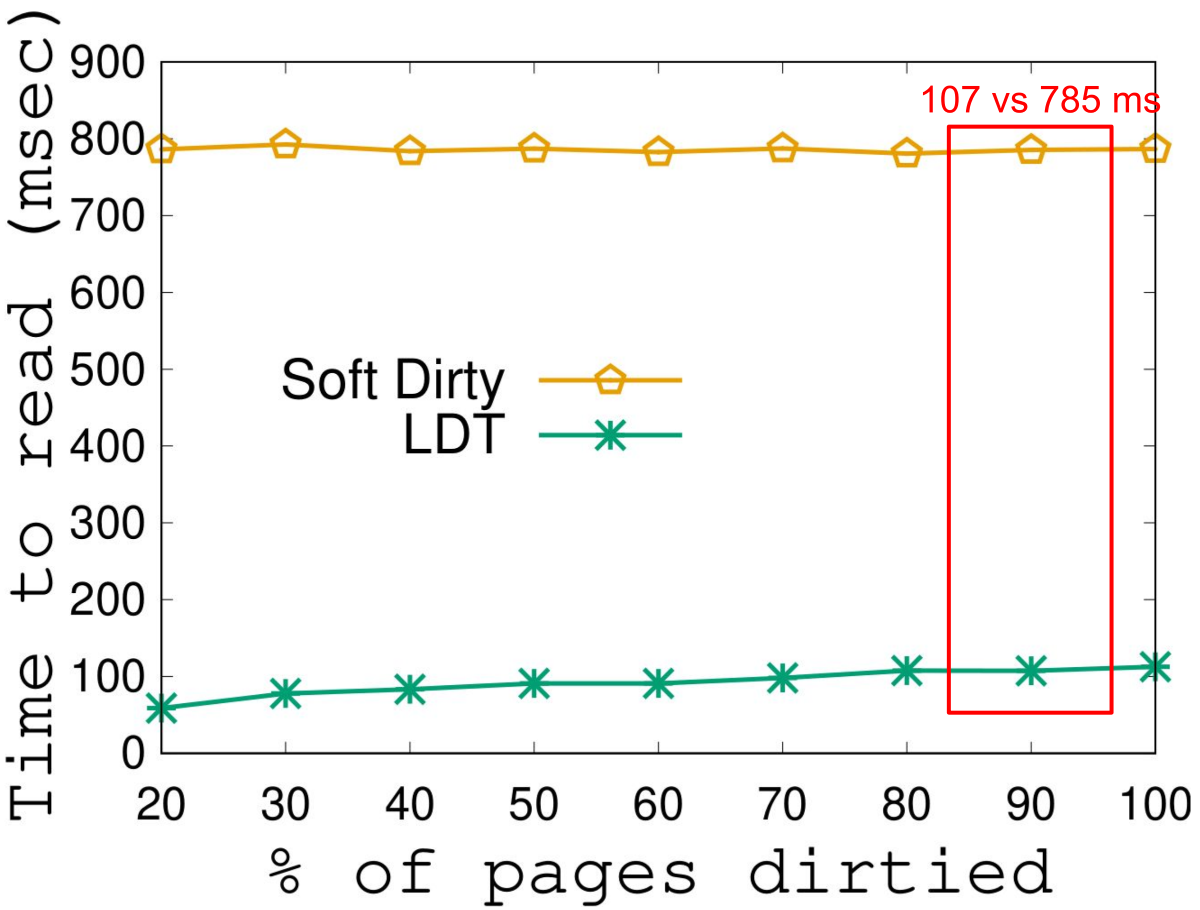

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- Soft dirty takes more time because it reports dirty status for entire address space

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- LDT showed ~2.4x improvement over state of the art dirty tracking for a workload with 75% writes.

Questions?