Reducing Write Barrier Overheads for Orthogonal Persistence

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Reducing Write Barrier Overheads for Orthogonal Persistence

Persistence

- Non-volatile memory (NVM)
  - Intel Optane
  - Objects in byte-addressable NVM can be accessed in the same way as those in DRAM
  - Faster than SSD but slower than DRAM
  - Hybrid systems used in practice

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- Non-volatile memory (NVM)
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  - Objects in byte-addressable NVM can be accessed in the same way as those in DRAM
  - Faster than SSD but slower than DRAM
  - Hybrid systems used in practice
- Issues
  - Which objects must be made persistent ? When should the object become persistent ?
  - Tedious and error-prone task for programmers

Reducing Write Barrier Overheads for Orthogonal Persistence

Orthogonal Persistence

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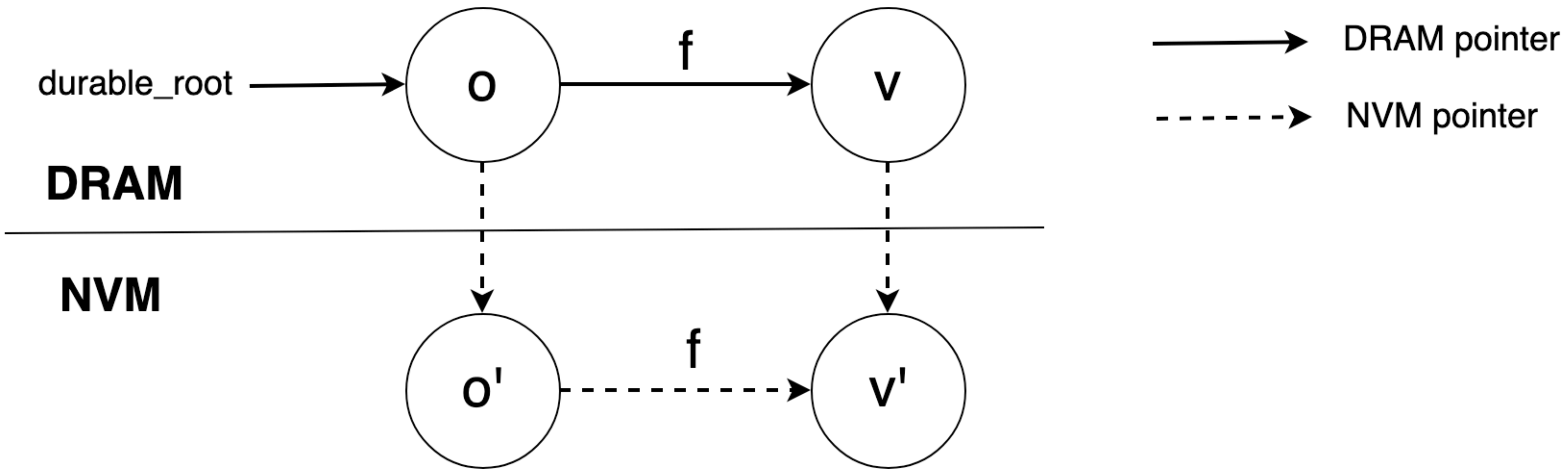
- Persistence of objects decided by reachability
- Objects reachable from persistent roots are copied to NVM without programmer's intervention (Replication-based object persistence) [Matsumoto et al. 2022]



Orthogonal Persistence

- Persistence of objects decided by reachability
- Programmers can annotate static fields as persistent roots
- Objects reachable from persistent roots are copied to NVM without programmer's intervention
- Issues
  - Java supports multi-threading
  - Concurrent access: One thread is modifying an object while another thread is attempting to copy it to NVM.

Concurrent Access

Case 1: Replica of o is absent

Copier Thread

durable_root = o

Writer Thread (o.f = v)

```
def putfield( o, f, v ):
        o[f] = v

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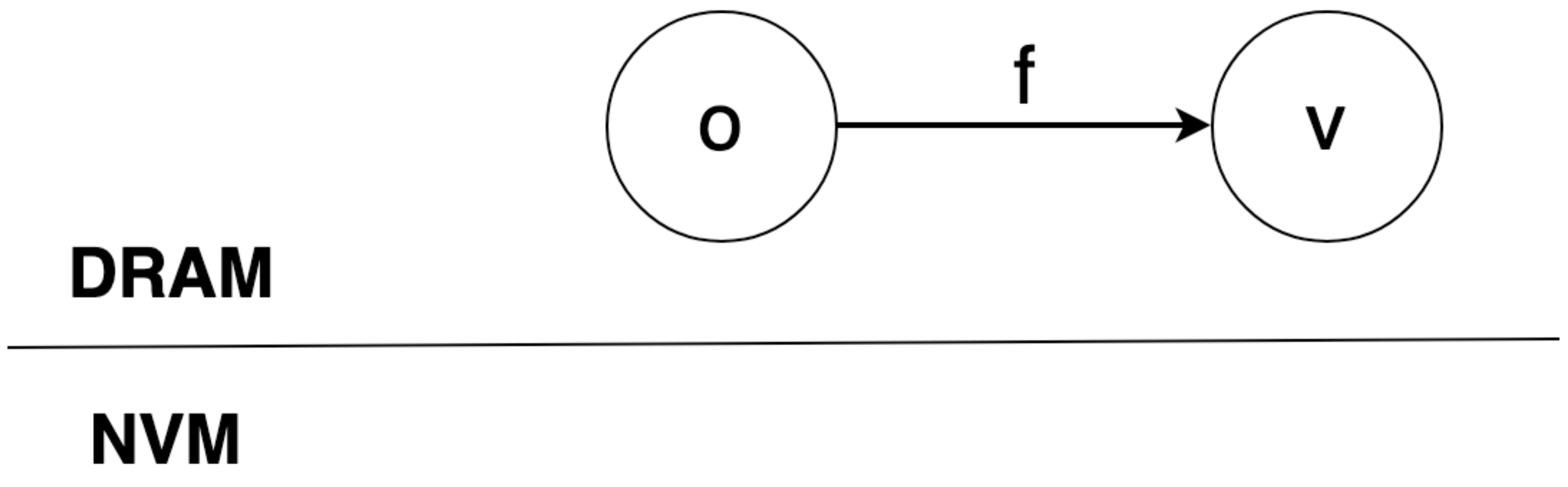

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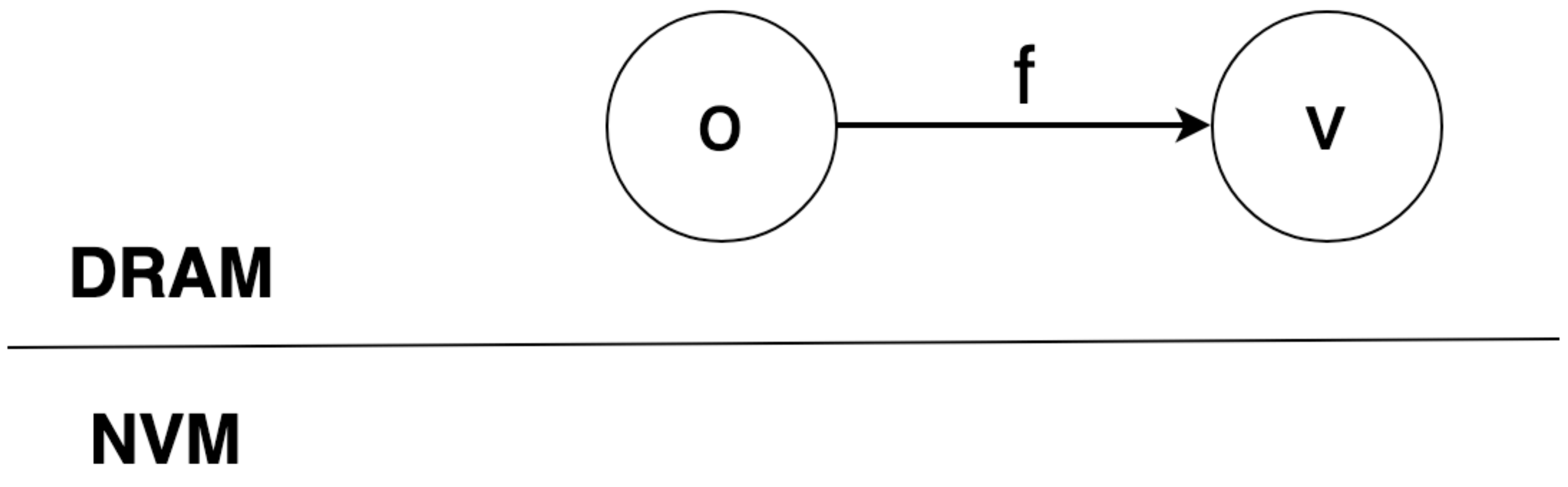

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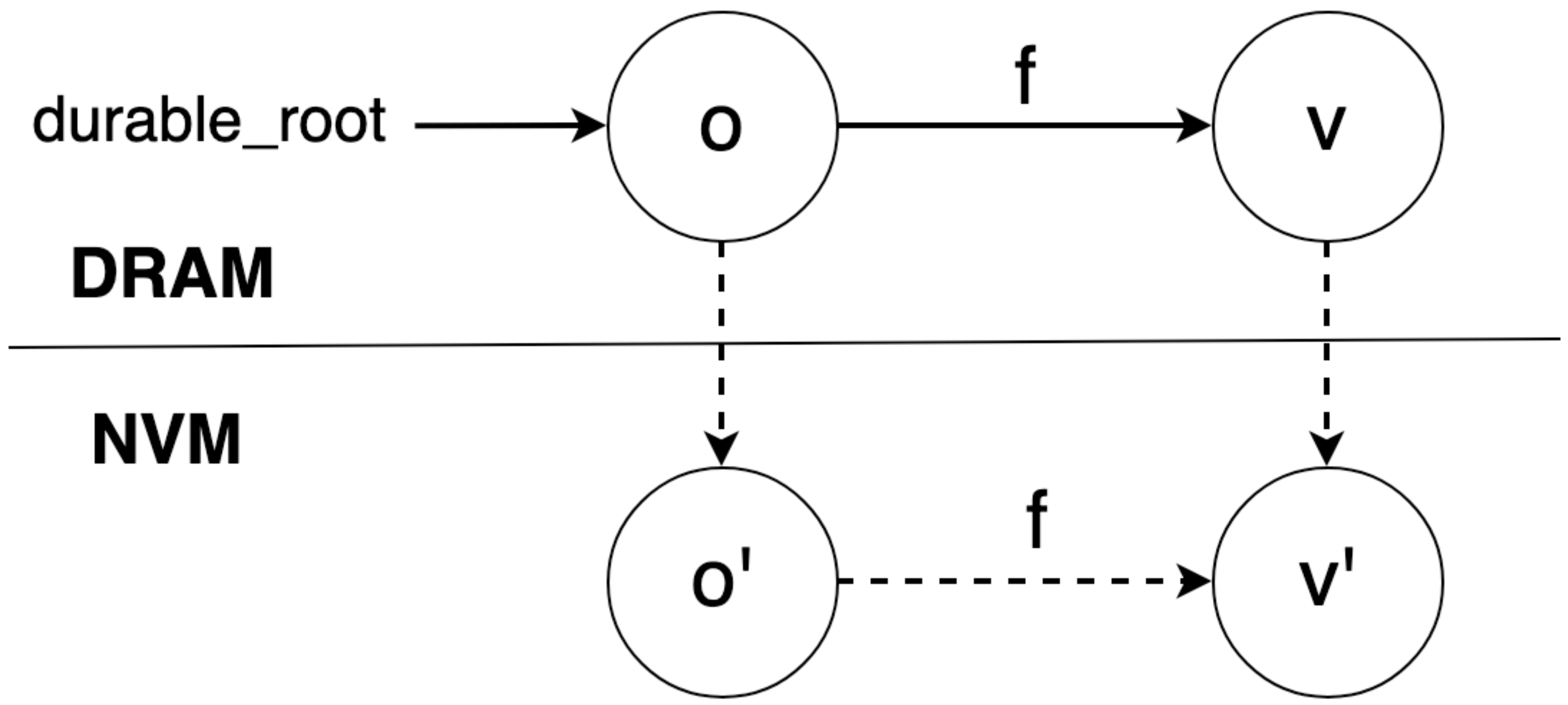

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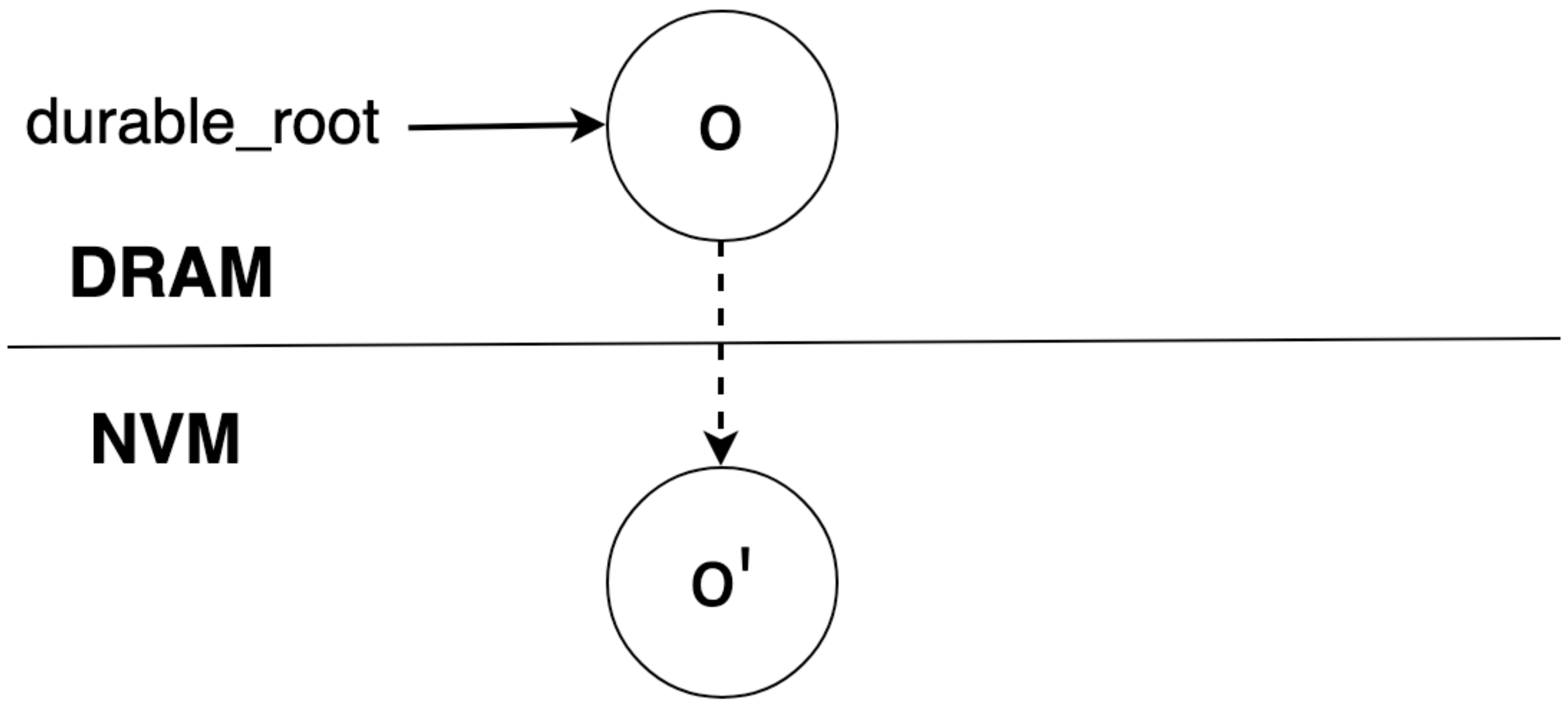

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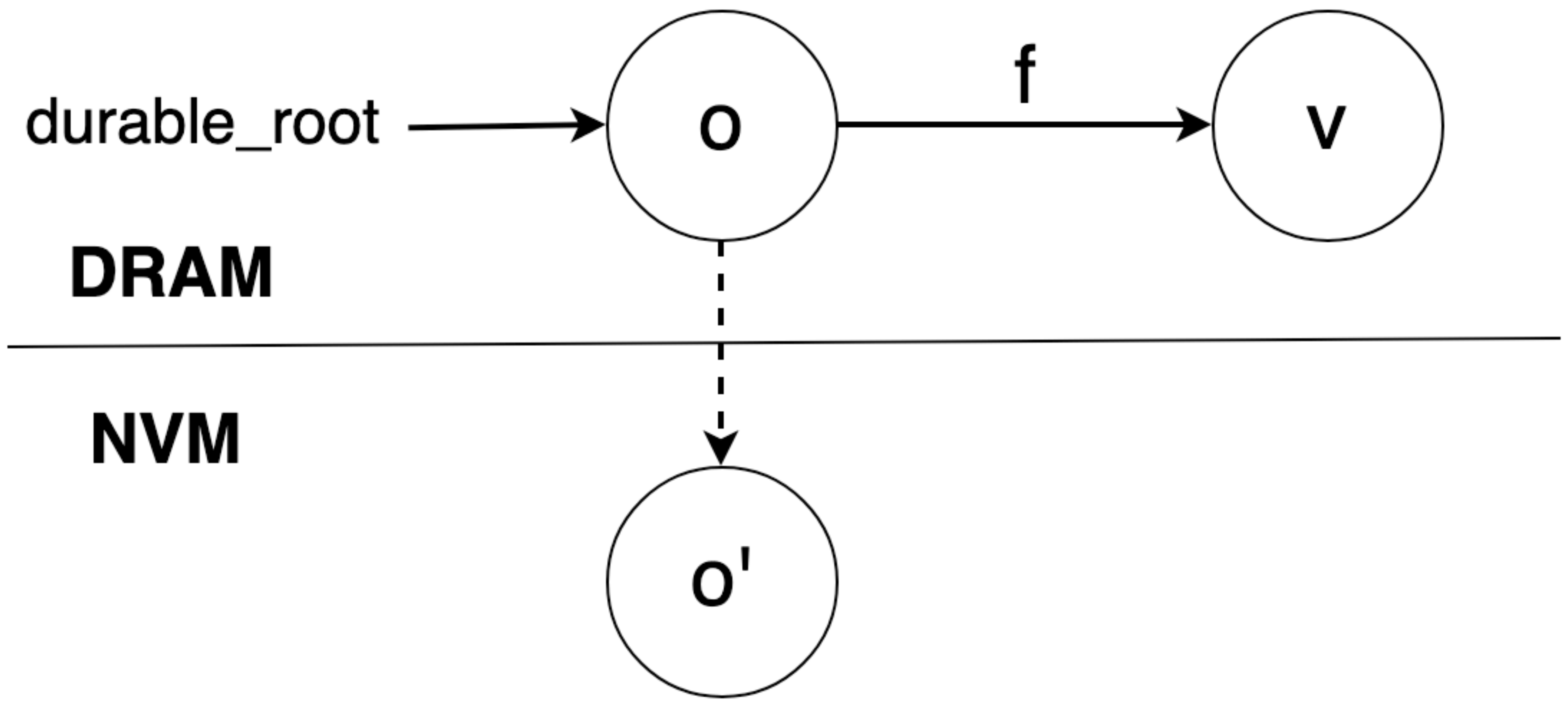

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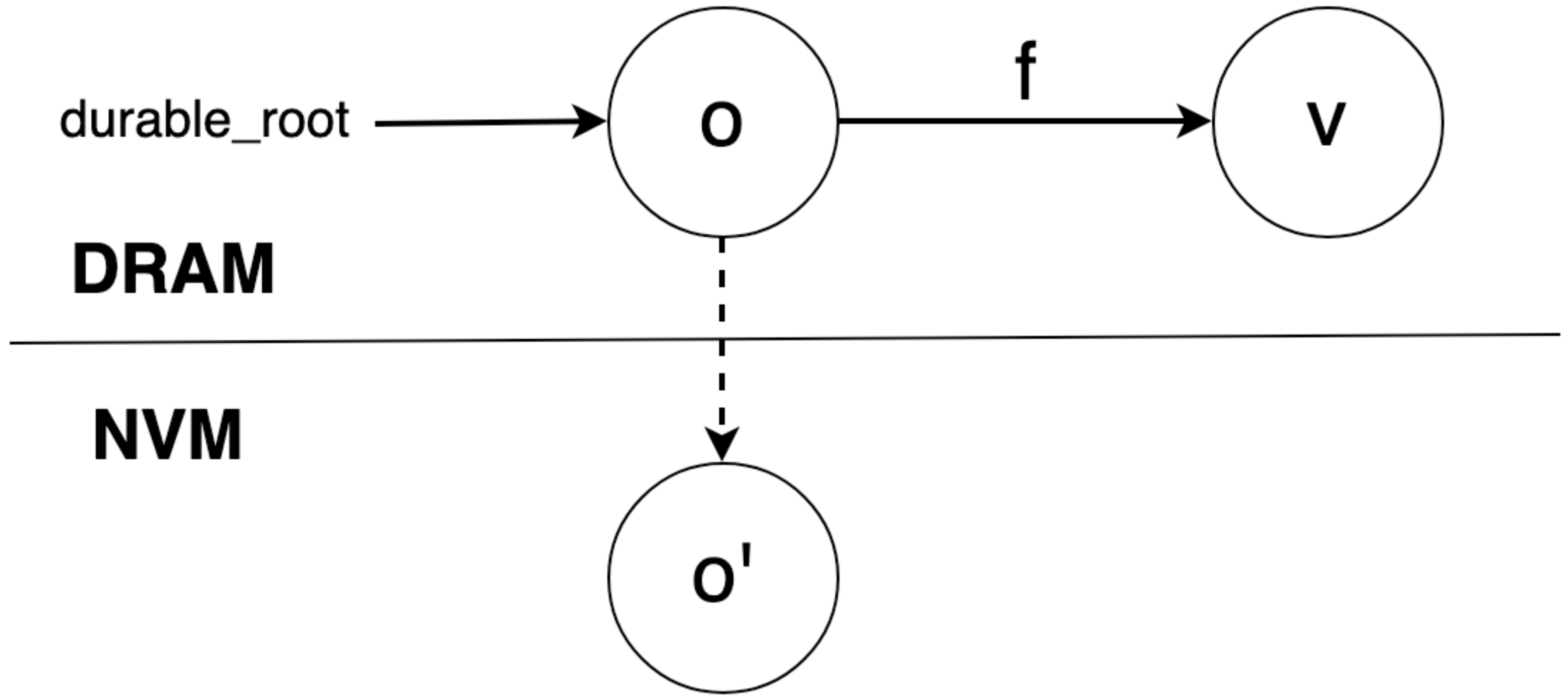

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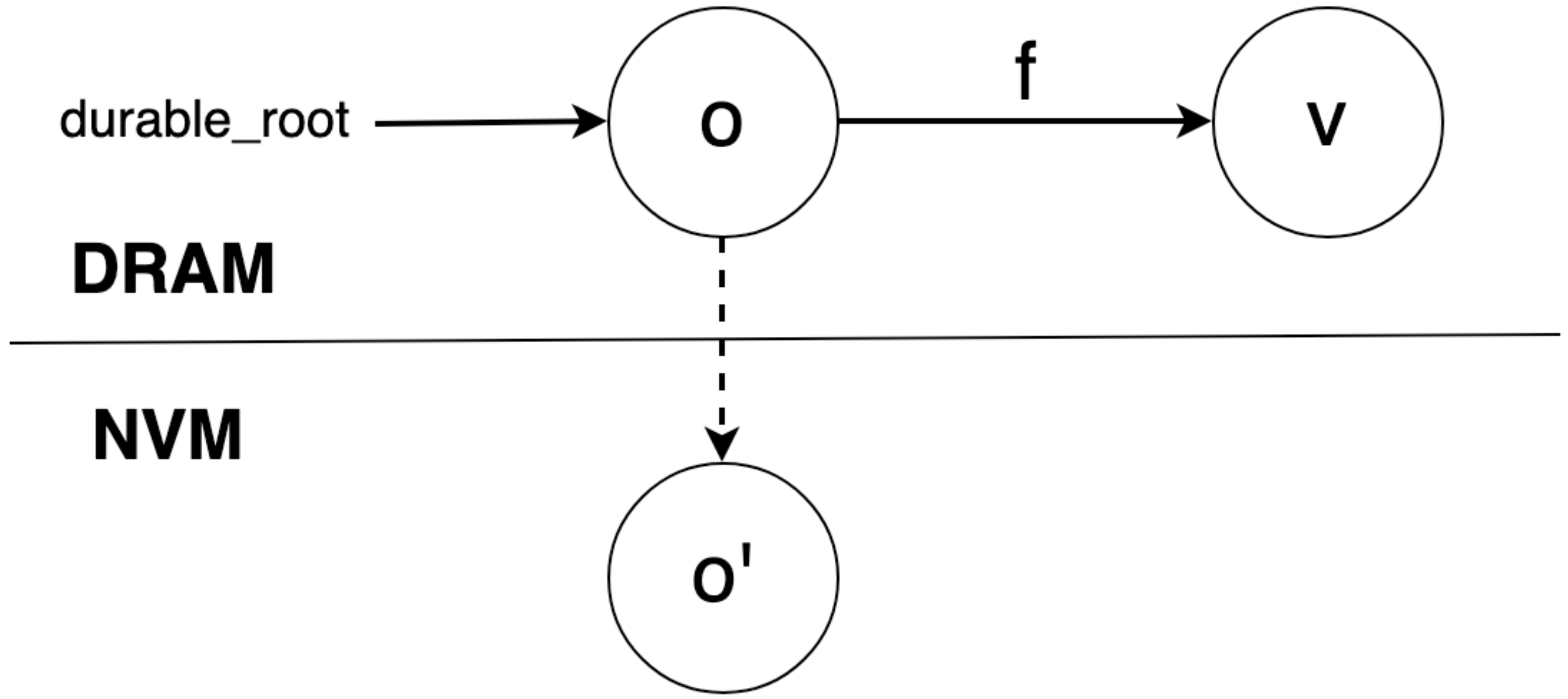

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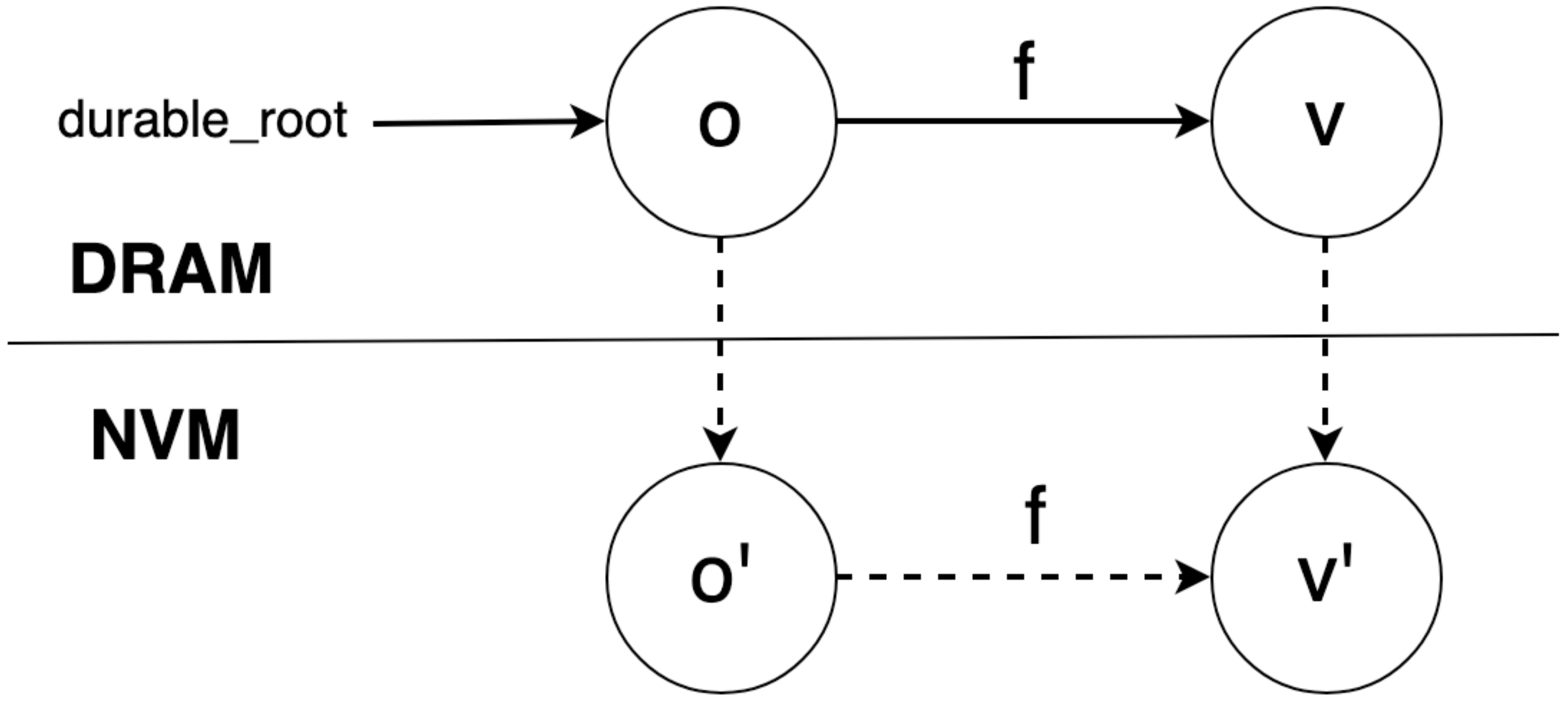

Concurrent Access

Case 3: Instructions are reordered (x86 Weak memory consistency model)

Concurrent Access

Case 3: Read at Line 4 is reordered with Write at Line 2

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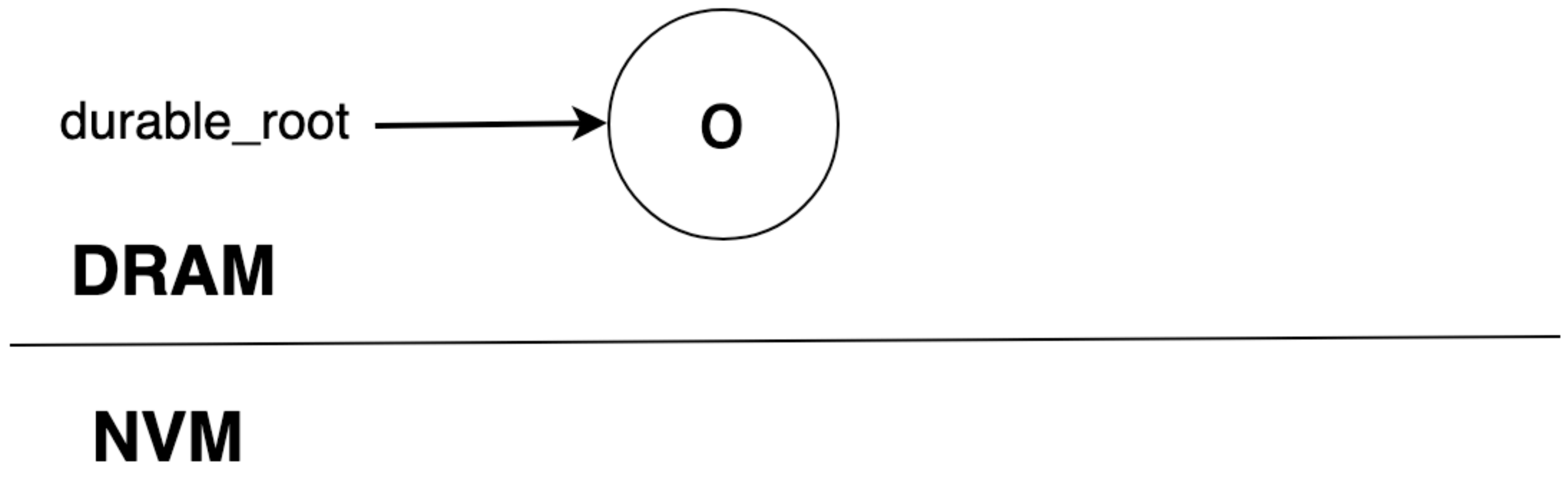

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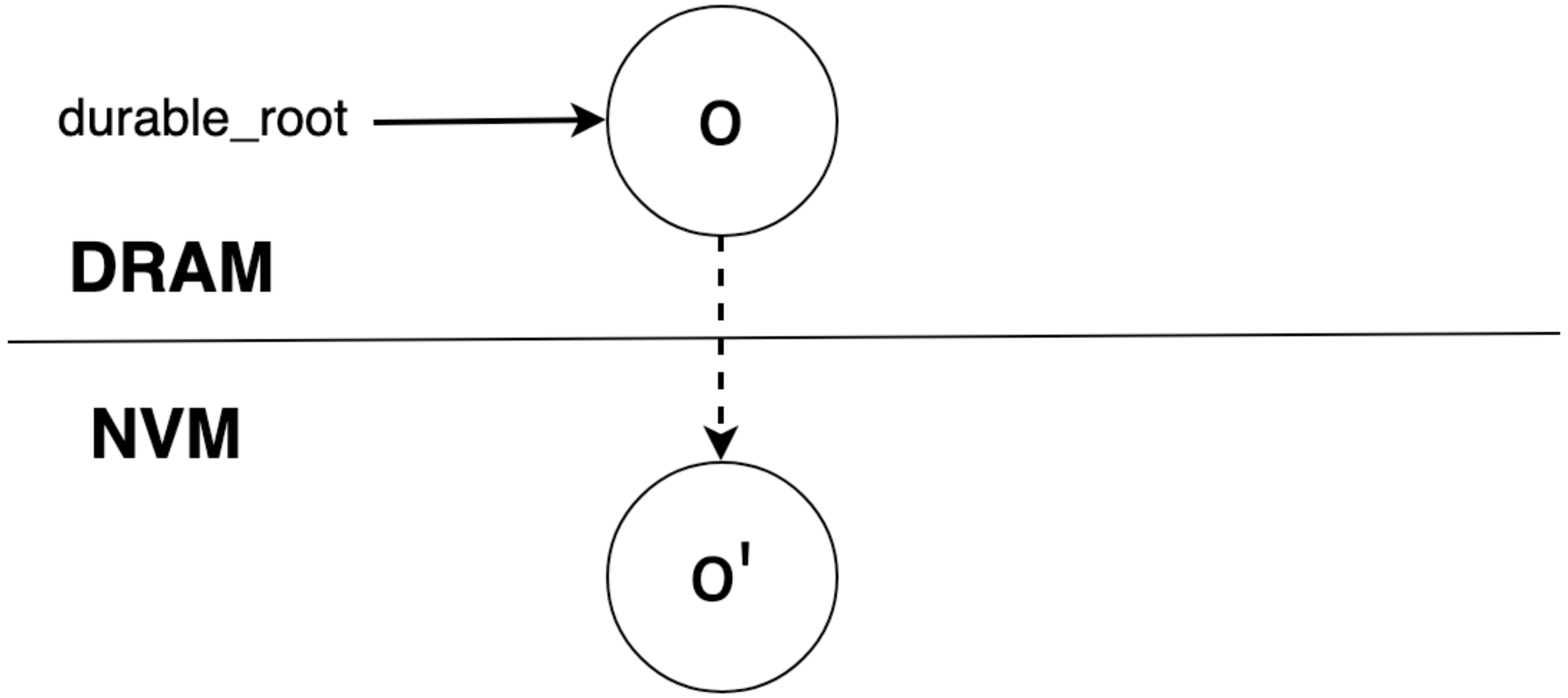

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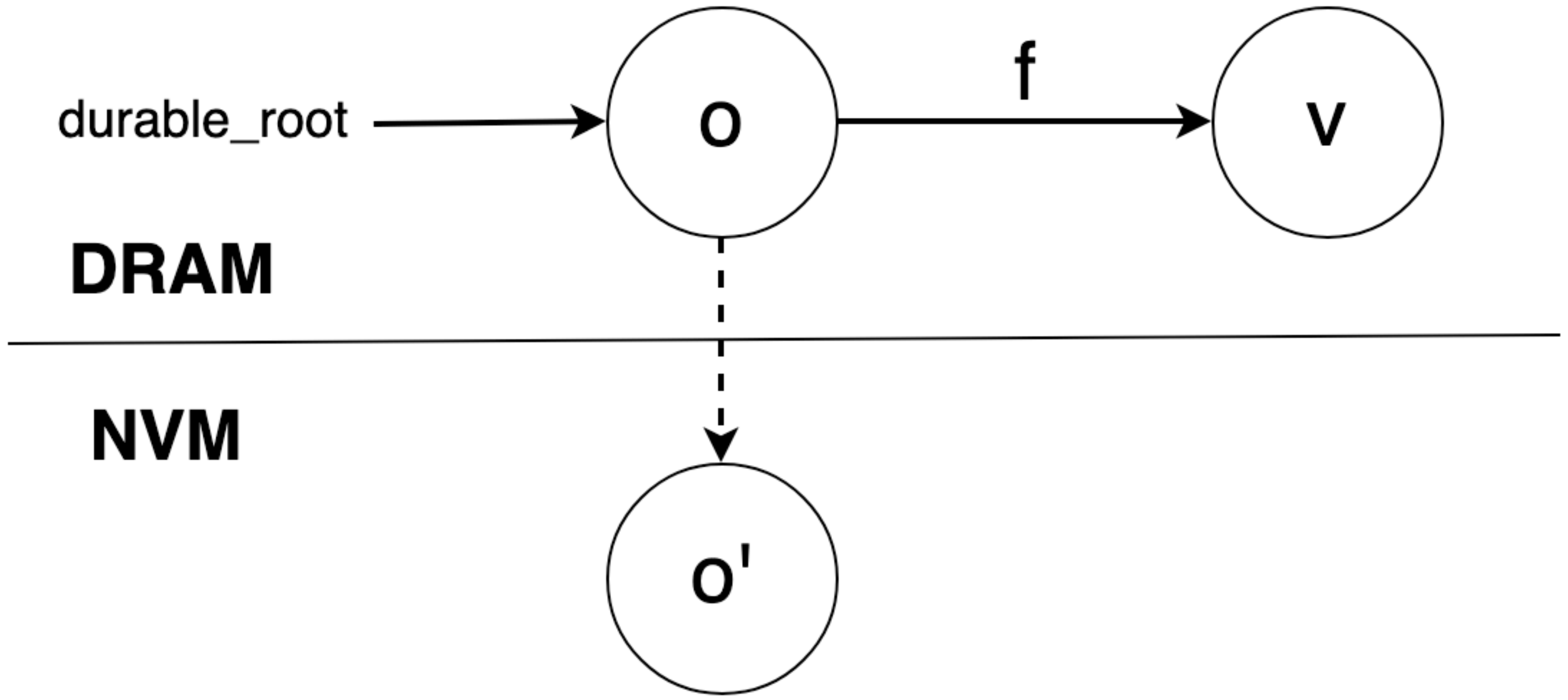

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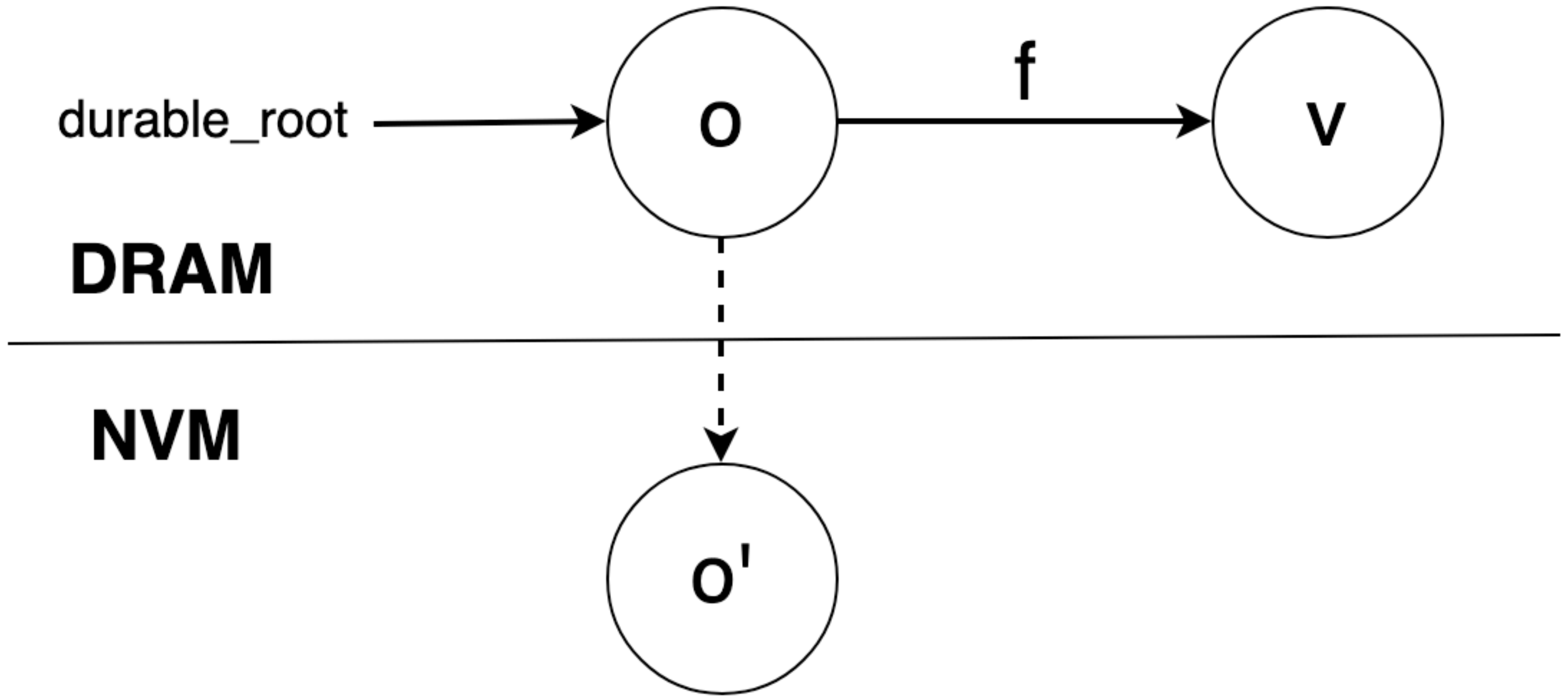

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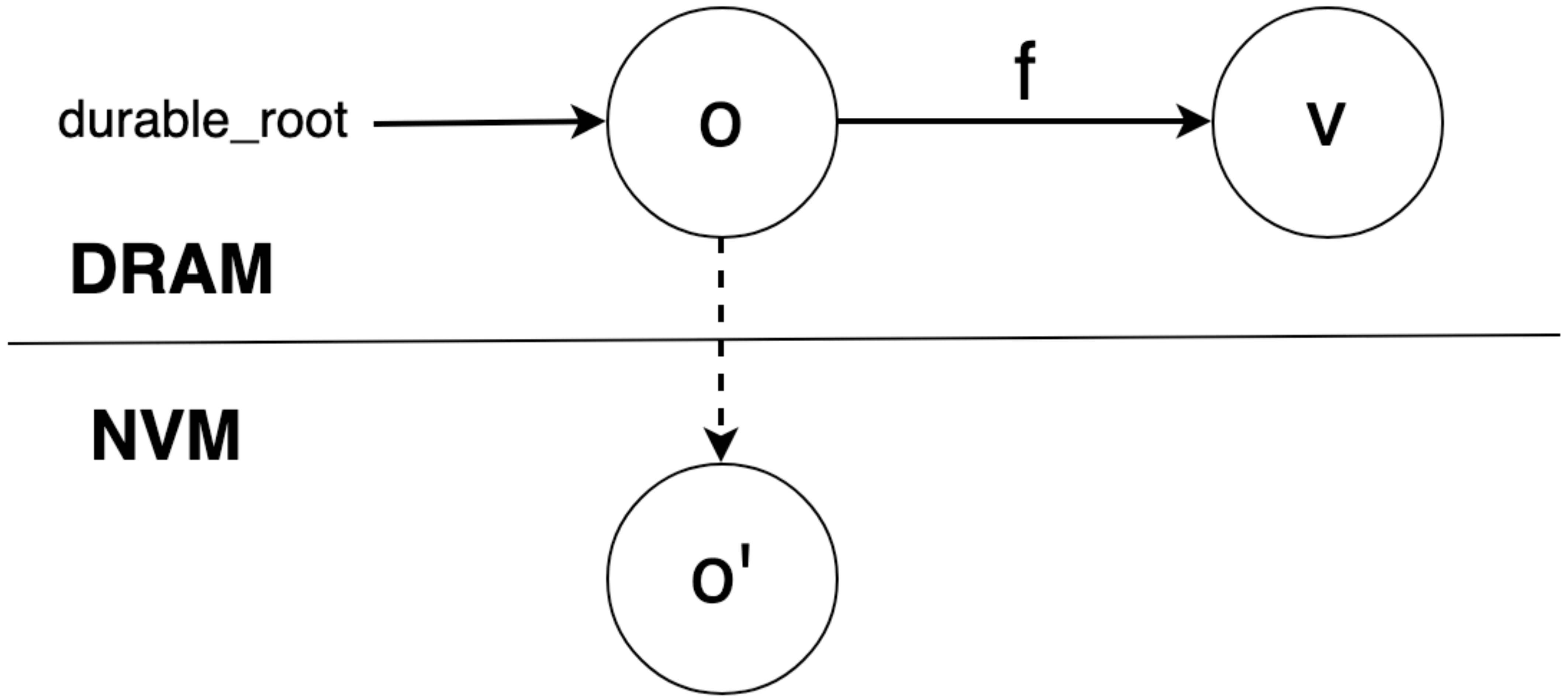

Copies inconsistent !!

[Matsumoto et al. 2022]

Reducing Write Barrier Overheads for Orthogonal Persistence

Write Barrier

Copier Thread

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Writer Thread (o.f = v)

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def putfield( o, f, v ):
    o[f] = v
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- **MFENCE** ensures all preceding load and store instructions become globally visible before any that follow it.
- Writer-wait approach
- **Issue** - MFENCE is executed for all field write instructions.

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- All putfield instructions will execute the write barrier
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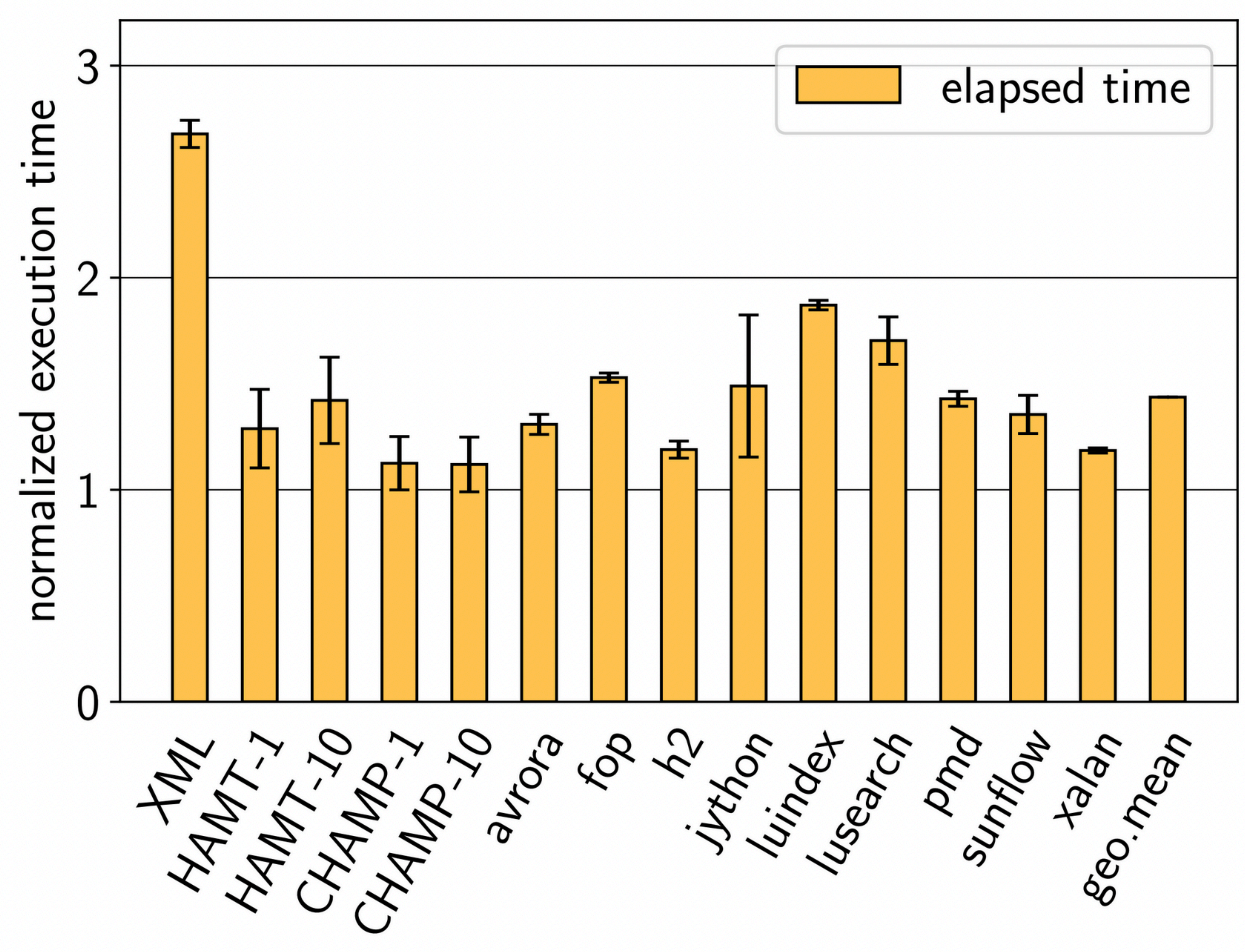
- All putfield instructions will execute the write barrier
- Even if durable roots are absent, write barrier is executed.
- Increases execution time of the program
- Average overhead of 43.7% on the benchmarks in the absence of durable roots.



Elapsed times normalised to standard HotSpot VM

Reducing Write Barrier Overheads for Orthogonal Persistence

Intuition

- Frequency of copying << Frequency of writing
  - Shift the overhead to copier
- Copier thread performs a **Handshake** with all the threads and waits for acknowledgement
- Copier thread performs copy only when **Handshake** is acknowledged

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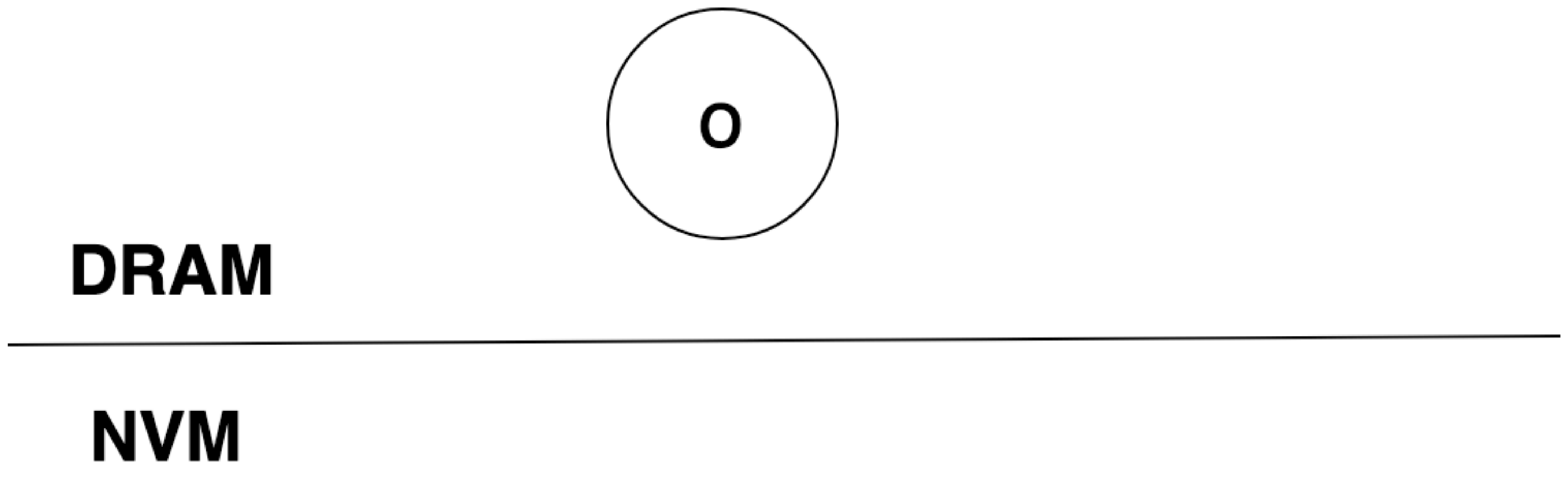

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do:
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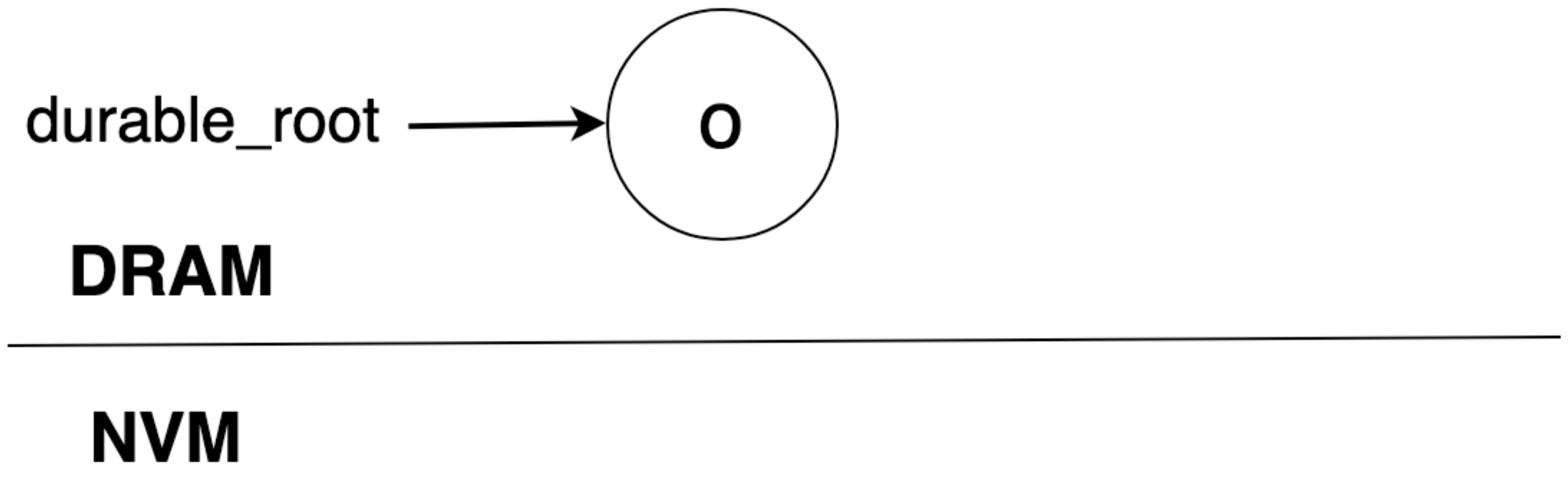

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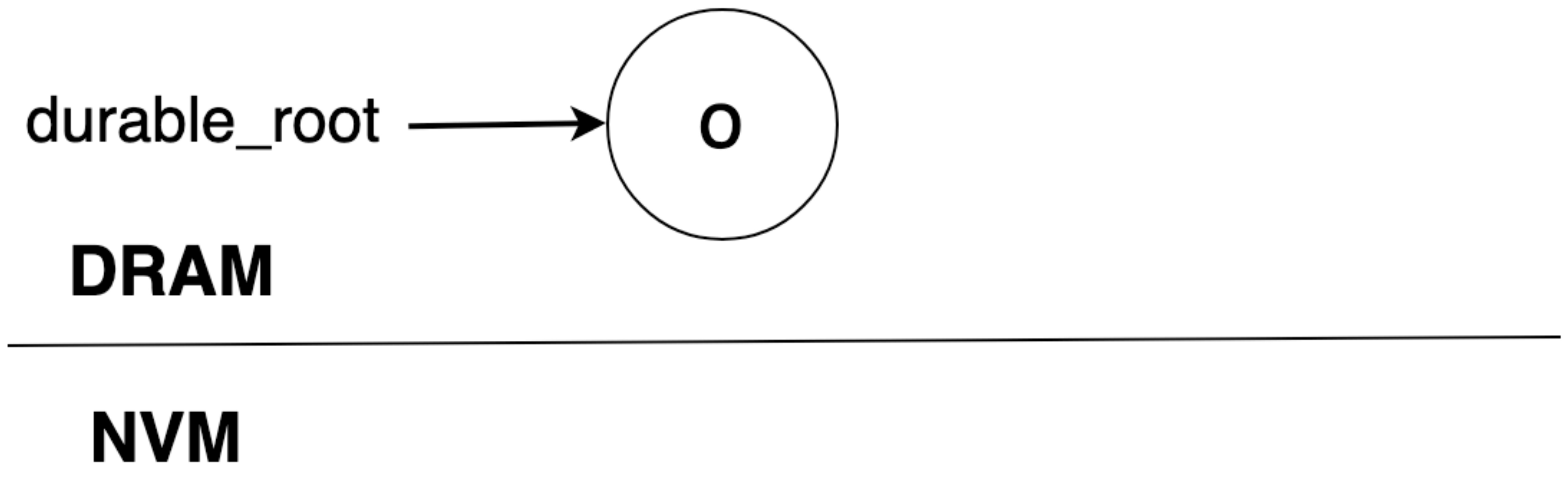

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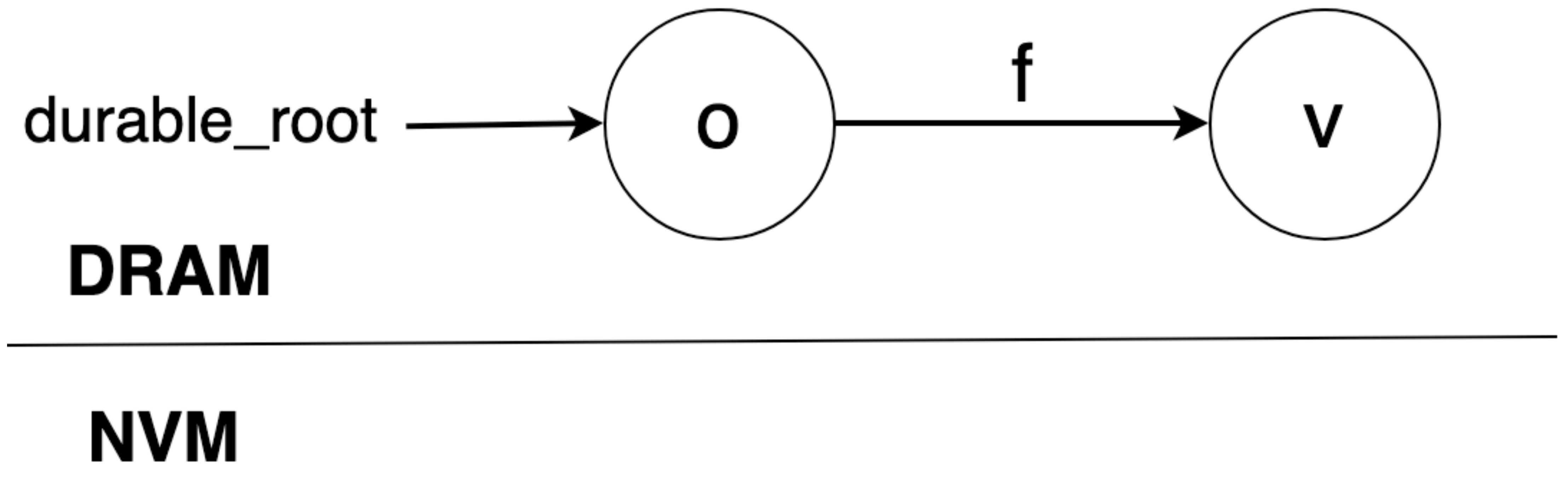

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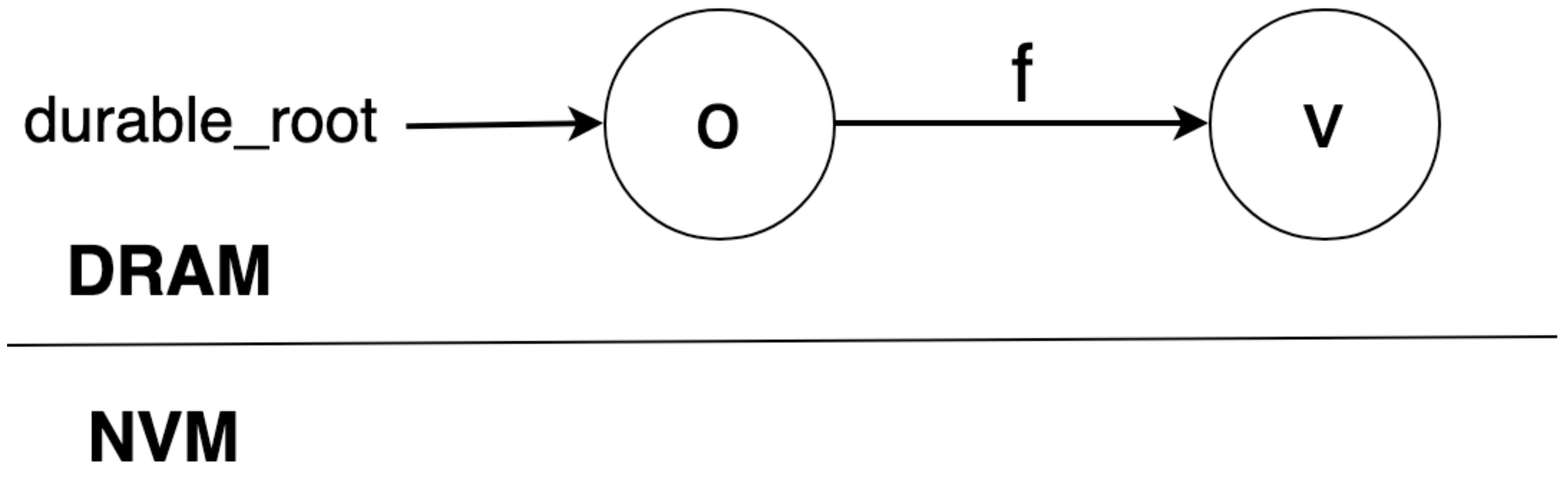

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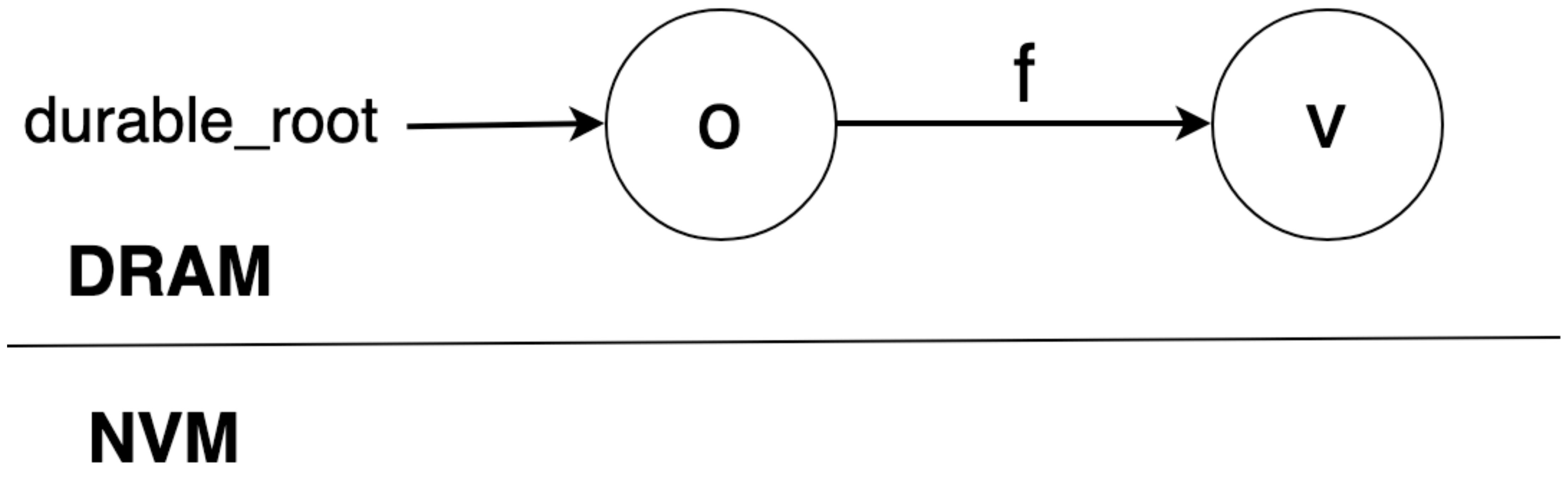
GC safepoint



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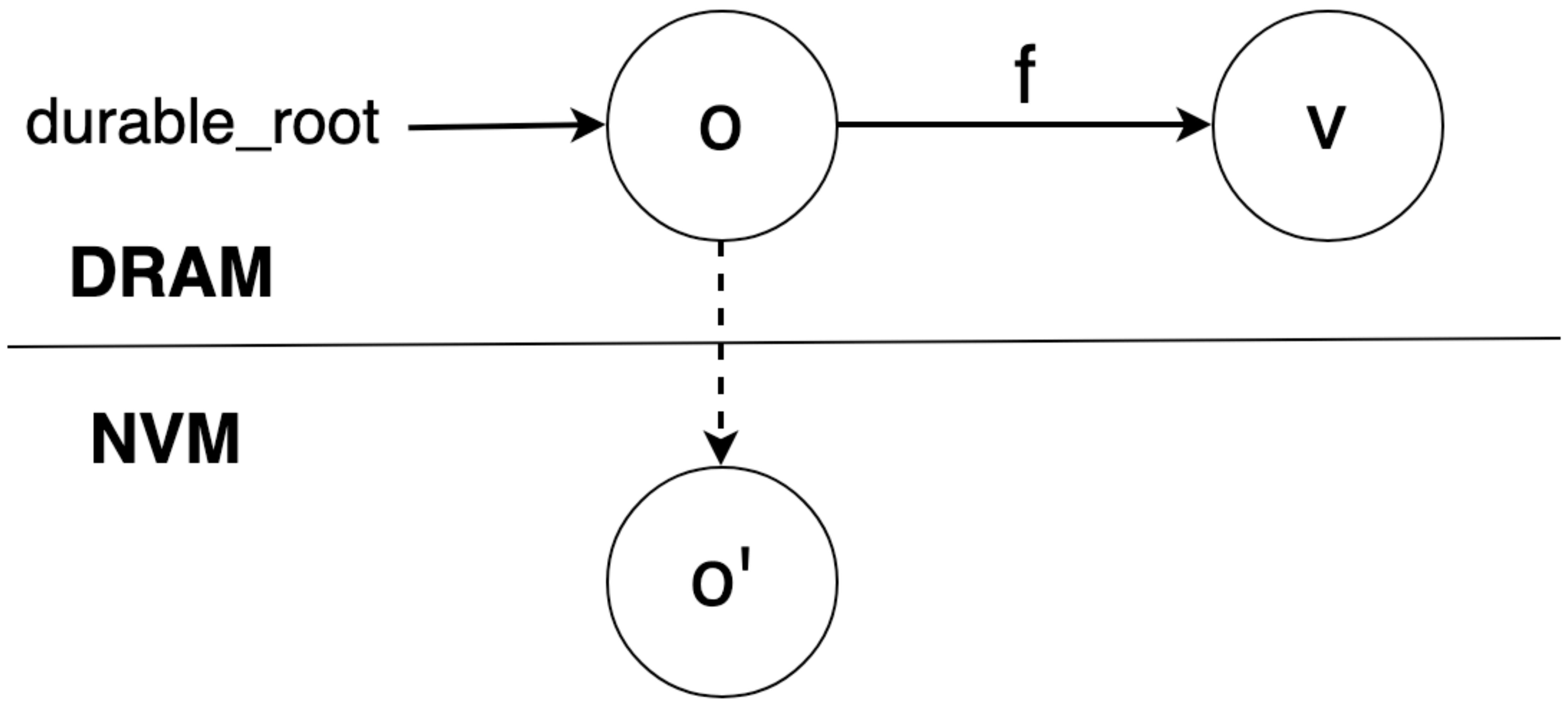

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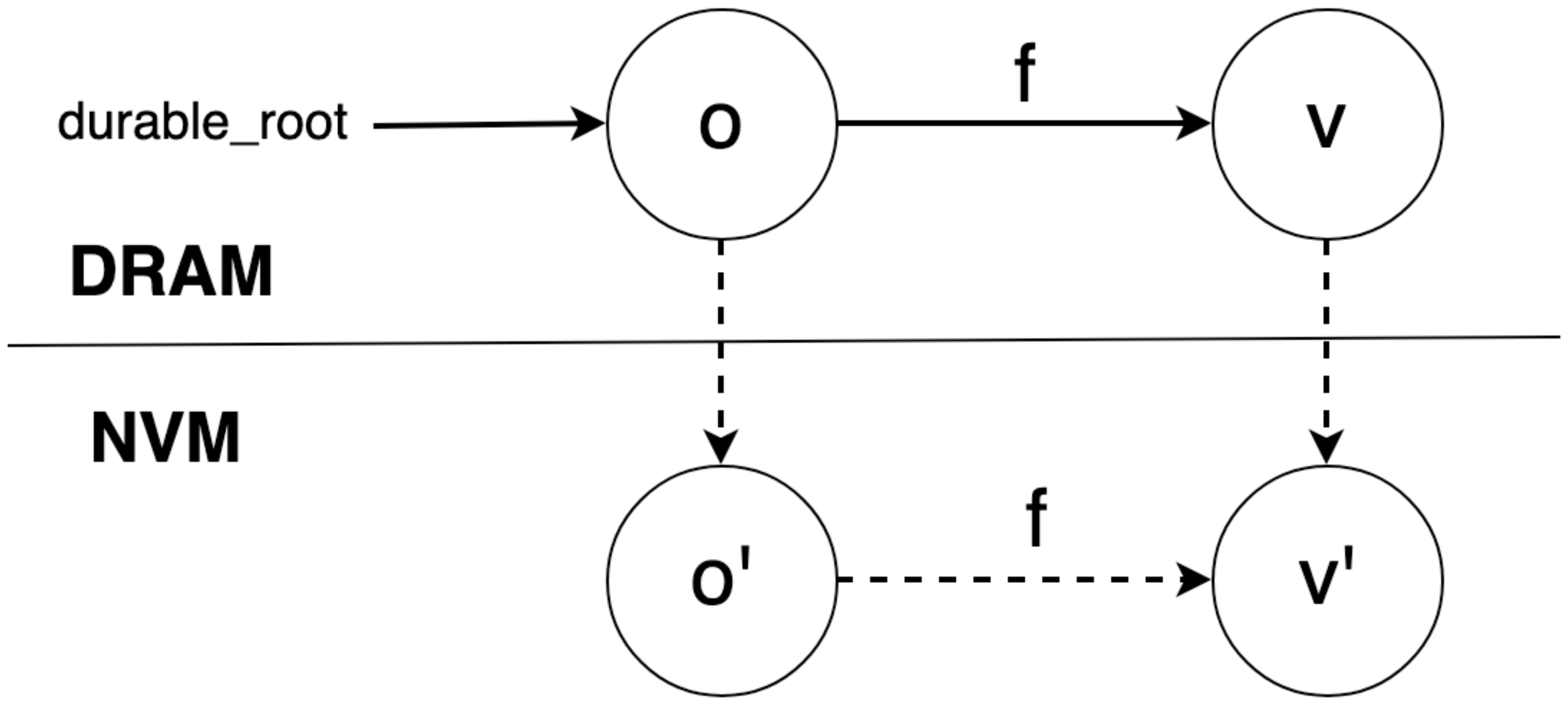
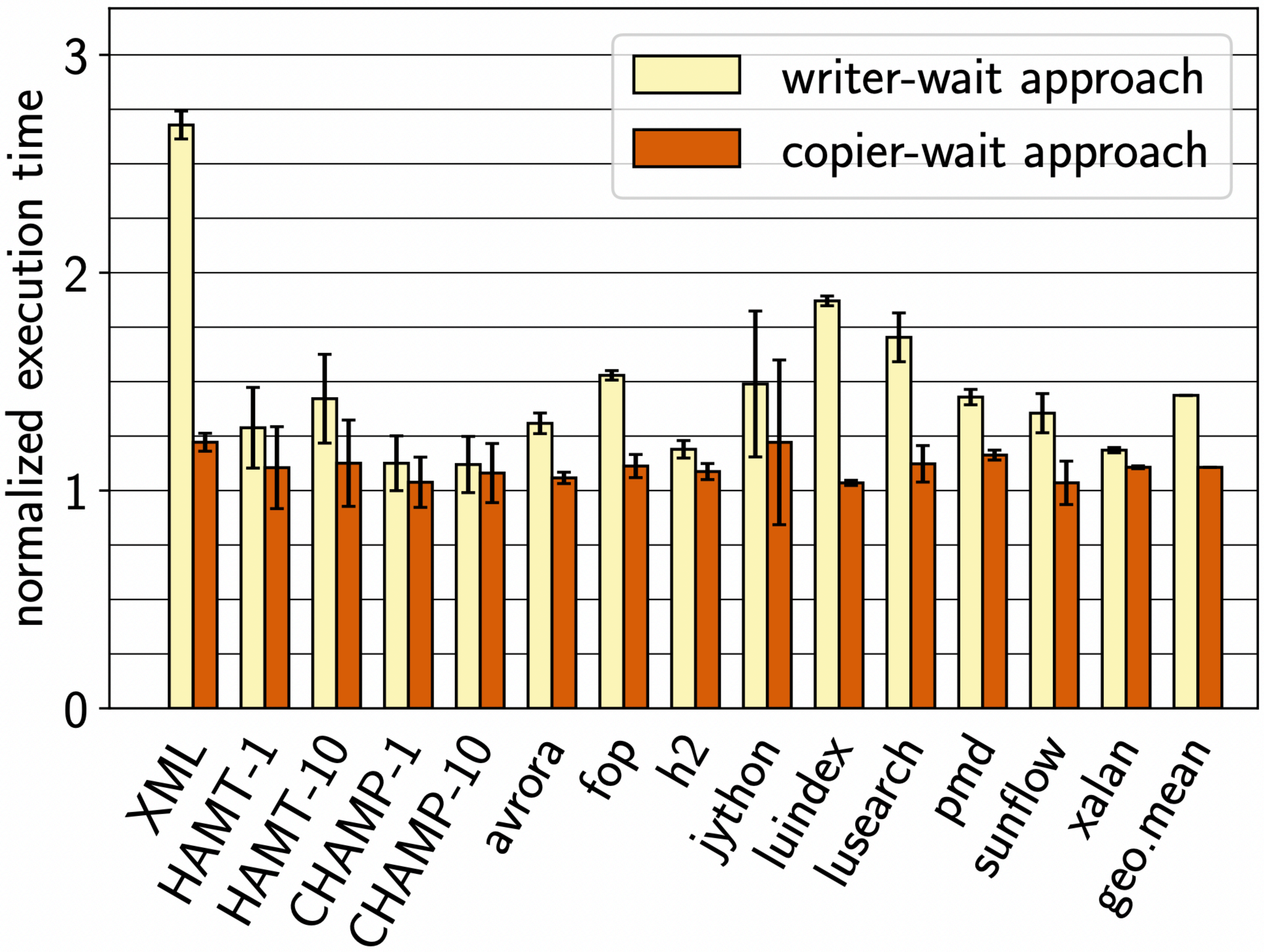


Does shifting overhead to the copier benefit programs that rarely make objects persistent ?

No durable roots in program



Elapsed times normalised to standard HotSpot VM

writer-wait approach
43.7% overhead on average

copier-wait approach
10.6% overhead on average

What about programs that frequently make objects persistent ?

Overheads of Copier-wait

- When objects are frequently made persistent, copier-wait approach has high overheads

- Handshake overhead of 37.9 % compared to writer-wait approach when all static fields are annotated as durable roots.

Overheads of Copier-wait

- When objects are frequently made persistent, copier-wait approach has high overheads
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- Do we always need handshake ?

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Do we always need handshake ?

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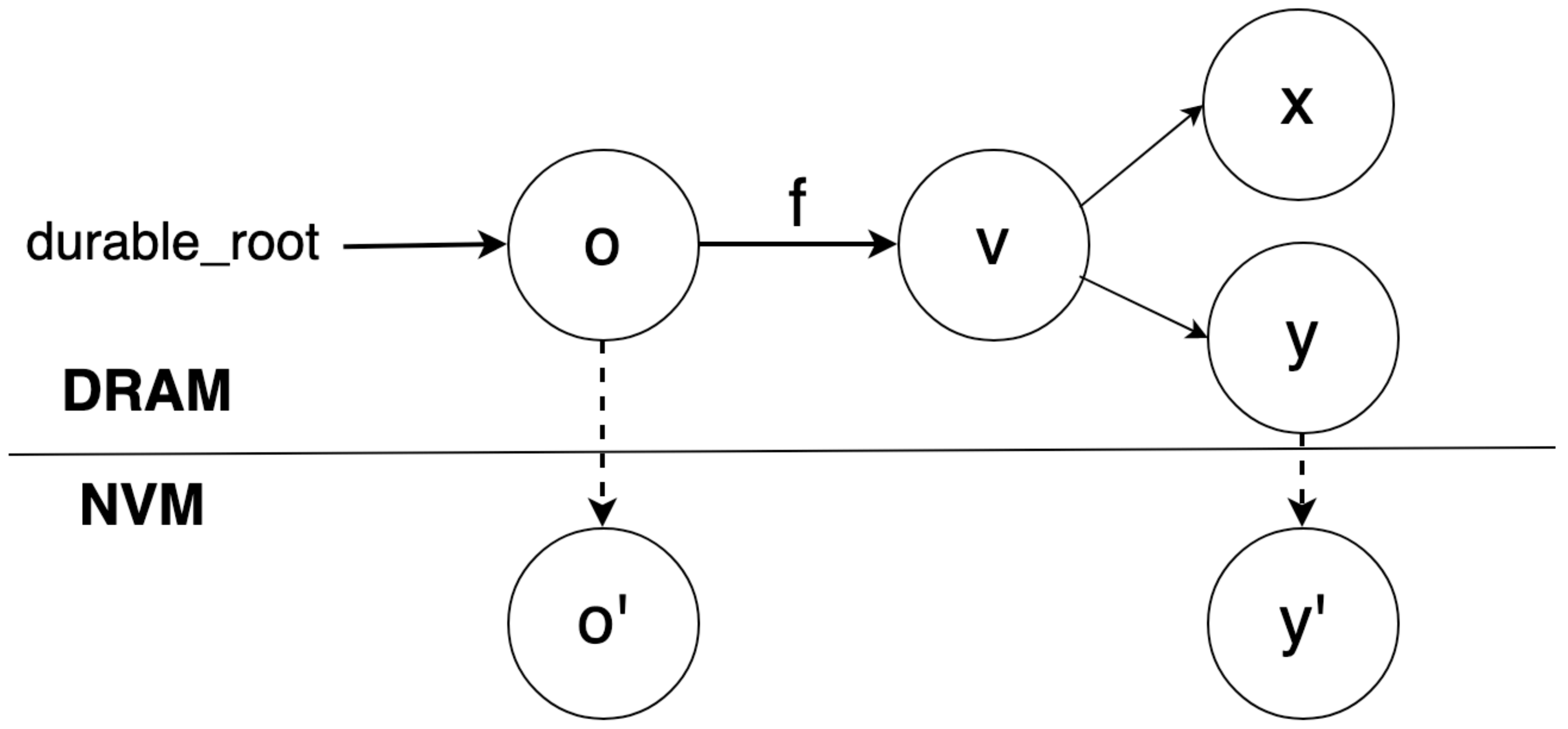

If all the objects reachable from v (including) are, either

- Thread Local or
- Persistent

Then handshake can be elided

Persistence-Aware Escape Analysis

- Combined Points-to-Escape analysis is used to identify thread-local abstract objects
- Modify escape analysis to recognise a special abstract object
  - Persistent Object (**P**)

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- Escape Analysis

x = A.durable_root	x -> { **E** }
y = x.f	y -> { **E** }
y.f = z	y.f -> { **E** }
t = new Thread(w)	t -> { **E** } w -> { **E** }

Persistence-Aware Escape Analysis

- Combined Points-to-Escape analysis is used to identify thread-local abstract objects
- Modify escape analysis to recognise a special abstract object
  - Persistent Object (**P**)
- Persistence-Aware Escape Analysis

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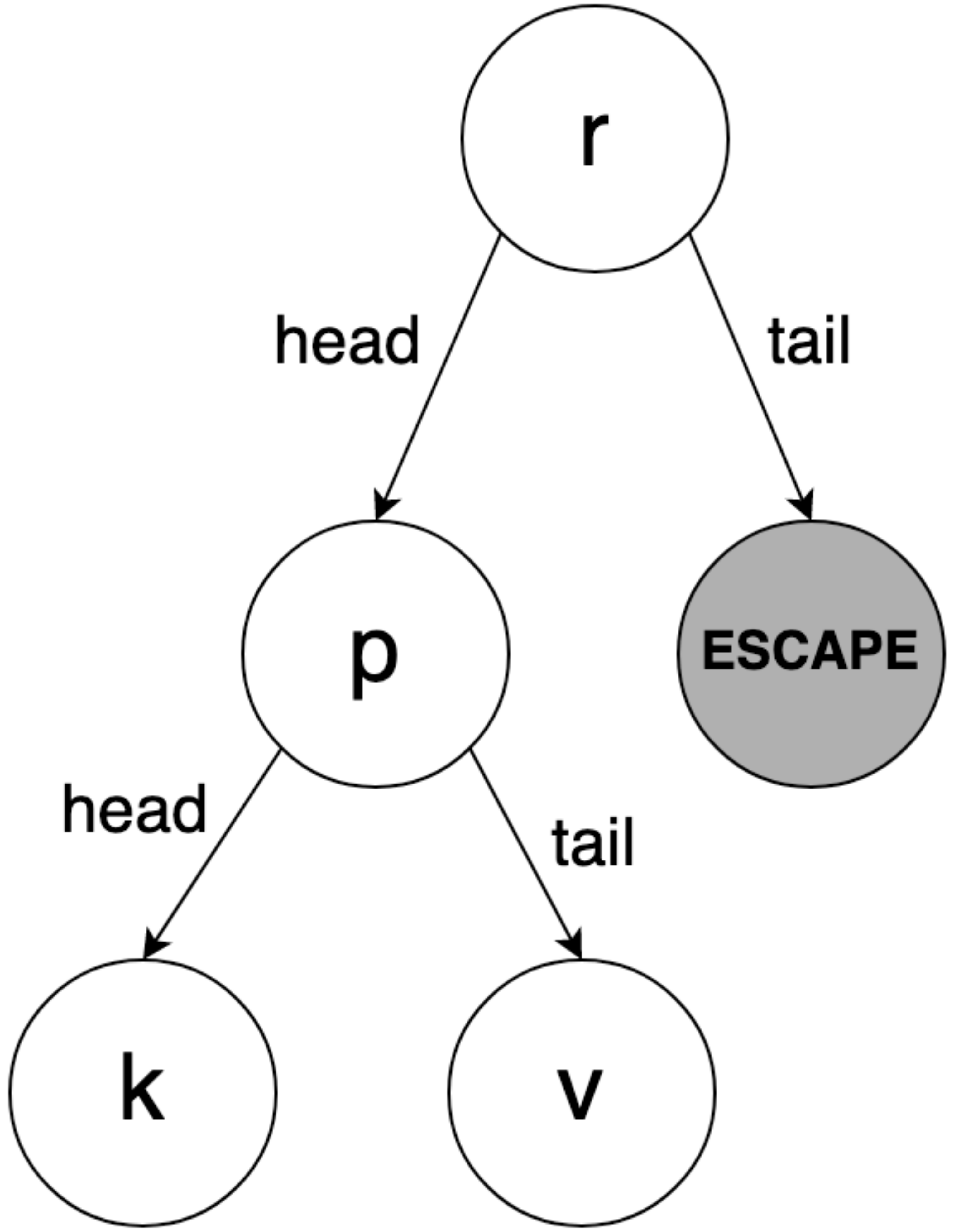
Example

```java
class Program {
  @durable_root static Pair assocList;
  @durable_root static int count;
  static void assoc(Object k, Object v) {
    Pair p = new Pair(); // p is volatile object
    p.head = k;
    p.tail = v;
    Pair r = new Pair(); // r is volatile object
    r.head = p;
    r.tail = Program.assocList;
    Program.assocList = r; // p and r become persistent
    Program.count = Program.count + 1;   } }
```



White objects are thread-local objects

Example

```
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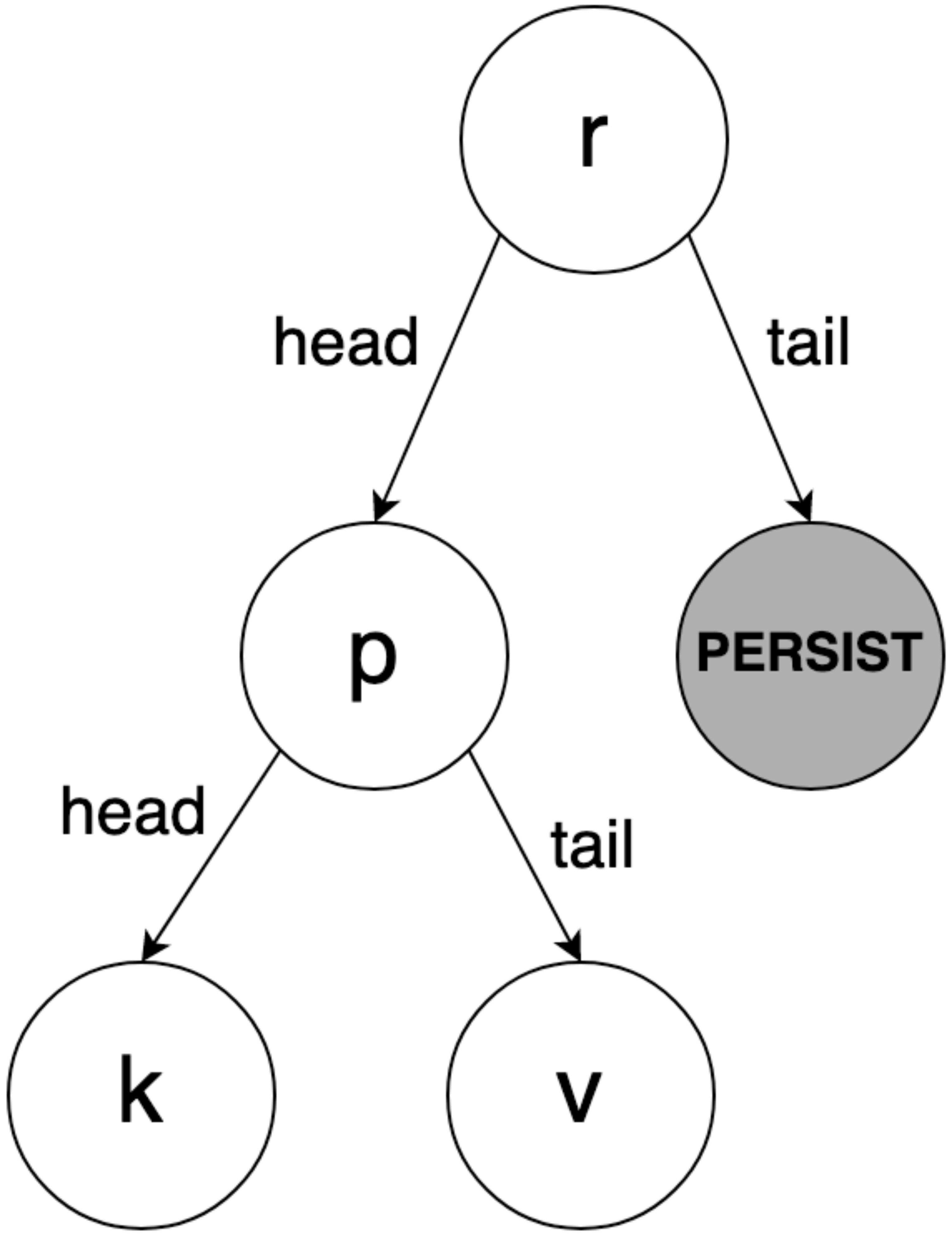
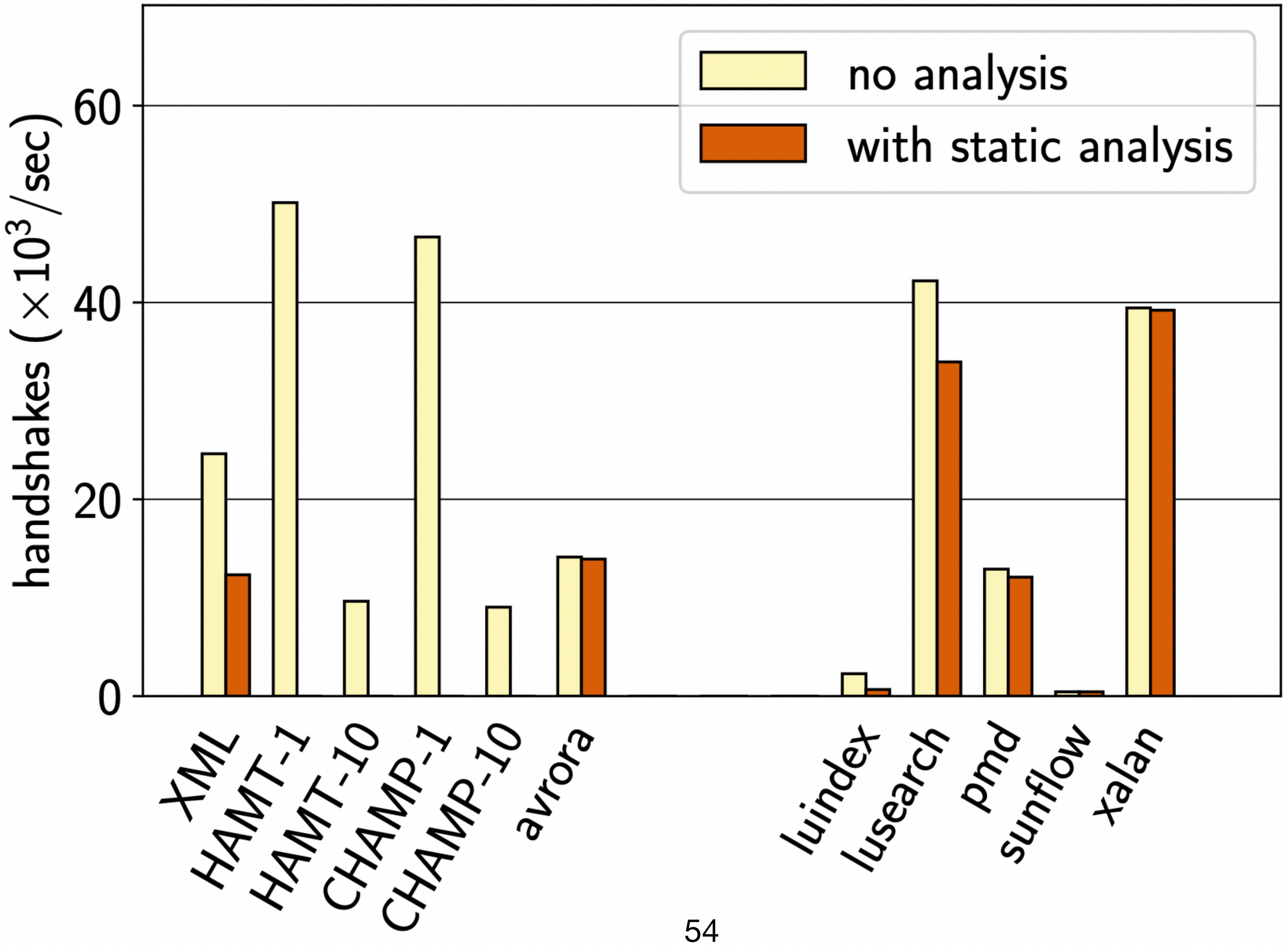


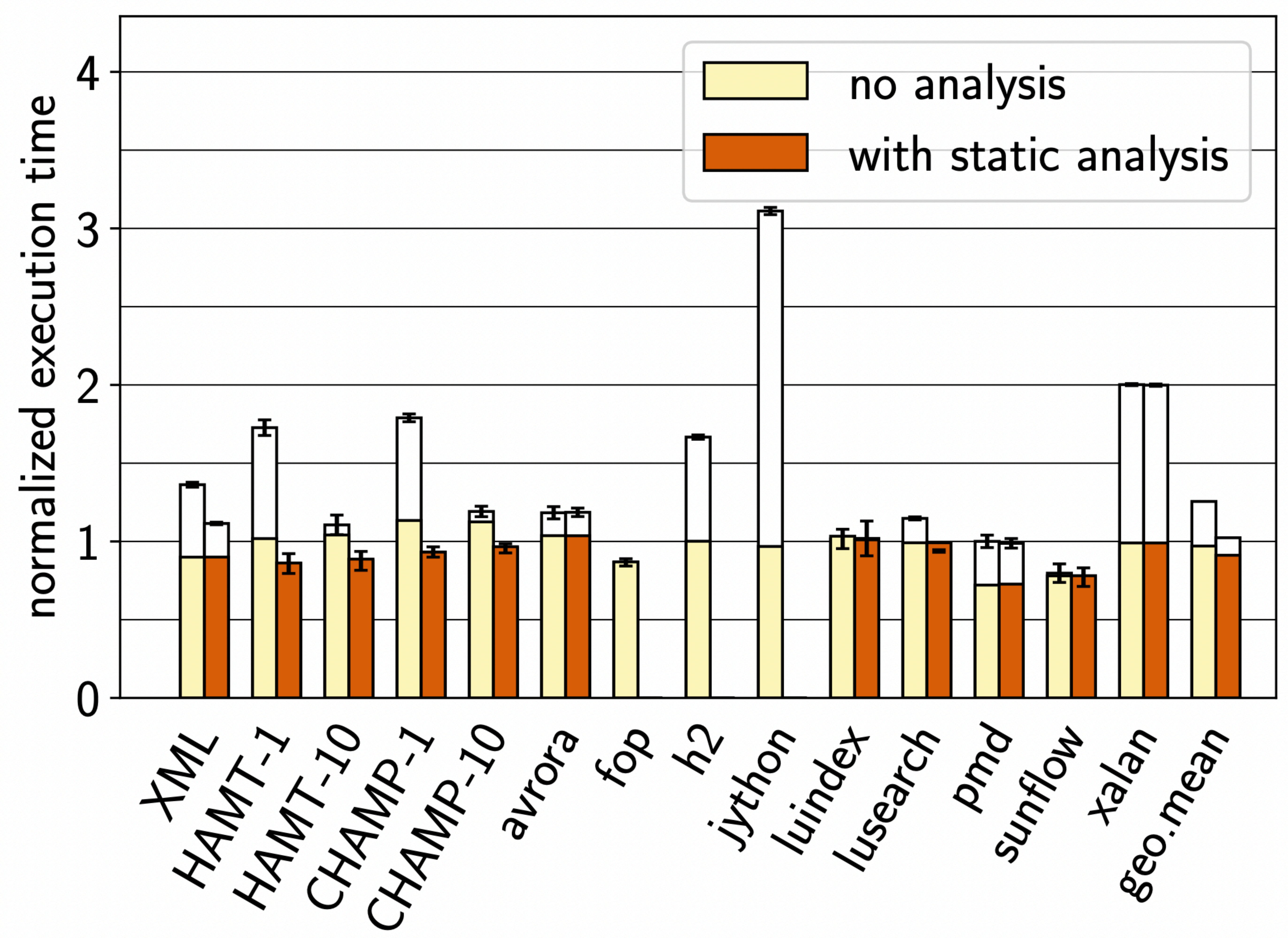
White objects are thread-local objects

Was static analysis successful in eliminating handshakes ?

Number of handshakes per second



Execution time



Execution time normalised to writer-wait approach

Static analysis eliminated 52% overheads on average

Copier-wait slower by 2.4% on average

Related Work

- AutoPersist [Shull et al. 2019] uses copier flag that is accessed atomically. Copier fails when race is detected
- QuickCheck [Shull et al. 2019] and P-INSPECT [Kokolis et al. 2020] try to reduce the write barrier overheads but fail to handle races.
- StaticPersist [Bansal 2023] uses static analysis to verify if programmer has correctly made the objects persistent (No pointer from persistent object to volatile object)

Covered in the paper

- Explanation of how the transitive closure of an object is copied.
- Handle race between copier and writer [Ragged Synchronization]
- Synchronization for multiple copiers trying to copy same object
- Correctness Argument
- Additional overheads eliminated by Persistence-aware Escape analysis
- Flow functions for Persistence-aware Escape analysis

Conclusion

- Shifted the overheads from writer thread to copier thread
- 23% performance improvement on average for programs that rarely make objects persistent
- Static analysis decreases 52% of persistence-related overheads in the copier-wait approach
- Performance of copier-wait approach comparable (better in some case) to writer-wait approach

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Thank You