ZIL Performance: How I Doubled Sync Write Speed

Agenda

1. What is the ZIL?
2. How is it used? How does it work?
3. The problem to be fixed; the solution.
4. Details on the changes I made.
5. Performance testing and results.

*Press "p" for notes, and "c" for split view.

1 – What is the ZIL?

What is the ZIL?

- ZIL: Acronym for (Z)FS (I)ntent (L)og
    - Logs synchronous operations to disk, before `spa_sync()`
    - What operations get logged?
        - `zfs_create`, `zfs_remove`, `zfs_write`, etc.
        - Doesn't include non-modifying ZPL operations:
            - `zfs_read`, `zfs_seek`, etc.
    - What gets logged?
        - The fact that a logical operation is occuring is logged
            - `zfs_remove` → directory object ID + name only
        - Not logging which blocks will change due to logical operation

When is the ZIL used?

- Always[*]
    - ZPL operations (`itx`'s) logged via in-memory lists
    - lists of in-memory `itx`'s written to disk via `zil_commit()`
    - `zil_commit()` called for:
        - *any* sync write[**]

[*]Except when dataset configured with: `sync=disabled`. [**]Except when dataset configured with: `sync=always`.

What is the SLOG?

- SLOG: Acronym for (S)eperate (LOG) Device
  - An SLOG is not necessary
    - By default (no SLOG), ZIL will write to main pool VDEVs
  - An SLOG can be used to improve latency of ZIL writes
    - When attached, ZIL writes to SLOG instead of main pool*
- Conceptually, SLOG is different than the ZIL
  - ZIL is mechanism for writing, SLOG is device written to
- ZIL is used, even if no SLOG attached

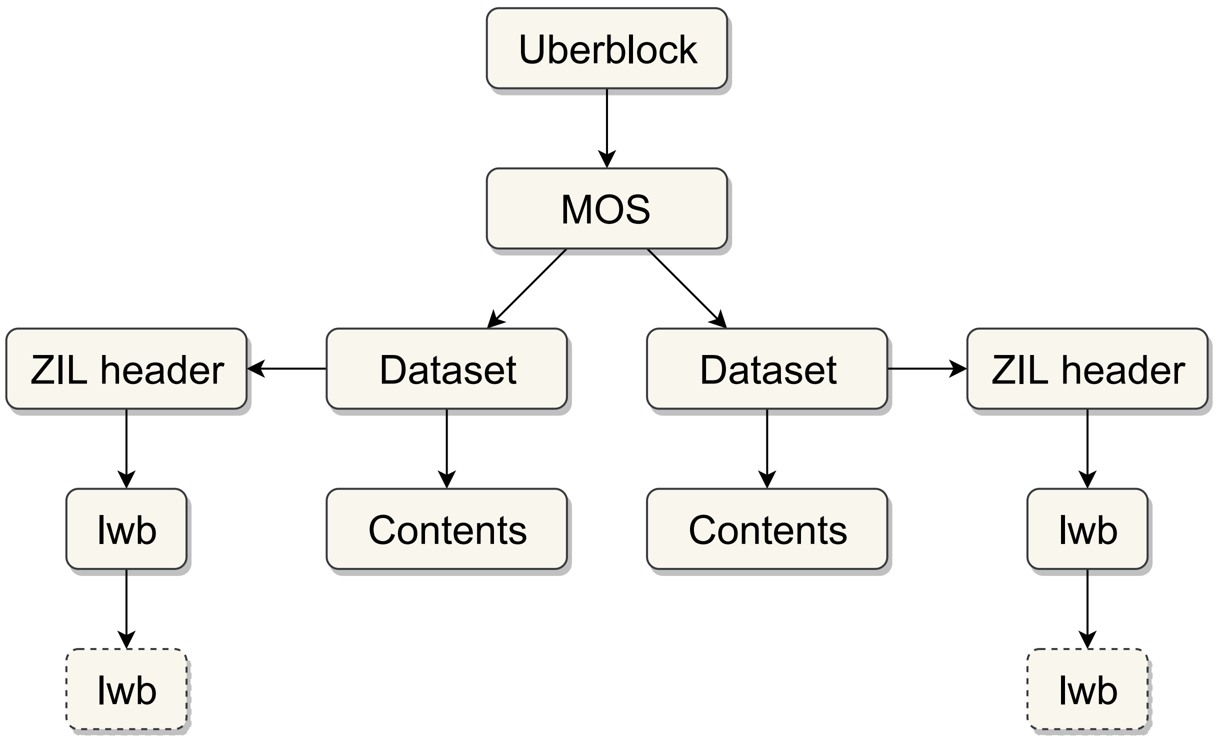
*For some operations; see code for details.

Why does the ZIL exist?

- Writes in ZFS are "write-back"
  - Data is first written and stored in-memory, in DMU layer
  - Later, data for whole pool written to disk via `spa_sync()`
- Without the ZIL, sync operations could wait for `spa_sync()`
  - `spa_sync()` can take tens of seconds (or more) to complete
- Further, with the ZIL, write amplification can be mitigated
  - A single ZPL operation can cause many writes to occur
  - ZIL allows operation to "complete" with minimal data written
- ZIL needed to provide "fast" synchronous semantics to applications
  - Correctness could be acheived without it, but would be "too slow"

ZIL On-Disk Format

- Each dataset has it's own unique ZIL on-disk
- ZIL stored on-disk as a singly linked list of ZIL blocks (`lwb`'s)



2 – How is the ZIL used?

How is the ZIL used?

- ZPL will generally interact with the ZIL in two phases:
    1. Log the operation(s) — `zil_itx_assign`
        - Tells the ZIL an operation is occuring
    2. Commit the operation(s) — `zil_commit`
        - Causes the ZIL to write log record of operation to disk

Example: `zfs_write`

- `zfs_write` → `zfs_log_write`
- `zfs_log_write`

  → `zil_itx_create`

  → `zil_itx_assign`
- `zfs_write` → `zil_commit`
- Most ZPL operations have a corresponding `zfs_log_*` function
  - `zfs_log_create`
  - `zfs_log_remove`
  - `zfs_log_link`
  - `zfs_log_symlink`
  - `zfs_log_truncate`
  - `zfs_log_setattr`
  - …

Example: `zfs_fsync`

- `zfs_fsync` → `zil_commit`
  - `fsync` doesn't create any new modifications
  - only writes previous `itx`'s to disk
    - thus, no `zfs_log_fsync` function

Contract between ZIL and ZPL.

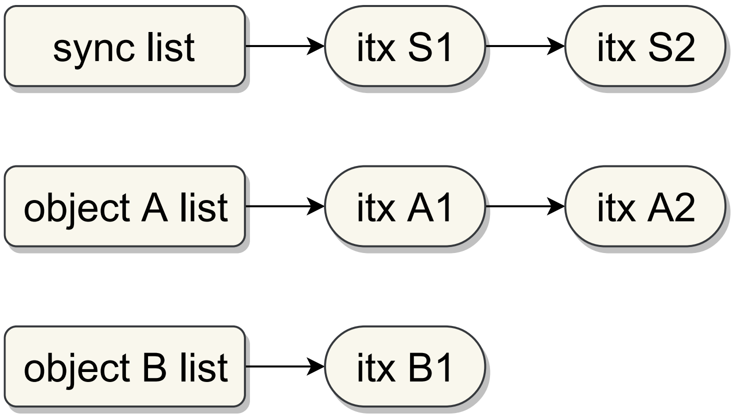
- Parameters to `zil_commit`: ZIL pointer, object number
    - These uniquely identify an object whose data is to be committed
- When `zil_commit` returns:
    - Operations *relevant* to the object specified, will be *persistent* on disk
    - relevant – all operations that would modify that object
    - persistent – Log block(s) written (completed) → disk flushed
- Interface of `zil_commit` doesn't specify *which* operation(s) to commit

2 – How does the ZIL work?

How does the ZIL work?

- In memory ZIL contains per-txg `itxg_t` structures
- Each `itxg_t` contains:
  - A single list of sync operations (for all objects)
  - Object specific lists of async operations

Example: itx lists



How are itx's written to disk?

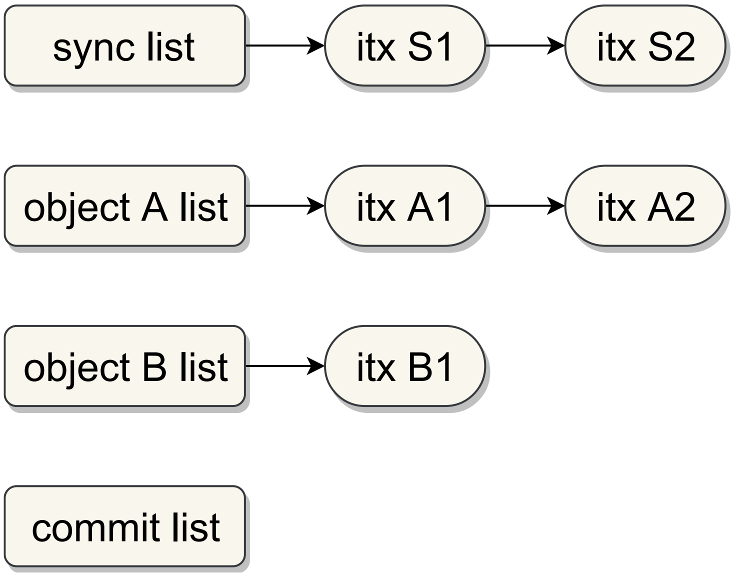
- `zil_commit` handles the process of writing `itx_t`'s to disk:

How are itx's written to disk?

- `zil_commit` handles the process of writing `itx_t`'s to disk:

    1. find all relevant `itx`'s, move them to the "commit list"

Example: `zil_commit` Object B



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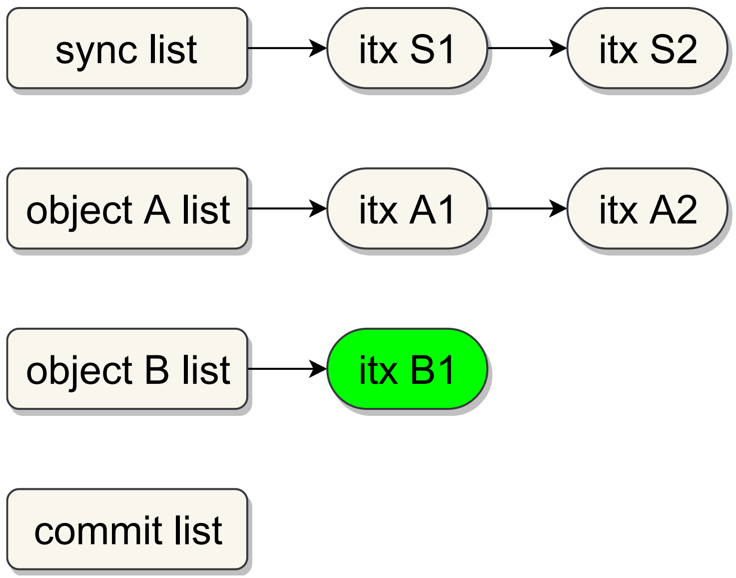

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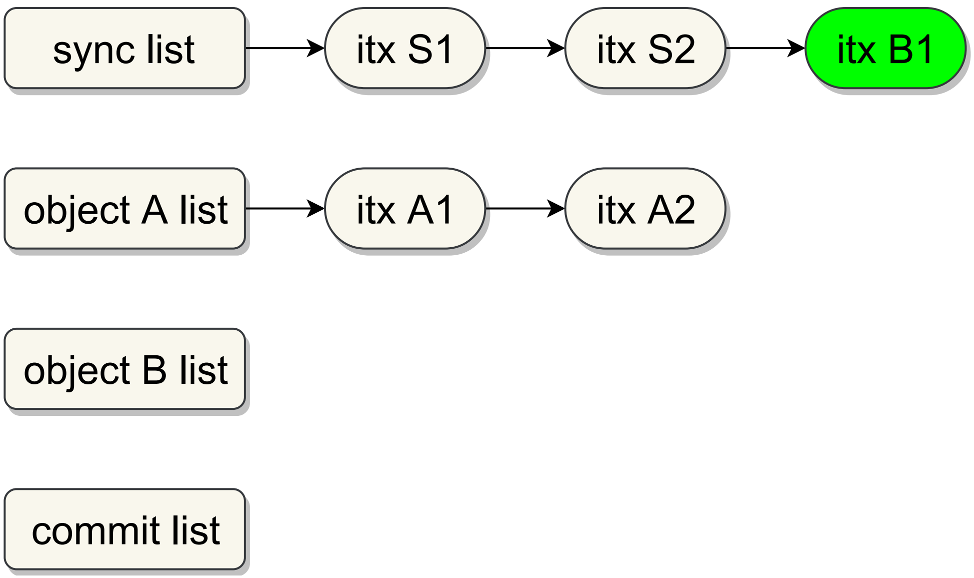

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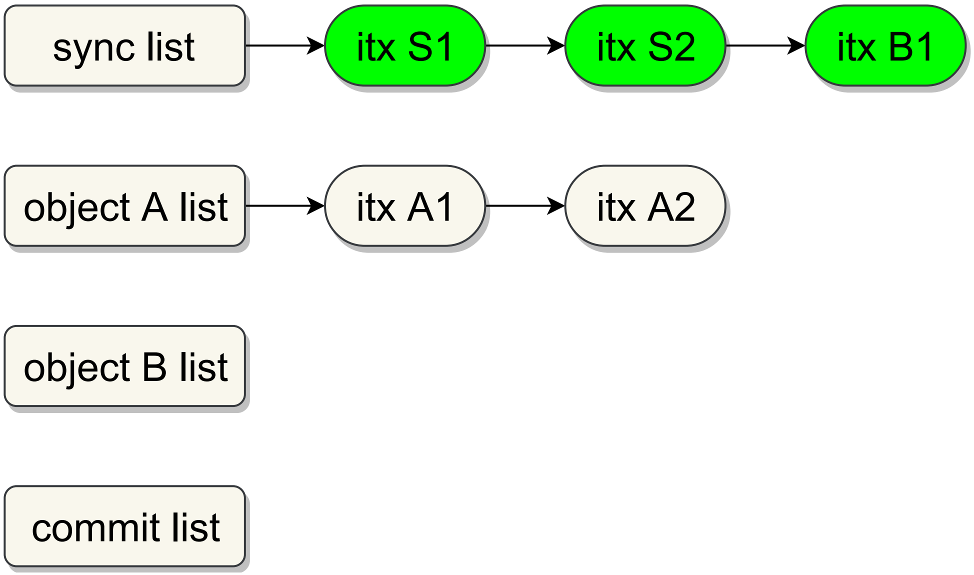

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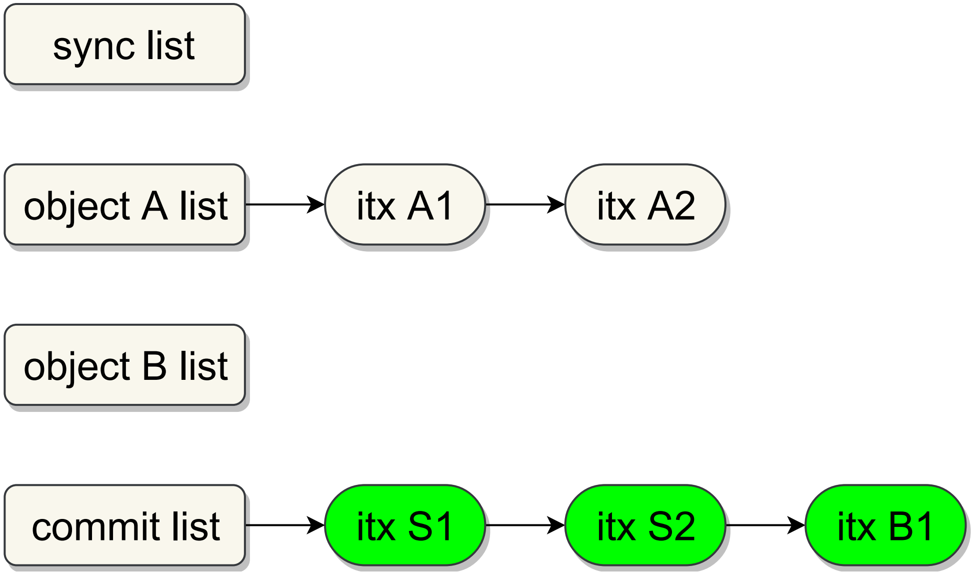

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- `zil_commit` handles the process of writing `itx_t`'s to disk:
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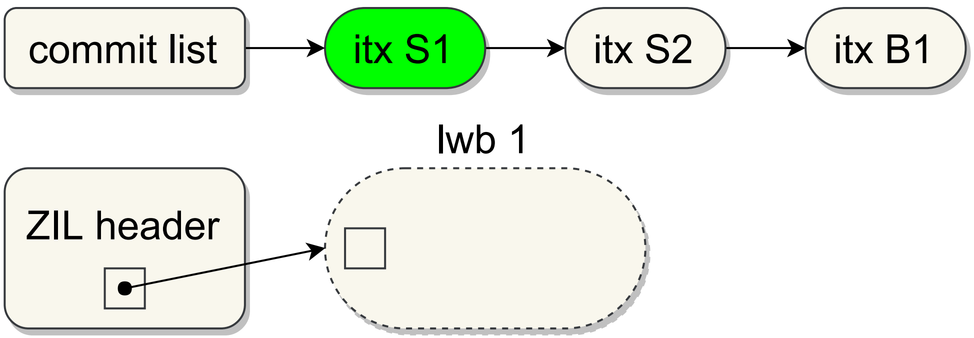

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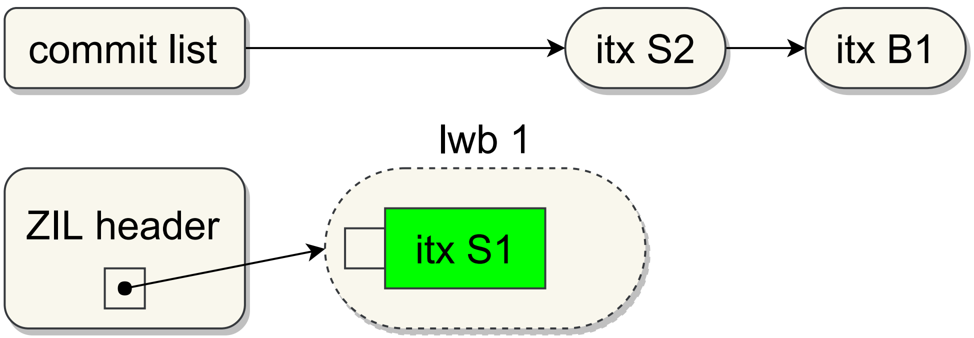

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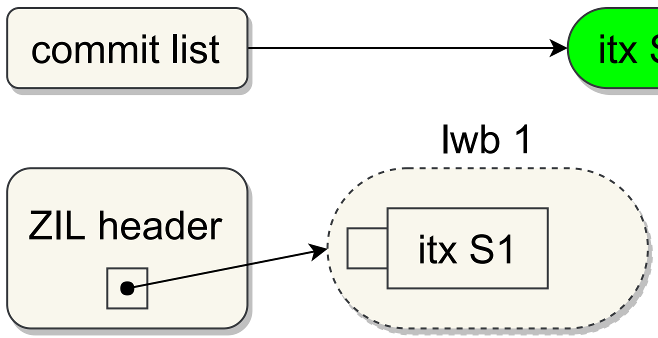

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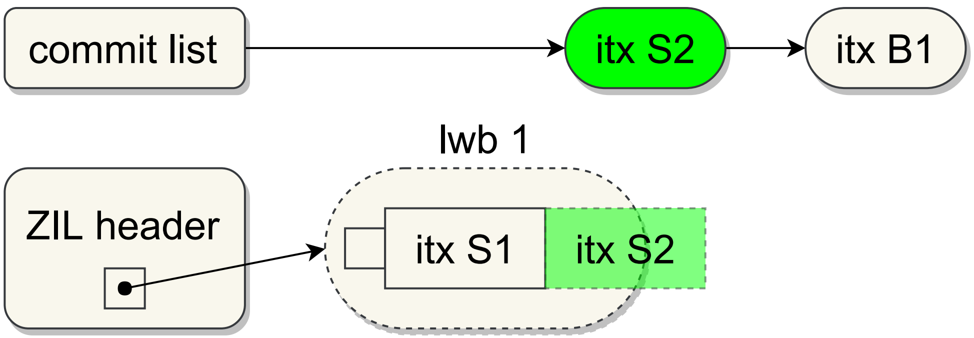

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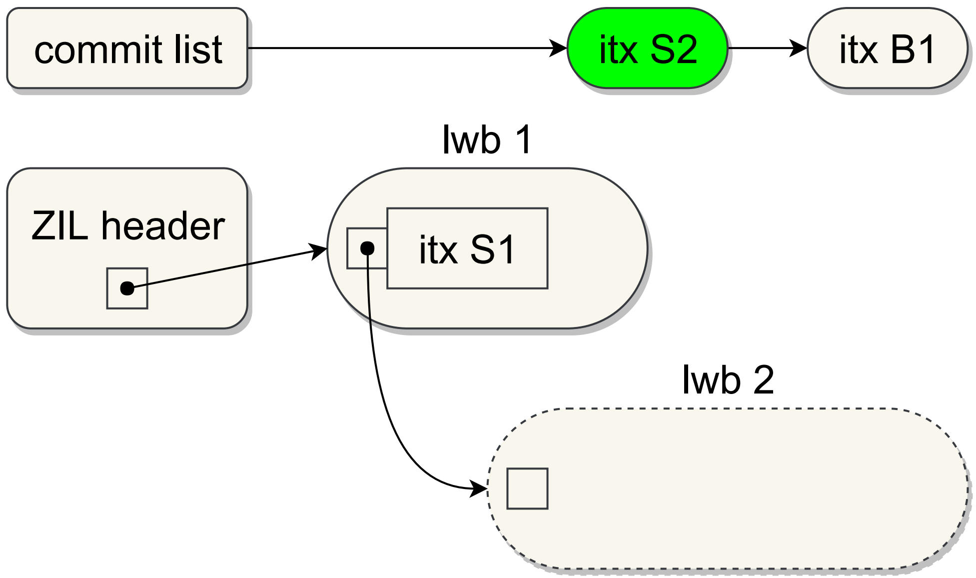

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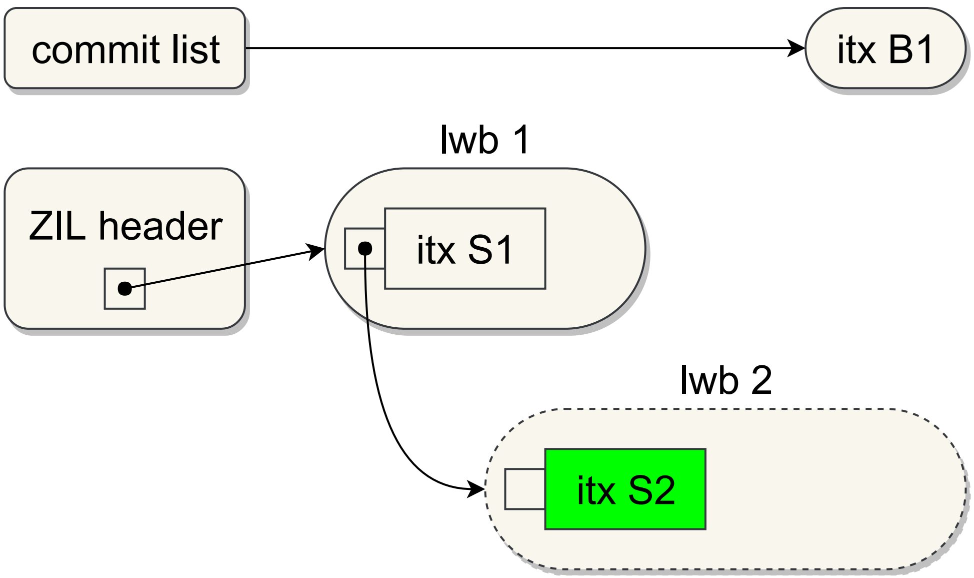

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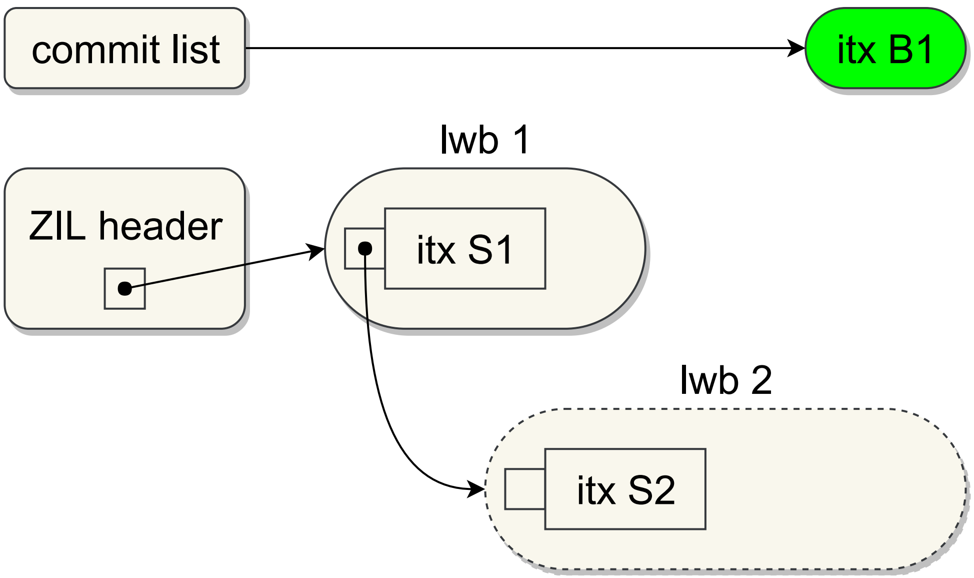

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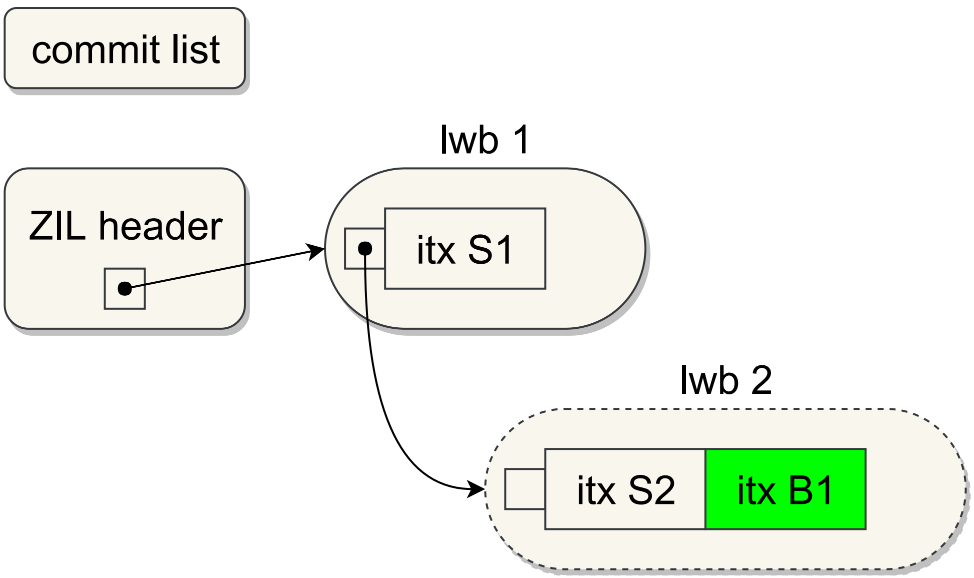

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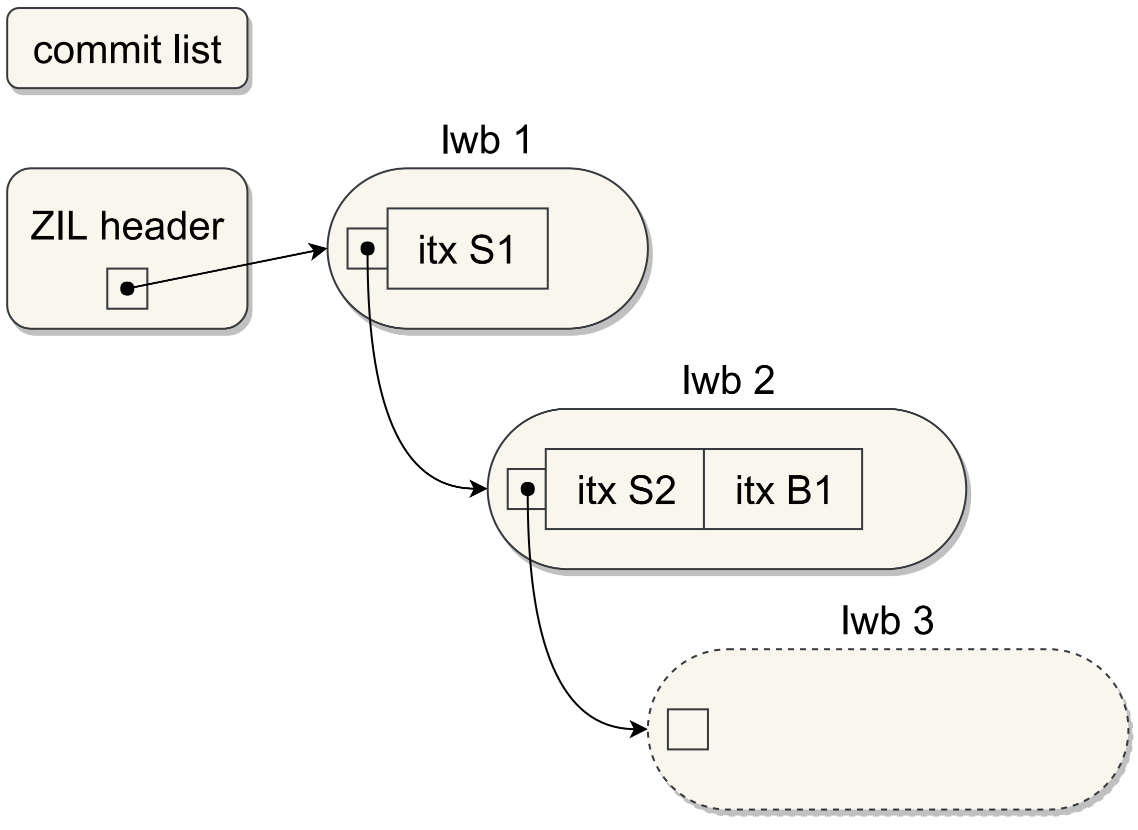

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- `zil_commit` handles the process of writing `itx_t`'s to disk:

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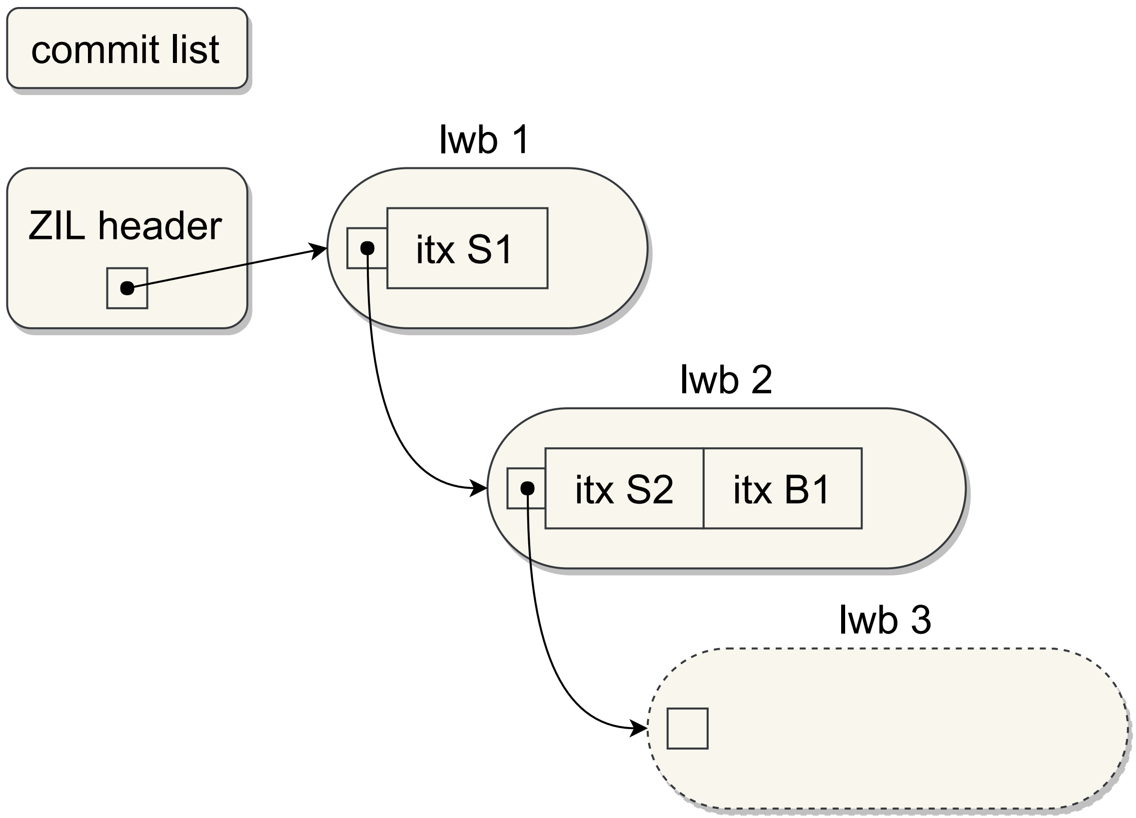

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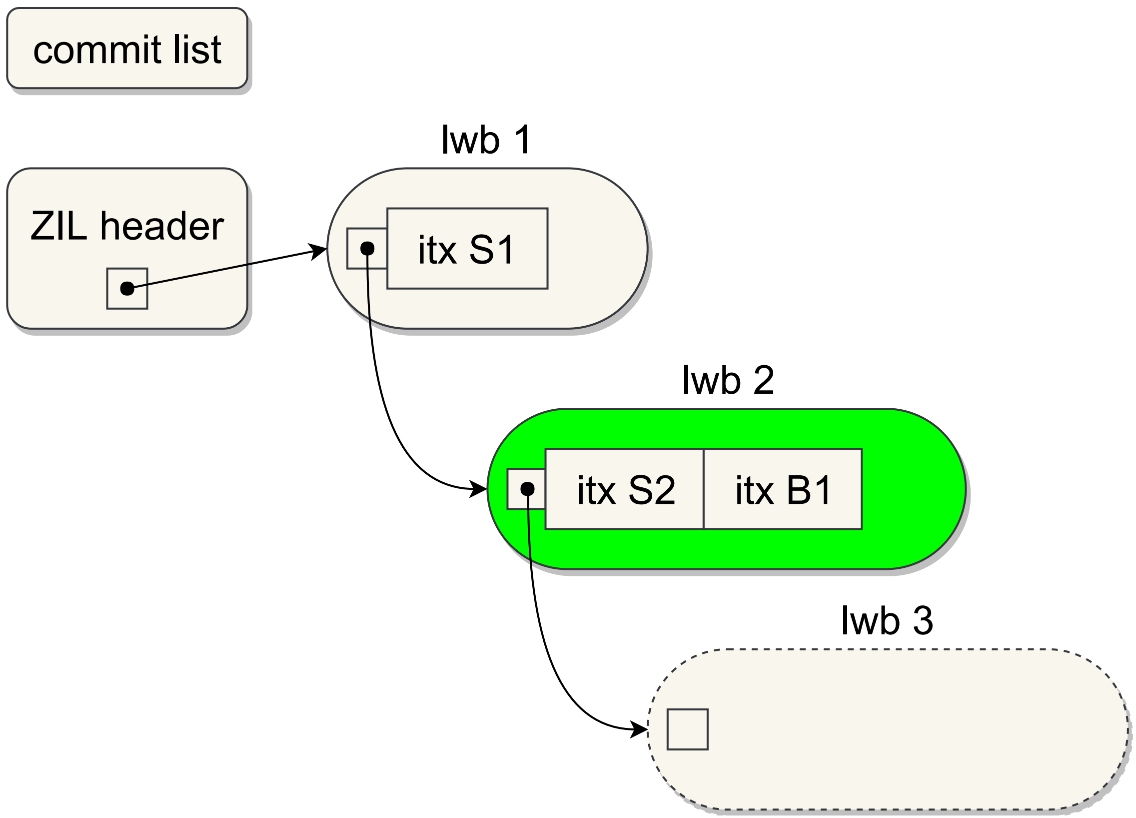

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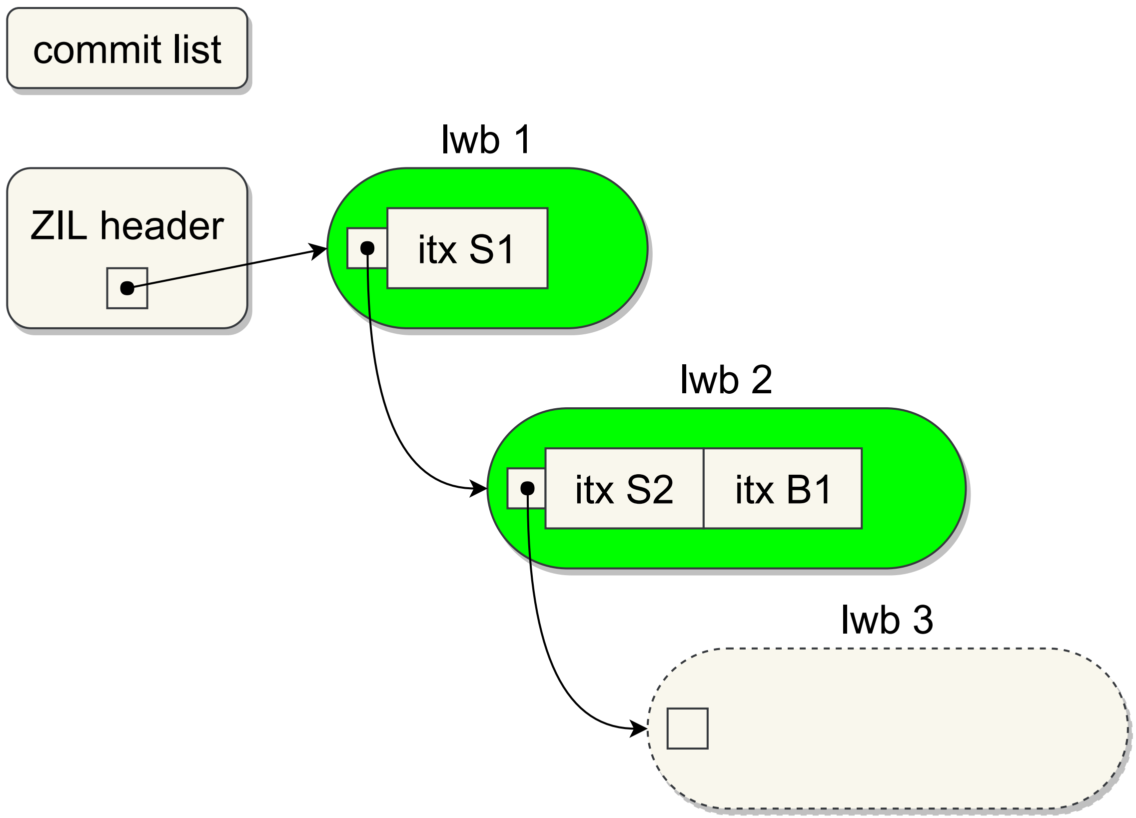

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  4. Flush VDEVs

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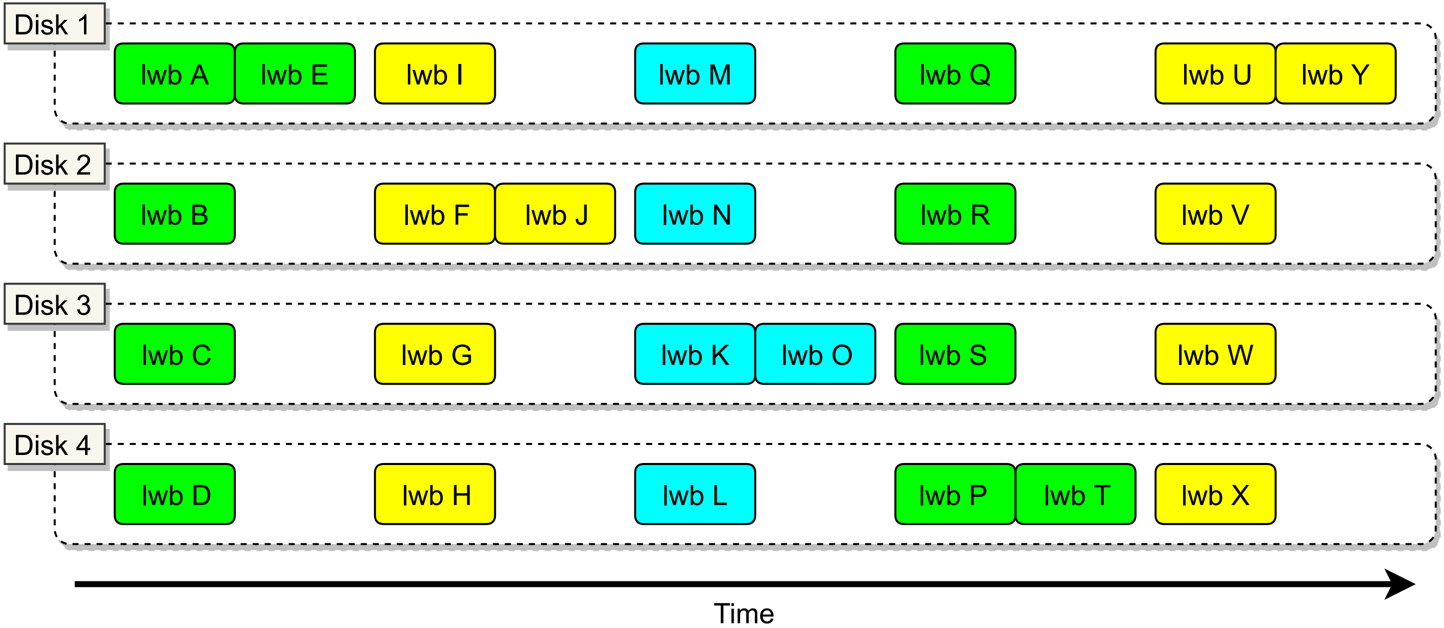
    3. ~~Wait for all ZIL block writes to complete~~
    4. ~~Flush VDEVs~~
    5. Notify waiting threads

3 – Problem

Problem

1. `itx`'s grouped and written in "batches"
    - The commit list constitutes a batch
    - Batch size proportional to sync workload on system
2. Waiting threads only notified when *all* ZIL blocks in batch complete
3. Only a single batch processed at a time

Problem



- Time spent servicing `lwb`'s for each disk
- Color indicates order waiting threads notified

Implications

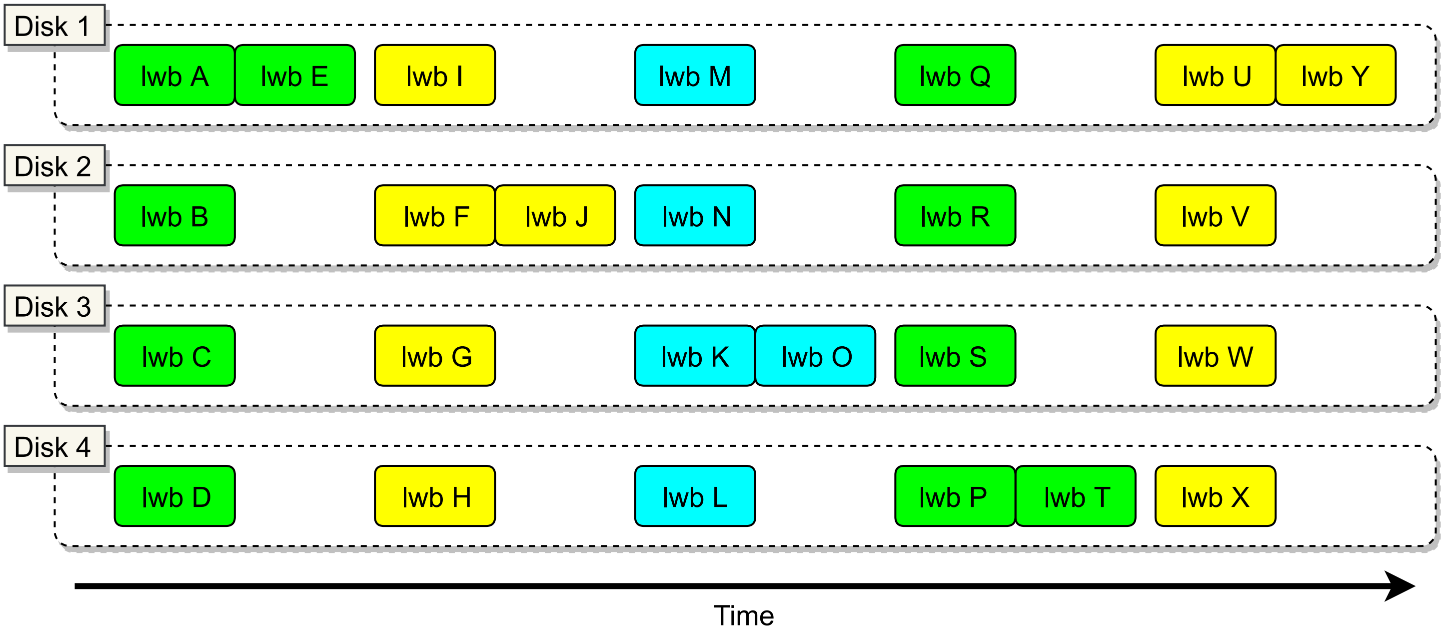
1. `zil_commit` latency proportional to system workload, *not* disk latency
    - Fast SLOG may not compensate for large workload
2. Disk "anomalies" → larger batches → increased `zil_commit` latency
    - e.g. temporary network delays when using network storage
3. New calls to `zil_commit` wait for "current" batch, *and* "next" batch
    - Average `zil_commit` latency equal to latency of 1.5 batches

3 – Solution

Solution

- Remove concept of "batches":
  1. Allow `zil_commit` to issue new ZIL block writes immediately
     - In contrast to waiting for the current batch to complete
  2. Notify threads immediately when *dependent* `lwb`'s on disk
     - In contrast to waiting for *all* `lwb`'s on disk

Problem



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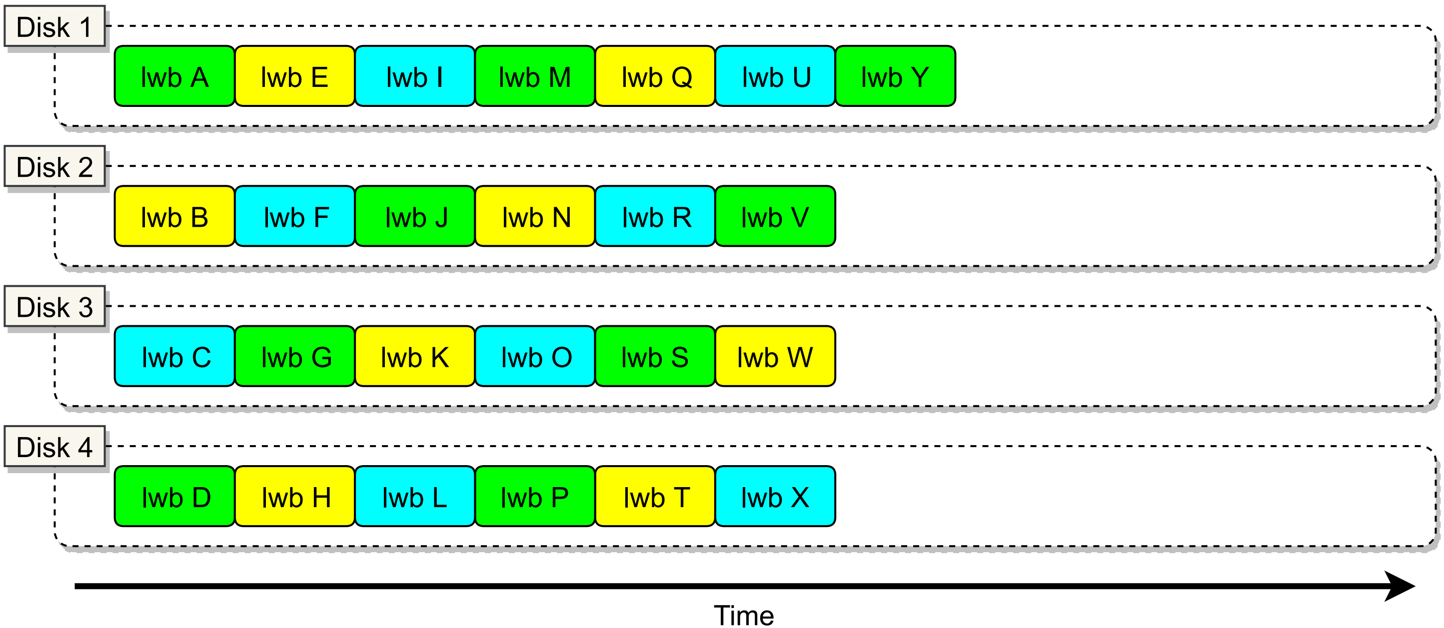

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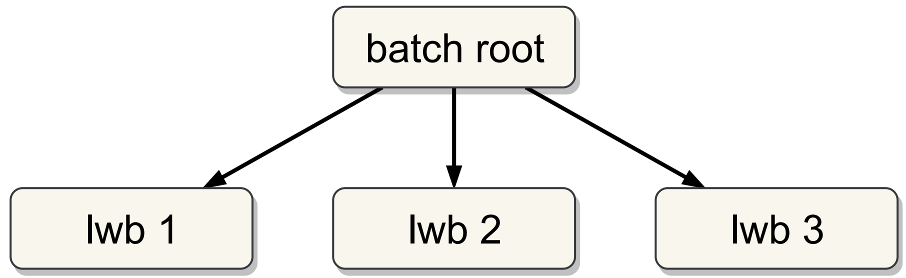
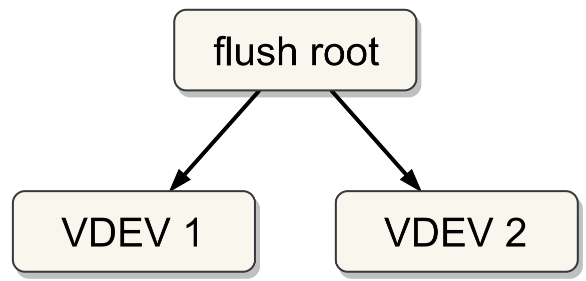
4 – Details on the Changes I Made

Before

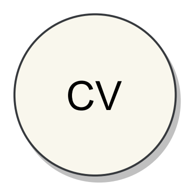
Step 1



Step 2



Step 3



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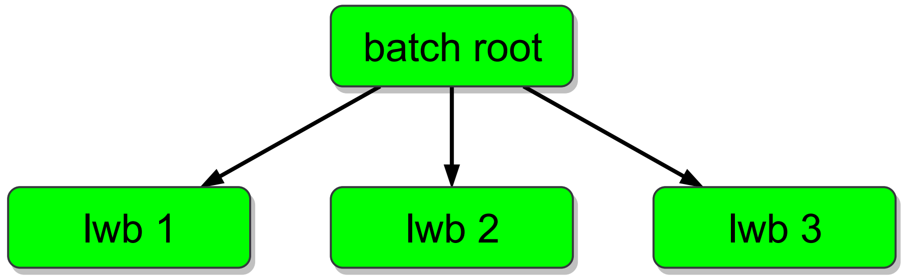

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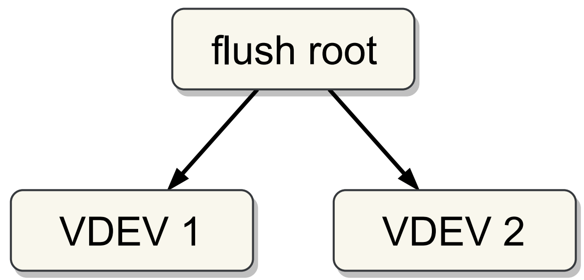

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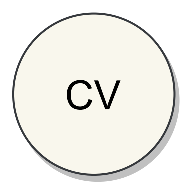

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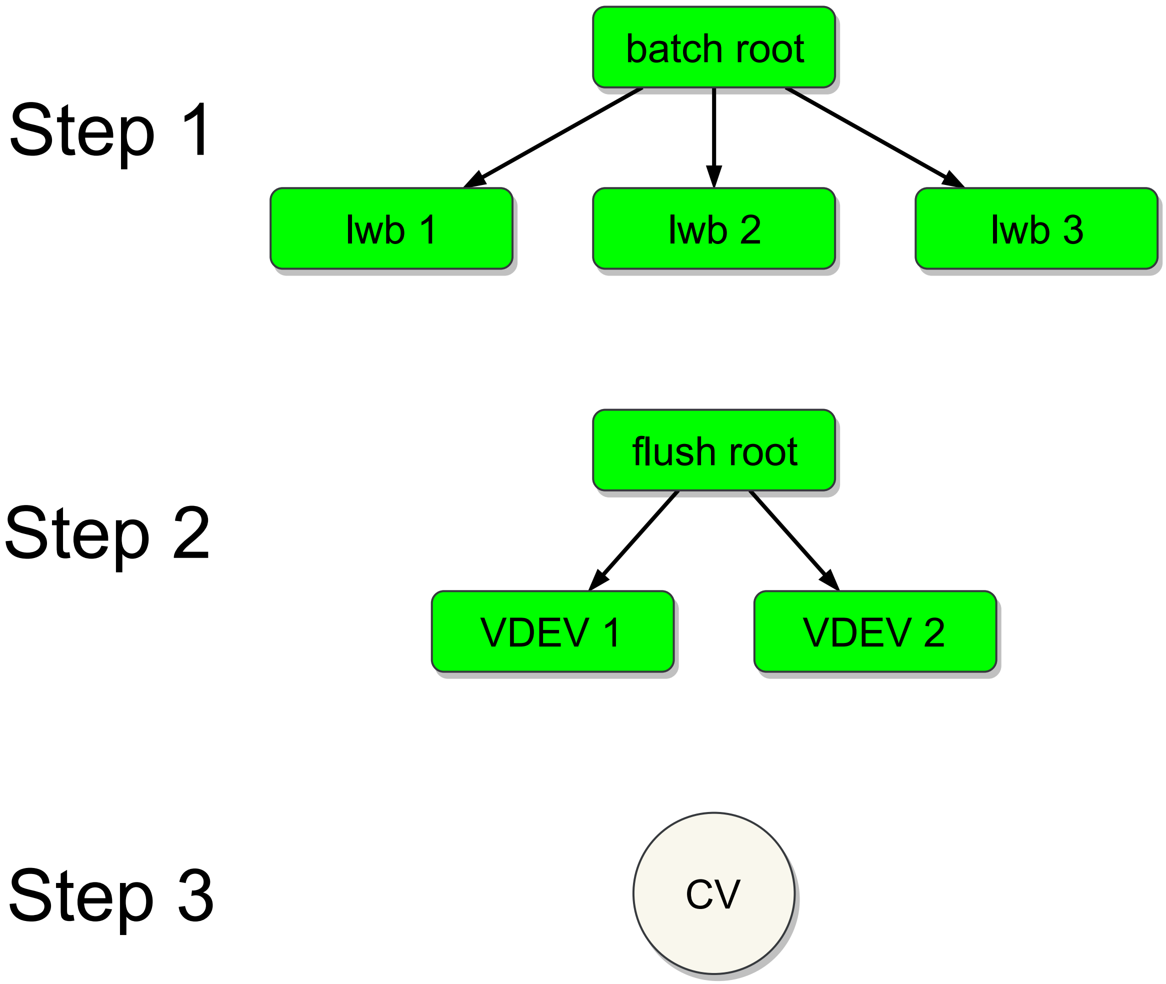
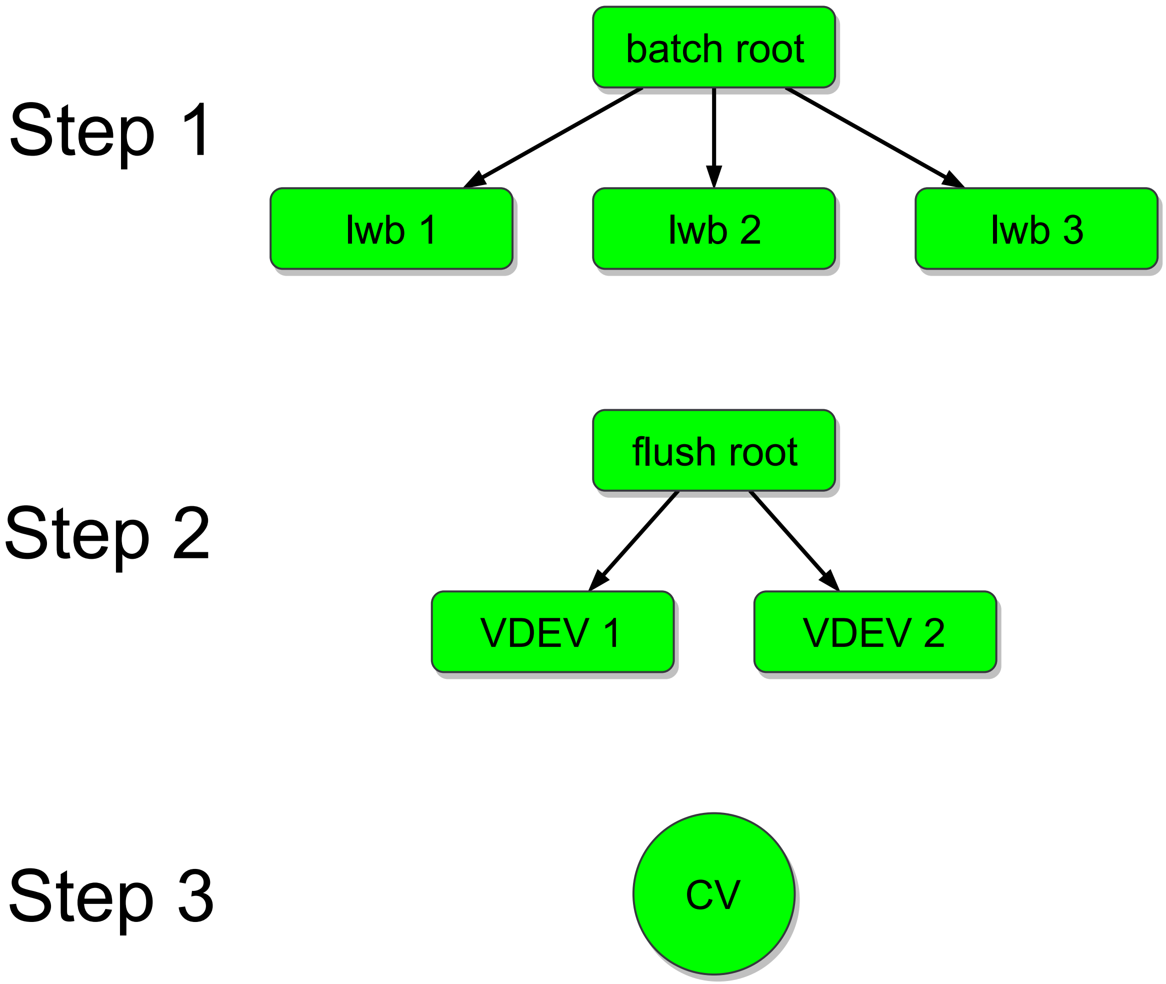

Step 1
batch root
lwb 1
lwb 2
lwb 3
Step 2
flush root
VDEV 1
VDEV 2
Step 3
CV

Before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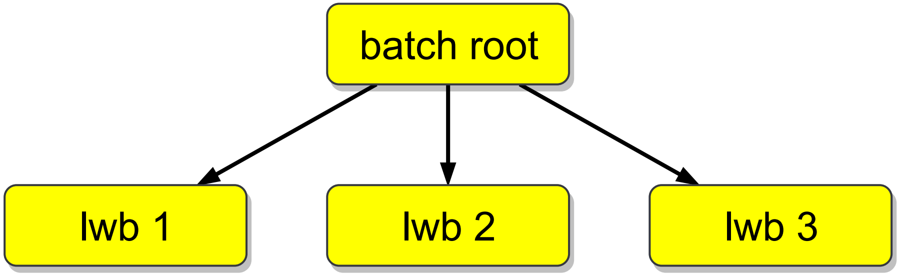

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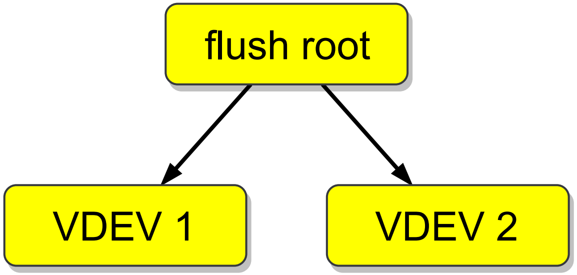

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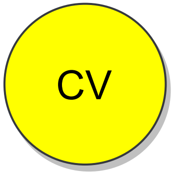

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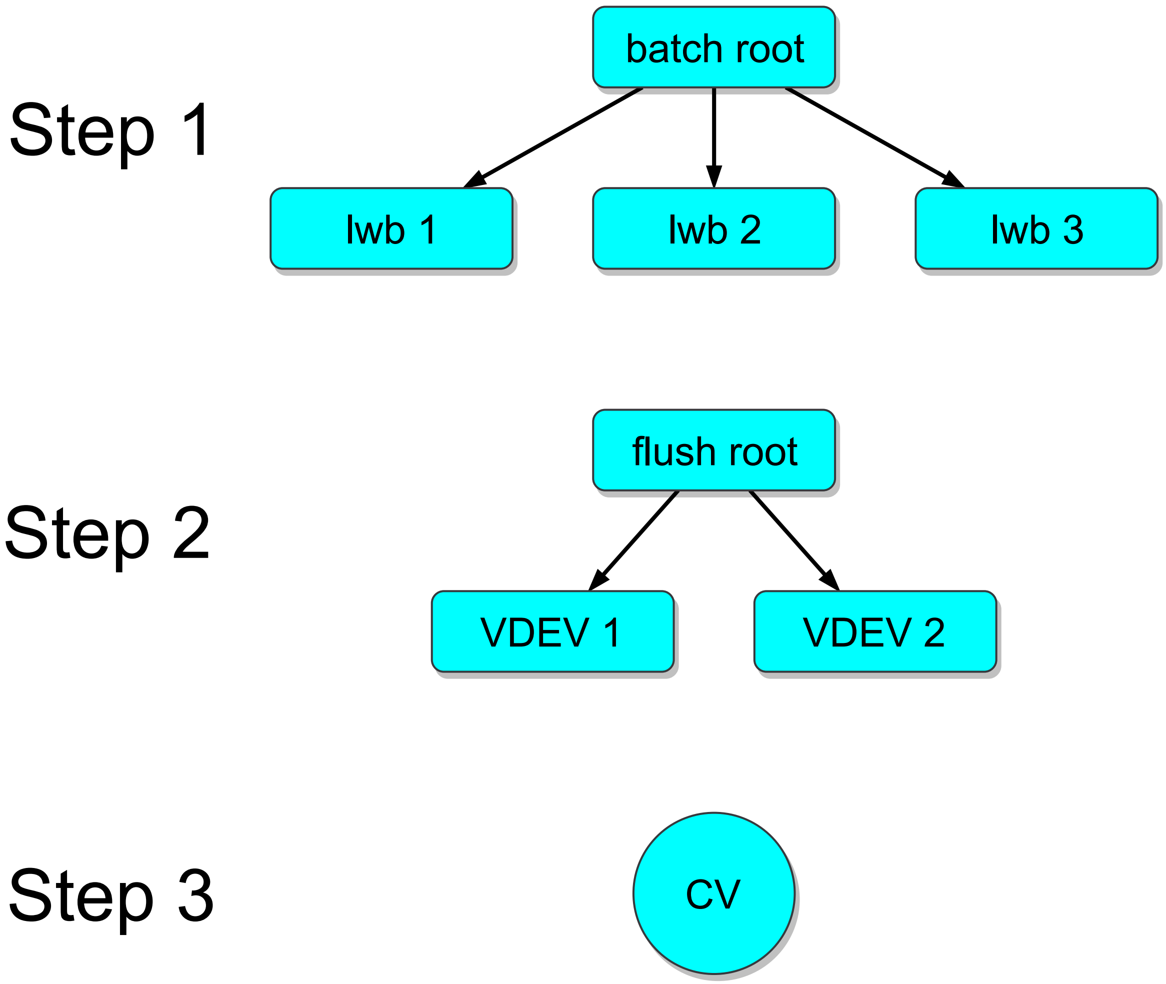

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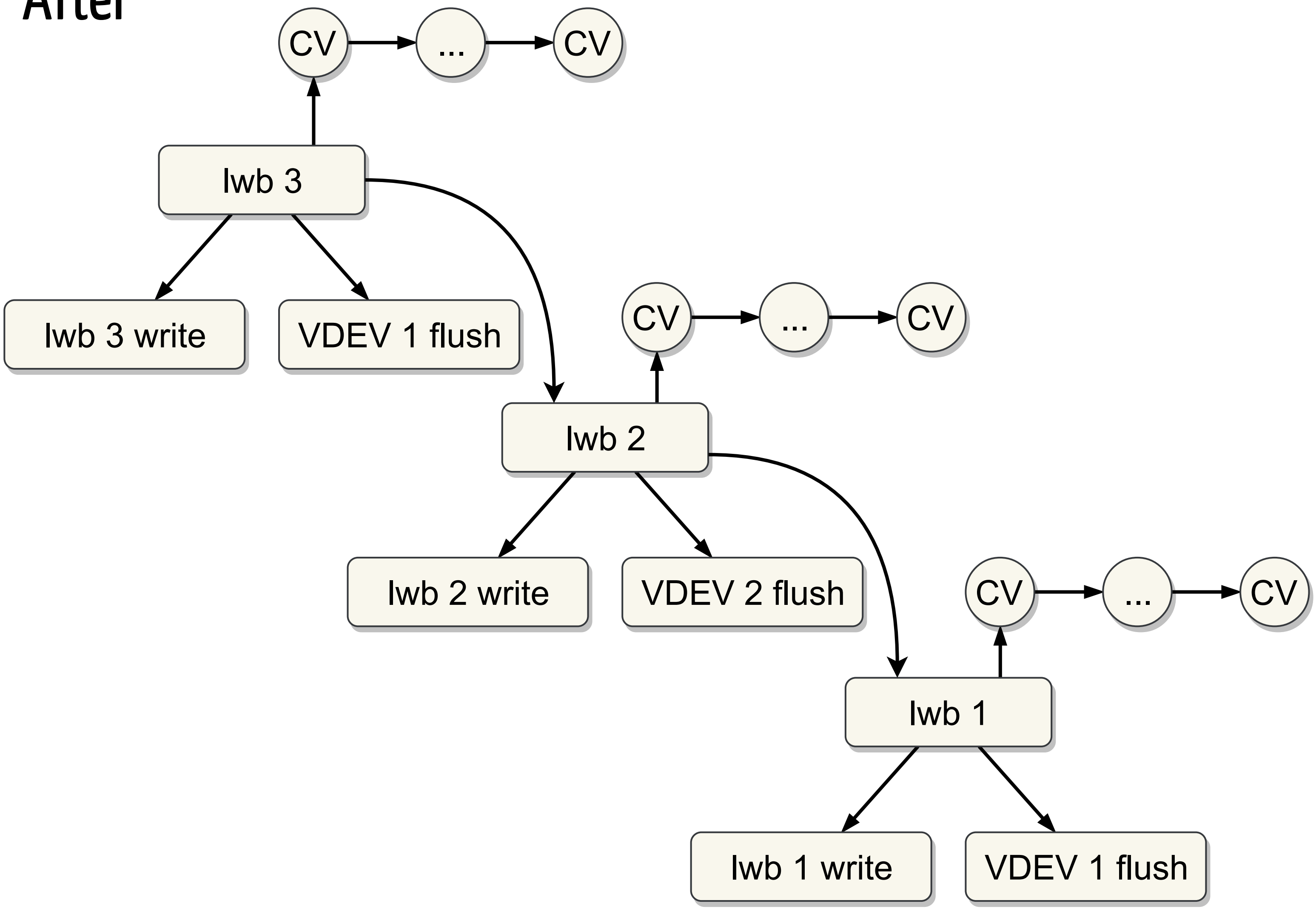
CV
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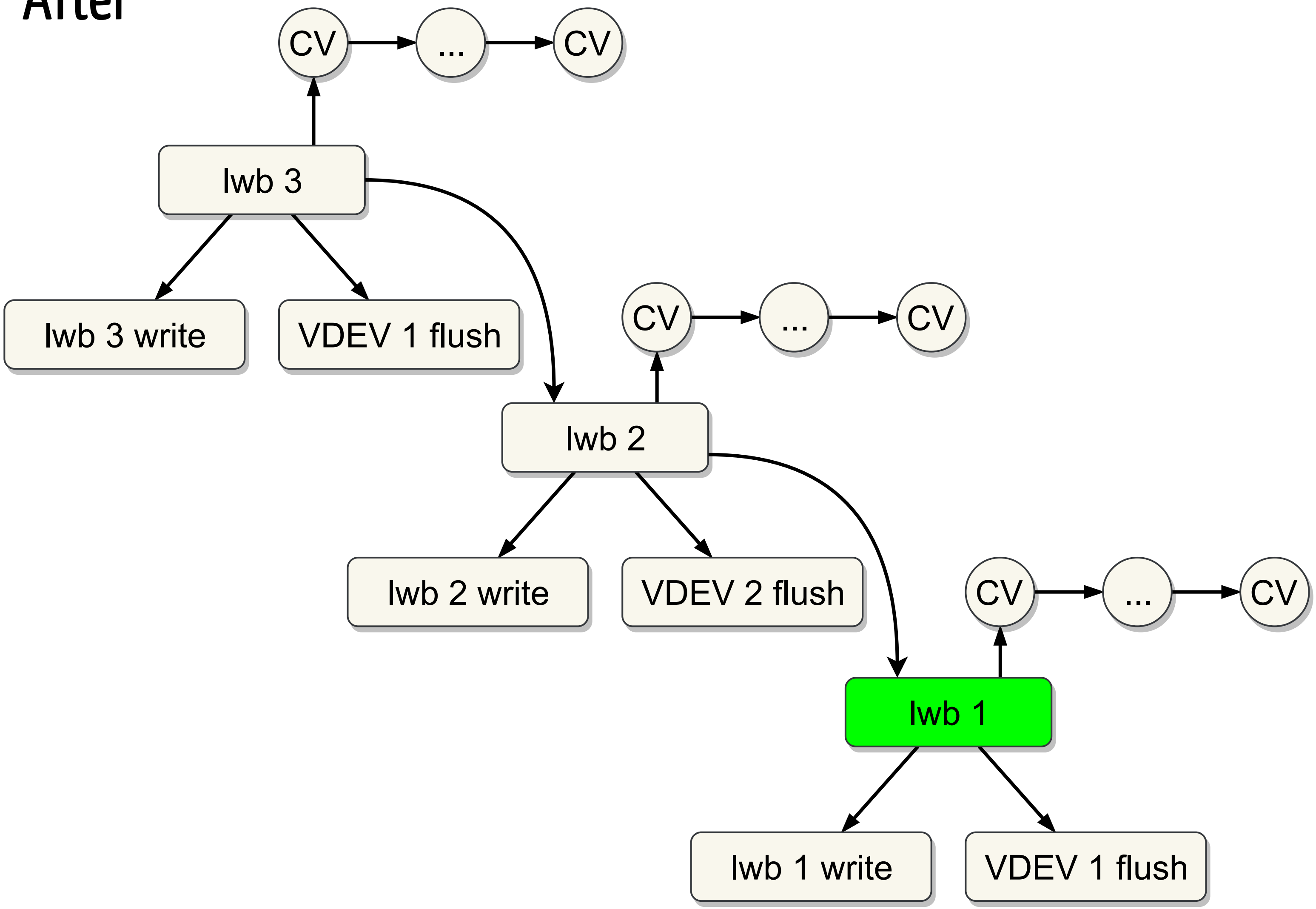
CV
lwb 3
lwb 3 write
VDEV 1 flush
CV
...
CV
lwb 2
lwb 2 write
VDEV 2 flush
CV
...
CV
lwb 1
lwb 1 write
VDEV 1 flush

After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lwb 3
lwb 3 write
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lwb 2 write
VDEV 2 flush
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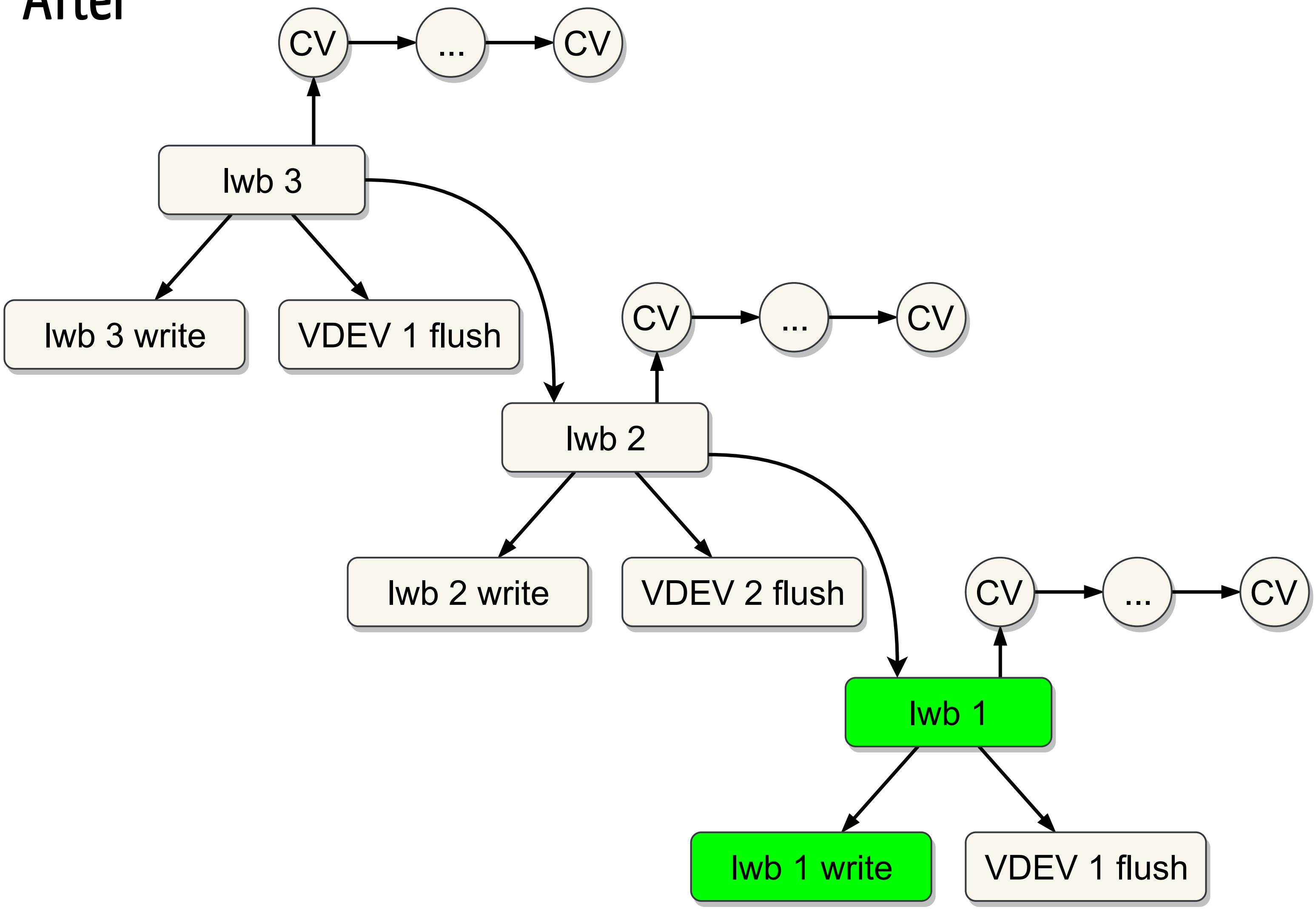
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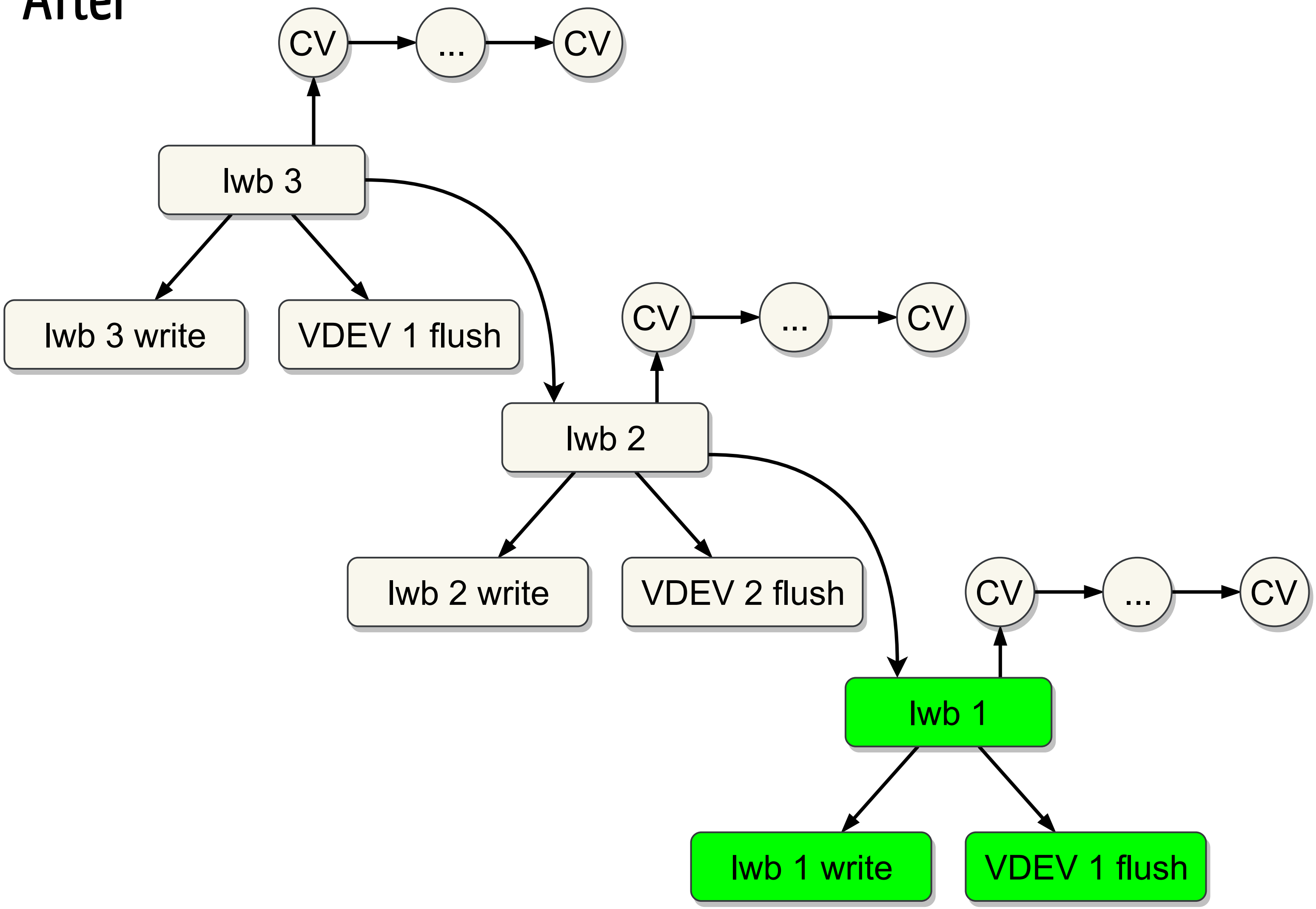
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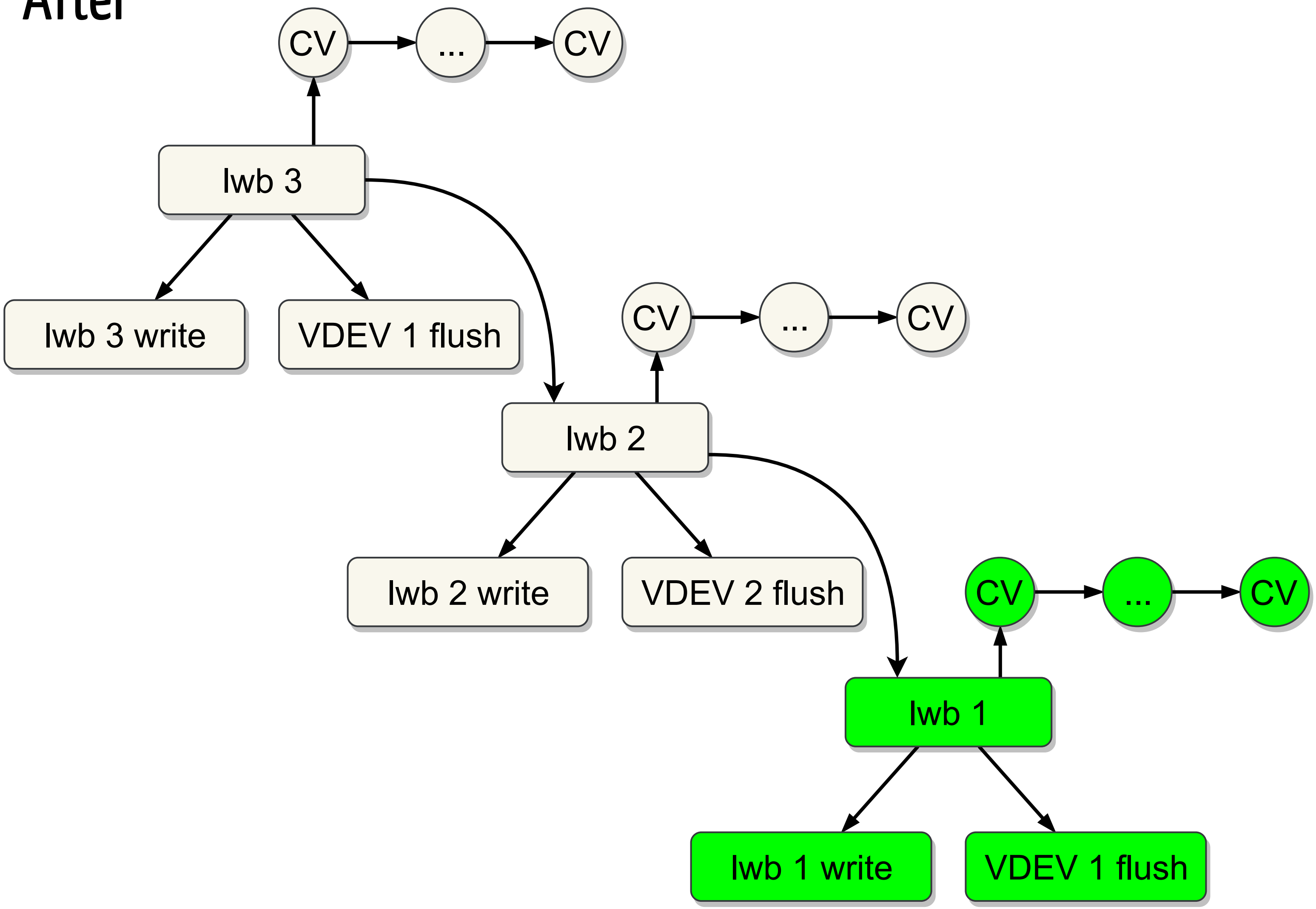

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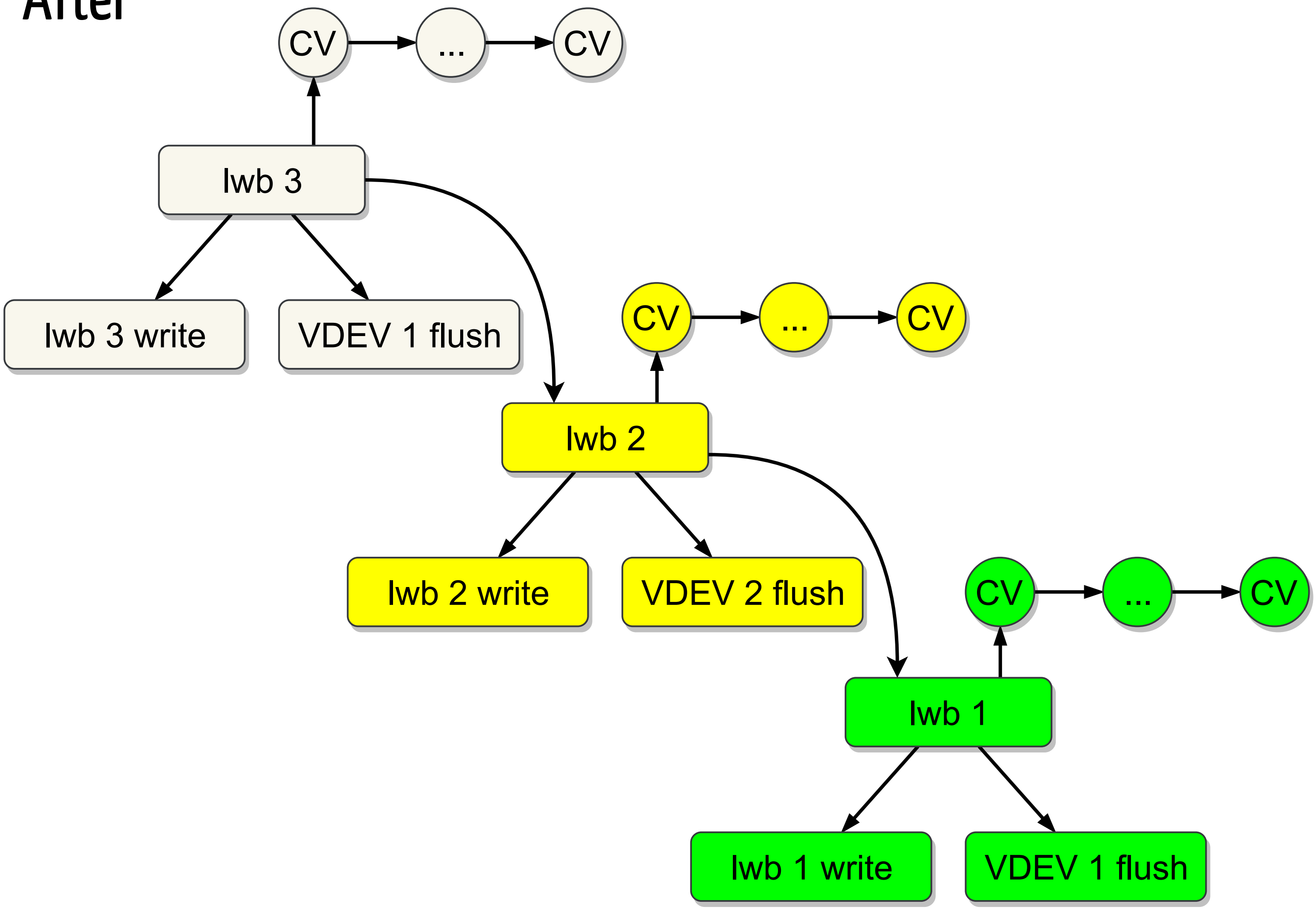
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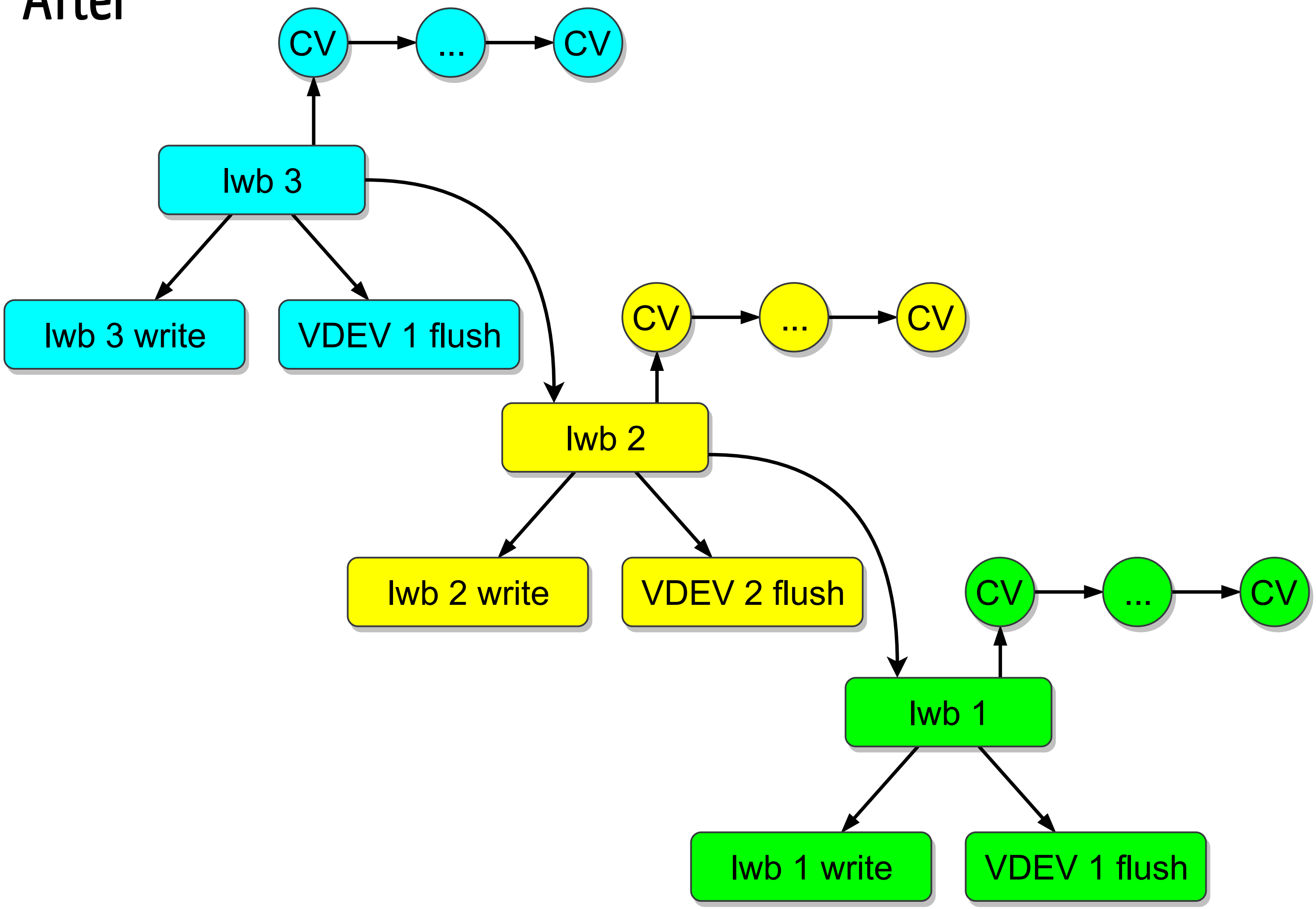

CV
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lwb 3
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CV
lwb 2
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VDEV 2 flush
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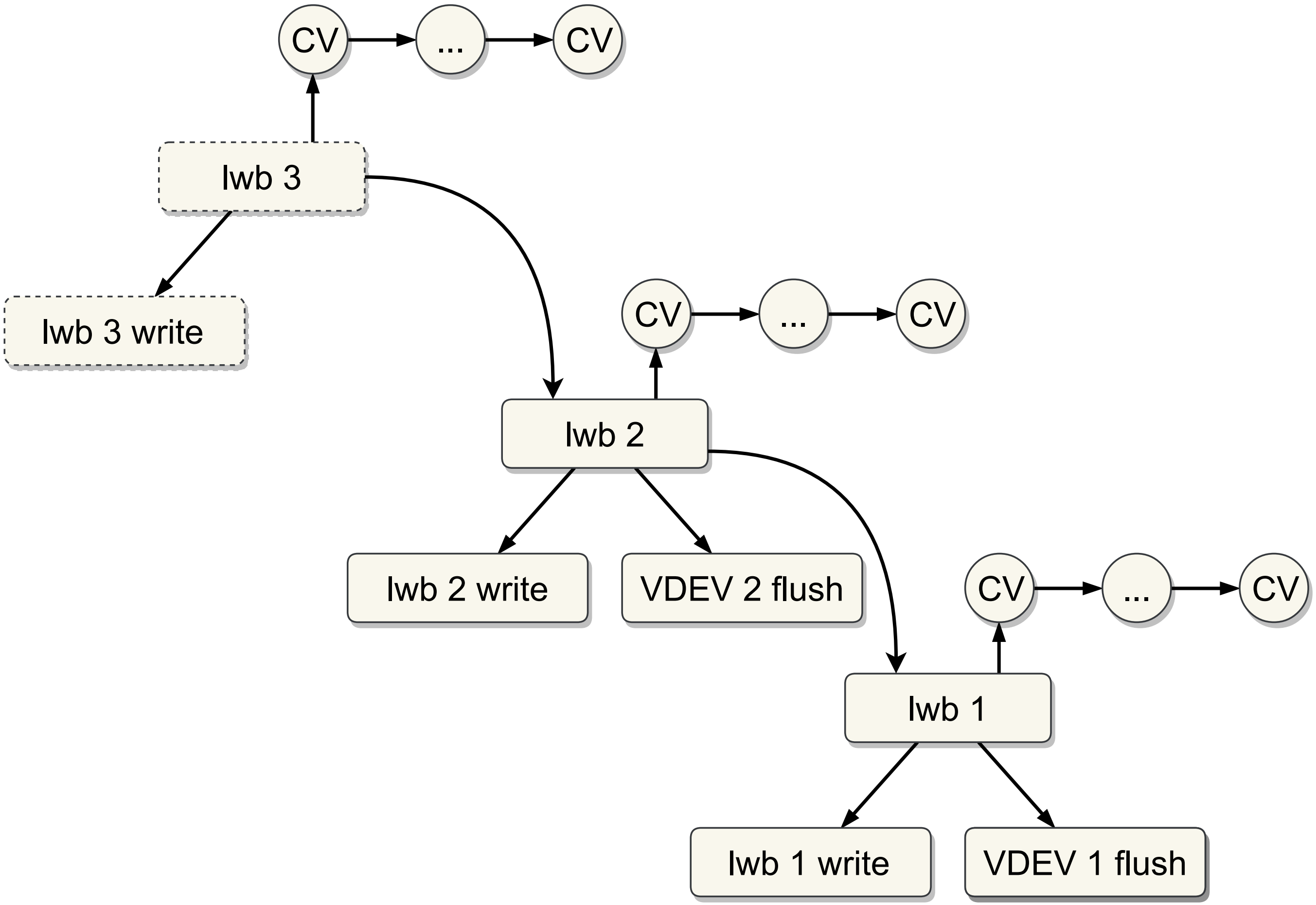
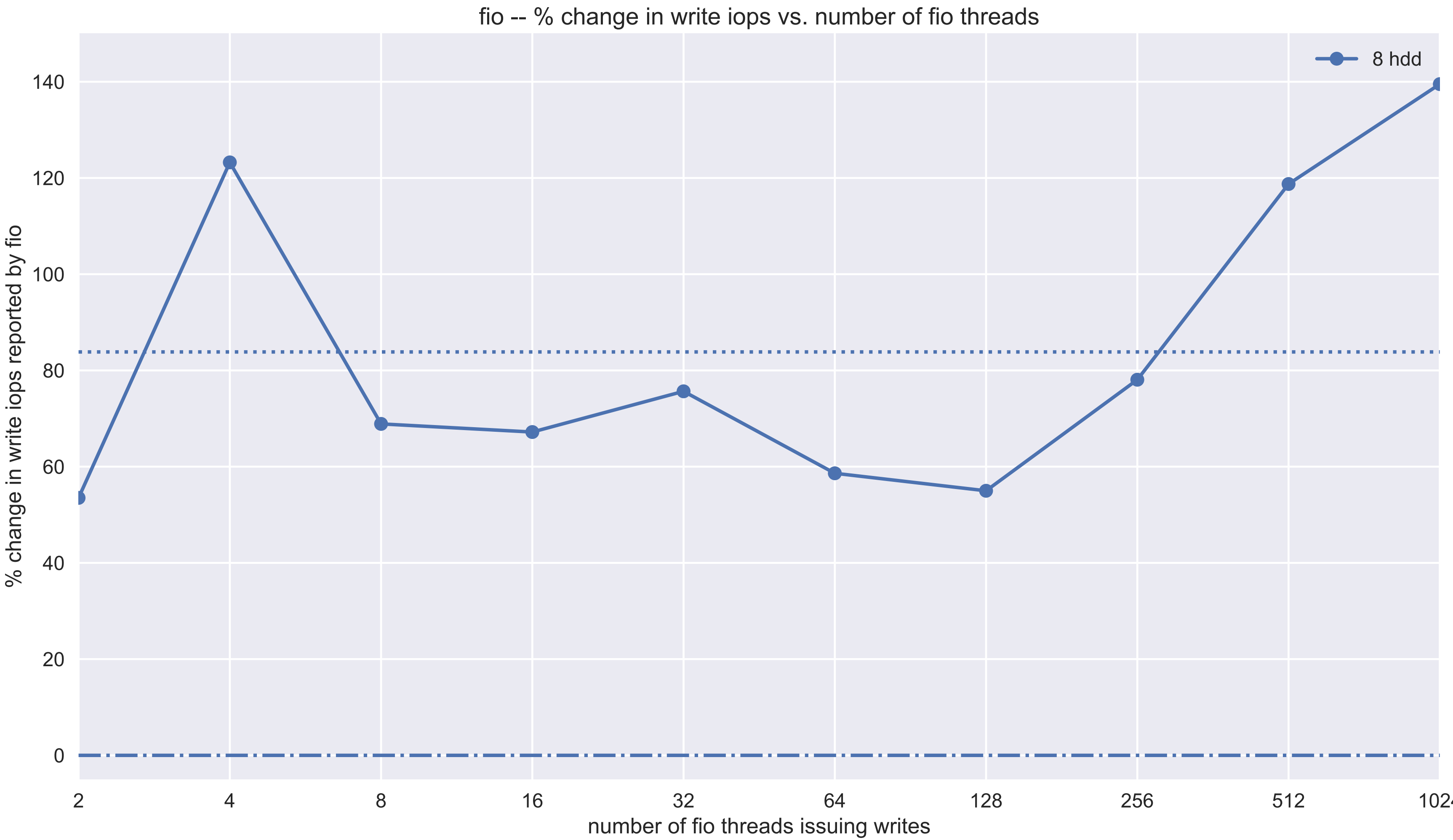
New Tunable: `lwb` Timeout



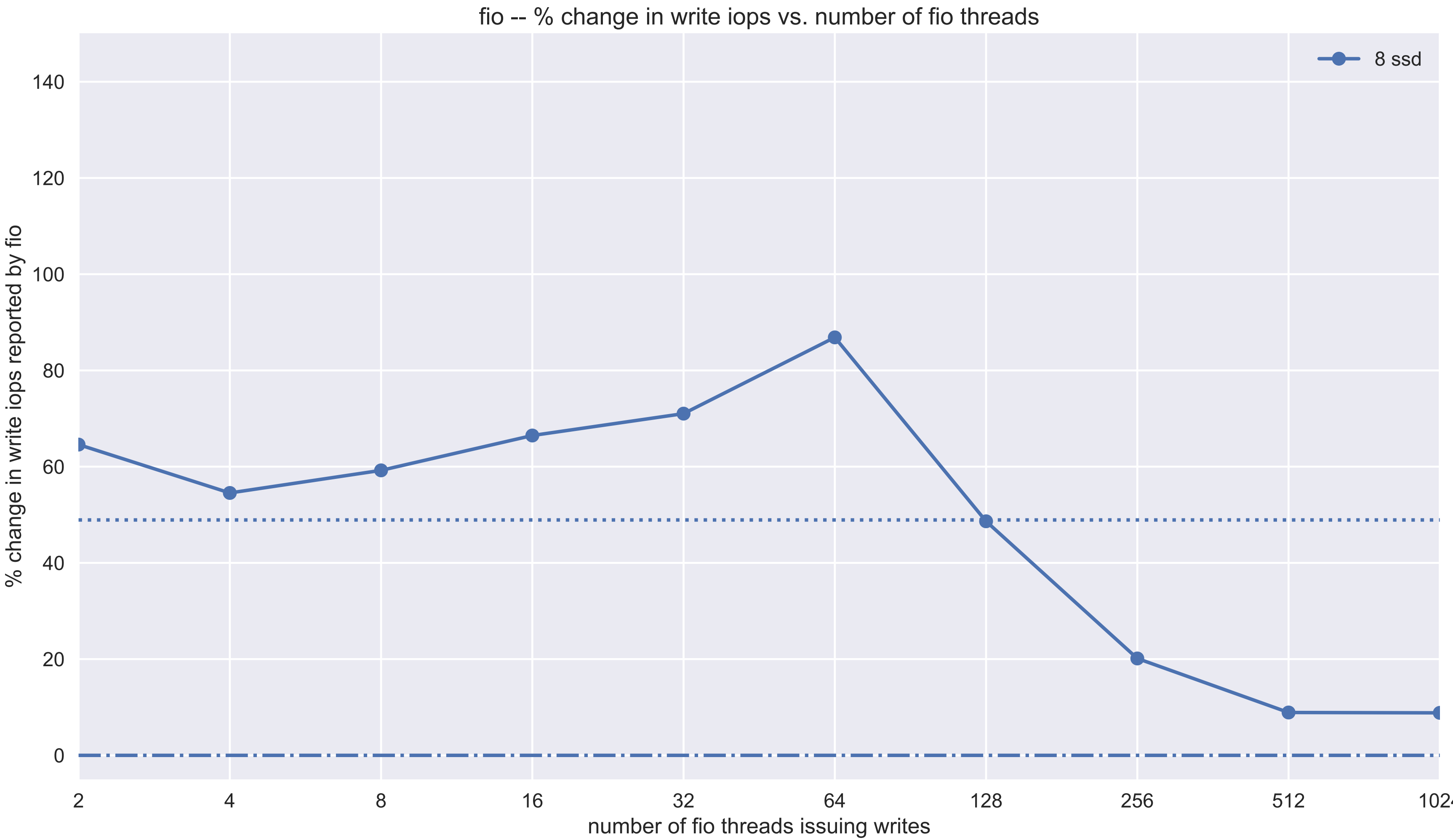
*New tunable named: `zfs_commit_timeout_pct`

5 – Performance testing and results

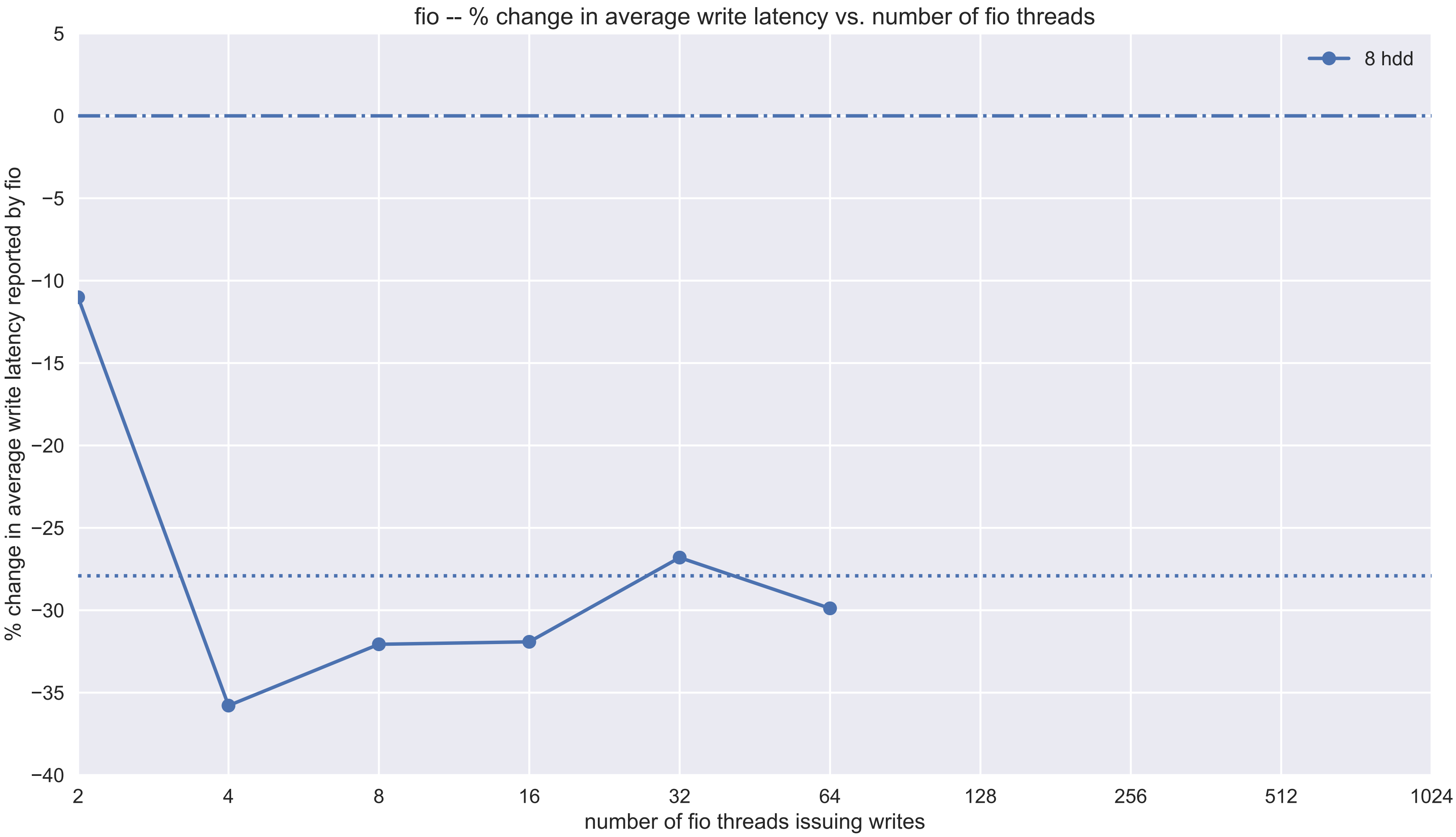
~83% Increase in IOPs on Average – Max Rate – 8 HDDs



~48% Increase in IOPs on Average – Max Rate – 8 SSDs

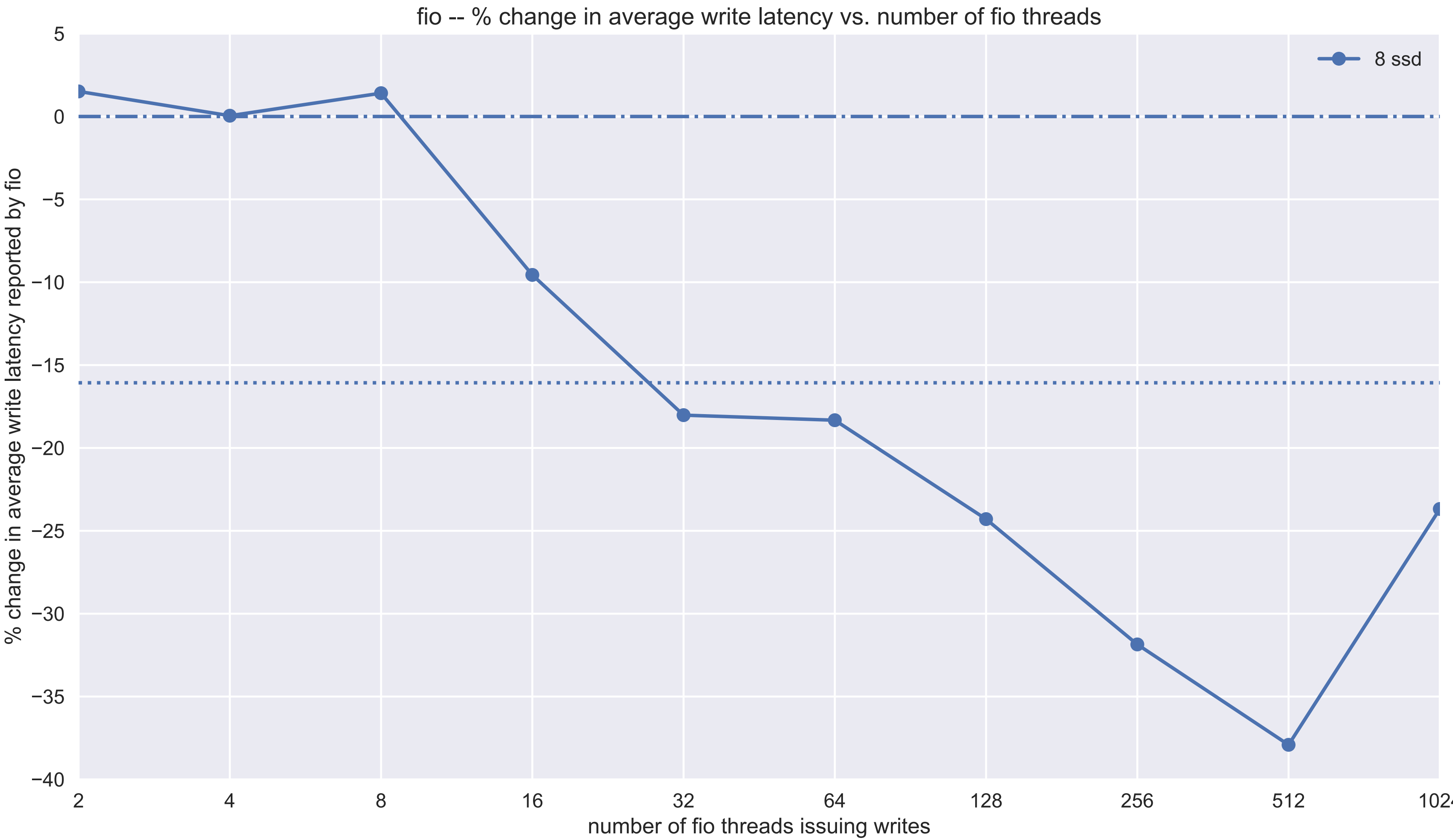


~27% Decrease in Latency on Average – Fixed Rate – 8 HDDs



*IOPs increased with new code, and >64 threads; those data points omitted.

~16% Decrease in Latency on Average – Fixed Rate – 8 SSDs



More Details

- Two `fio` workloads were used:
    1. each thread submitting sync writes as fast as it could
    2. each thread submitting 64 sync writes per second
- 1, 2, 4, and 8 disk zpools; both SSD and HDD
- `fio` threads ranging from 1 to 1024; increasing in powers of 2
- Full details can be found here

End