TRIM Explained

OpenZFS Developer Summit

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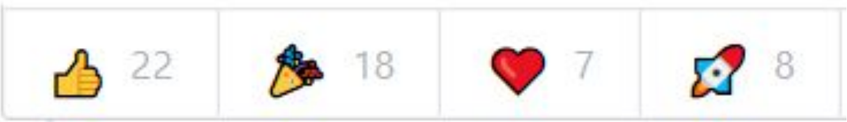
What is TRIM?

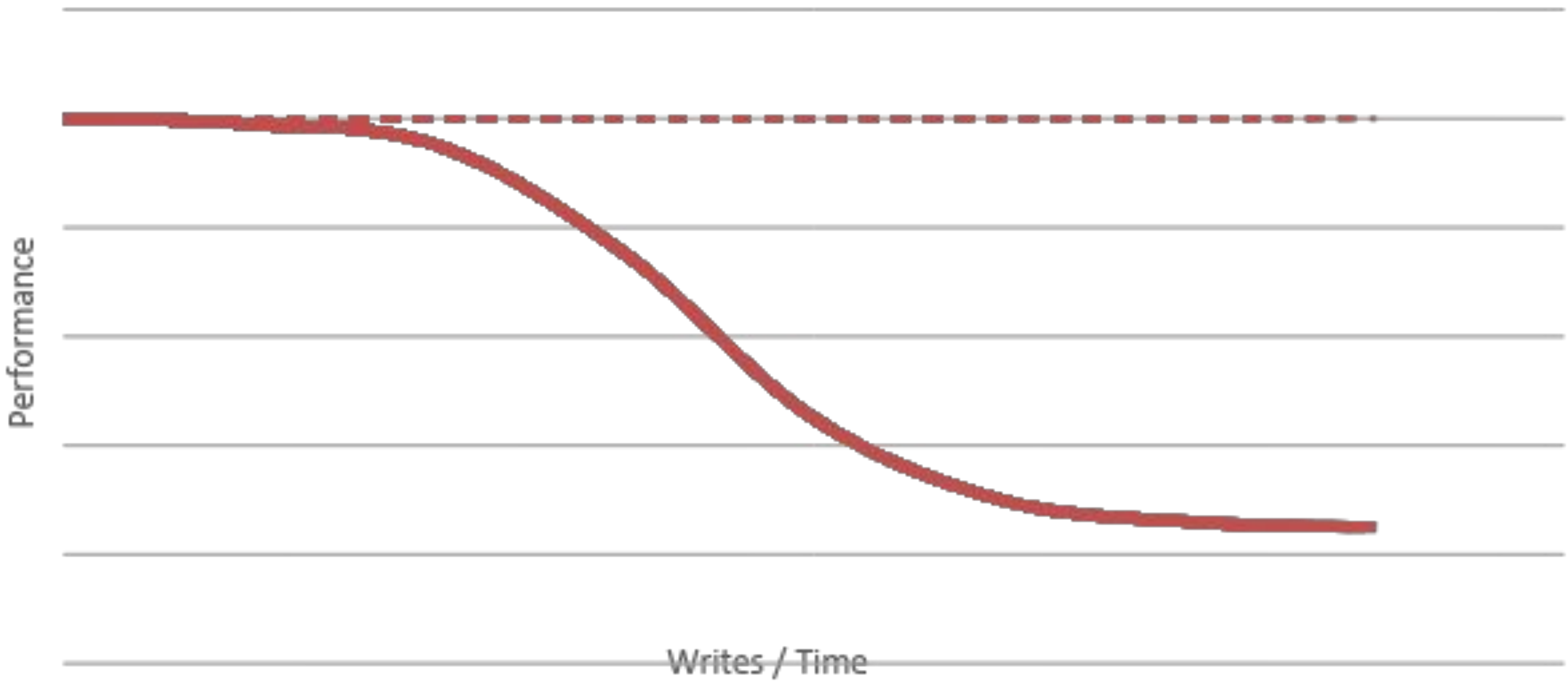
- TRIM is a command which allows the filesystem to notify the storage device which blocks are no longer in use.

- You may know it by a different name:
  - TRIM – ATA command set
  - UNMAP – SCSI command set
  - DISCARD – Linux terminology

- One of the most requested ZFS features
  - https://github.com/zfsonlinux/zfs/pull/8419



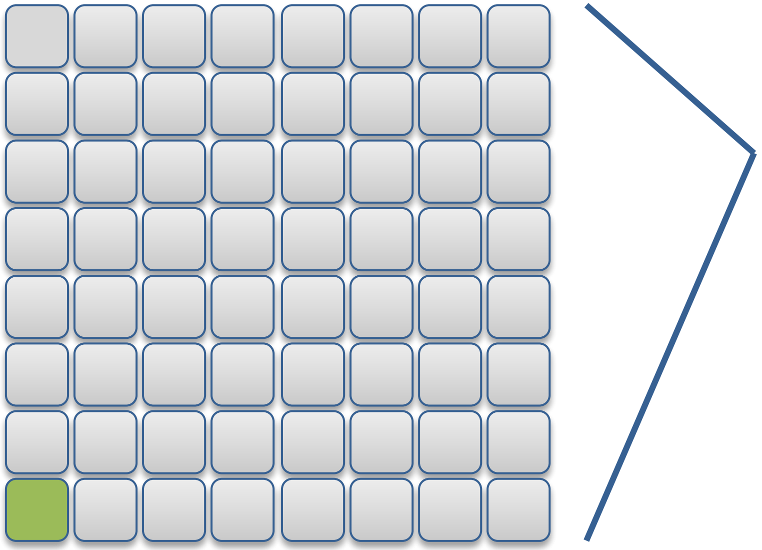
Expected SSD Performance



Decreased Performance Over Time

NAND Limitations and Block Sizes

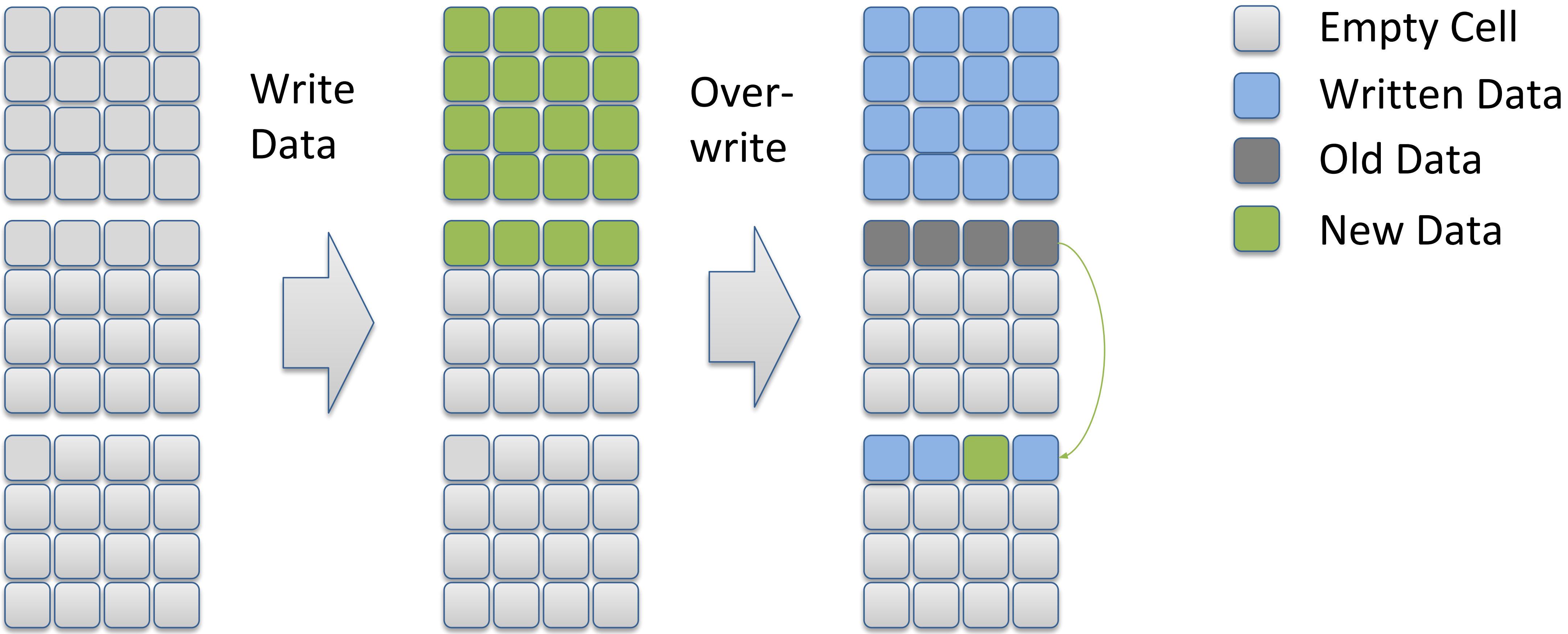
- Only empty pages may be written
- Only entire blocks may be erased
- Erasing a block is slow



256K - 4M Erasure Block

4K - 16K Page

Write Amplification



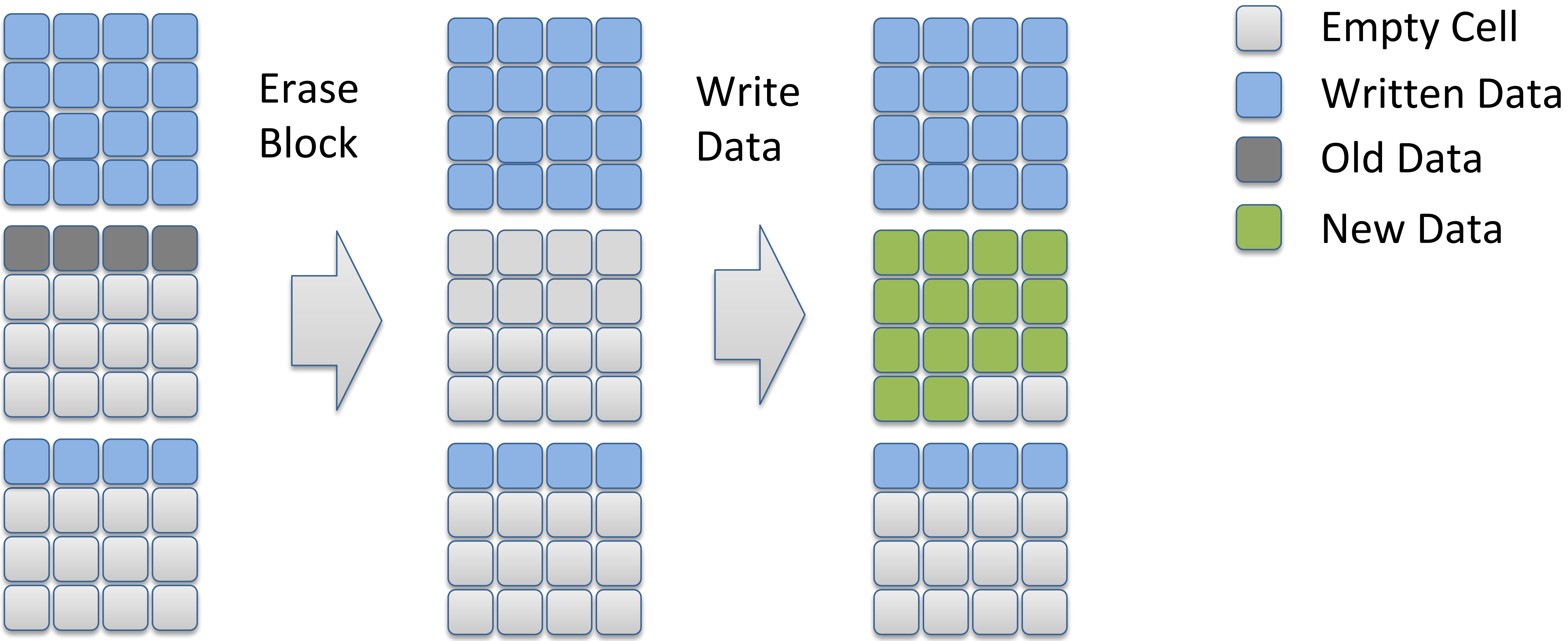
Write Data

Over-write

- ⬜ Empty Cell
- 🟦 Written Data
- ⬛ Old Data
- 🟩 New Data

Writes may be inflated since pages cannot be overwritten

Garbage Collection



Erase Block

Write Data

- ⬜ Empty Cell
- 🟦 Written Data
- ⬛ Old Data
- 🟩 New Data

Full erase/write cycles are expensive

Filesystem Support for TRIM

- Must be implemented in the filesystem; only it knows which sectors are in use
- Filesystems were originally optimized for HDDs; no need to notify device of unused sectors
- Efficient management of SSDs requires TRIM; internally the device can only do so much
- Motivations:
  - Reduced write amplification (fewer writes)
  - Higher write throughput (less read-erase-modify)
  - Increased device longevity (finite erase-write cycles)
- Automatic online TRIM support was added to: Ext4, Btrfs, FAT, JFS, XFS
- But it's tricky, often it is disabled by default due to performance concerns

TRIM must be implemented in the filesystem layer

Revisiting the Design

- Existing versions of TRIM worked well, why another version?
  - FreeBSD - added TRIM in version 9.2 (2012)
  - Nexenta - added TRIM to NexentaStor (2015)

- Design goals:
  - Online TRIM with negligible impact to running applications
  - Interoperates seamlessly with all existing OpenZFS features
  - Avoid introducing any duplicate functionality
  - Long term maintainability
  - Minimize platform specific dependencies

- We can learn from the previous versions

- And… a recent OpenZFS feature enables all of this

Building on the OpenZFS “vdev initialize” feature

- OpenZFS “vdev initialize” feature (aka eager zero)
  - Initializes all unallocated space in the background to prevent a first-access penalty
    - https://github.com/zfsonlinux/zfs/pull/8230
  - Introduced core infrastructure which could be extended for TRIM

- Key existing components:
  - Flexible administrative interface (CLI)
  - Ability to enable/disable new allocations for specified metaslab
  - Walks all unallocated space and submits I/Os for those vdev offsets

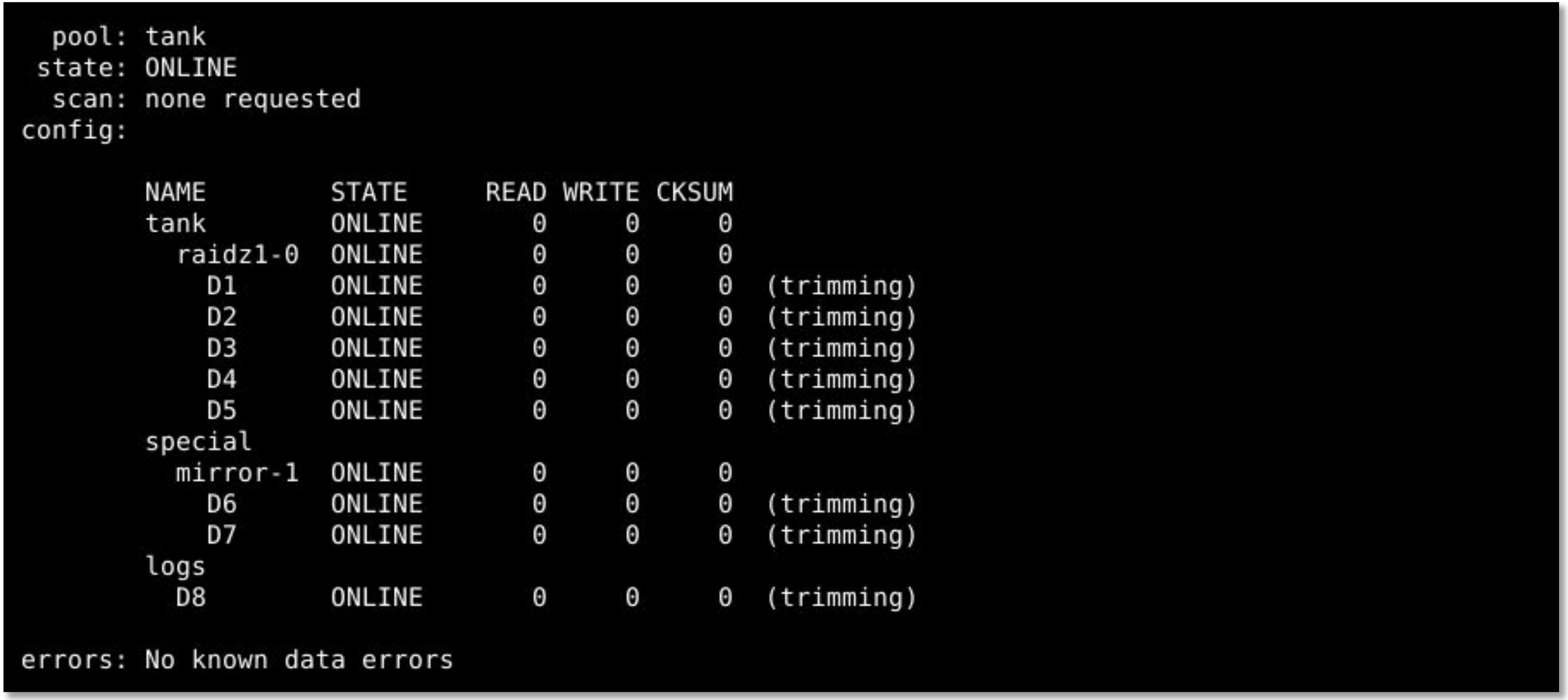
- New work required for TRIM
  - Modify or extend the existing code to be more generic
  - Add TRIM I/Os to the zio pipeline
  - Automatic background TRIM

Manual TRIM – “zpool trim”

```
zpool trim [-d] [-r rate] [-c | -s] pool [device…]
        -d     --secure     Request secure TRIM
        -r     --rate rate  Request specified TRIM rate
        -c     --cancel     Cancel running TRIM
        -s     --suspend    Suspend running TRIM
```

- Initiates an on-demand TRIM for all unallocated space in the pool
- Efficiently issues TRIM I/Os
  - Merges contiguous ranges in to one I/O
  - Skips very small ranges
  - Breaks large ranges into chunks
- Cancel / suspend / resume and in-progress TRIM
- TRIM state is preserved over a reboot (export / import)
- Clear progress reporting via “zpool status [-t]”
- CLI options are consistent with the “zpool initialize” command

“zpool status”

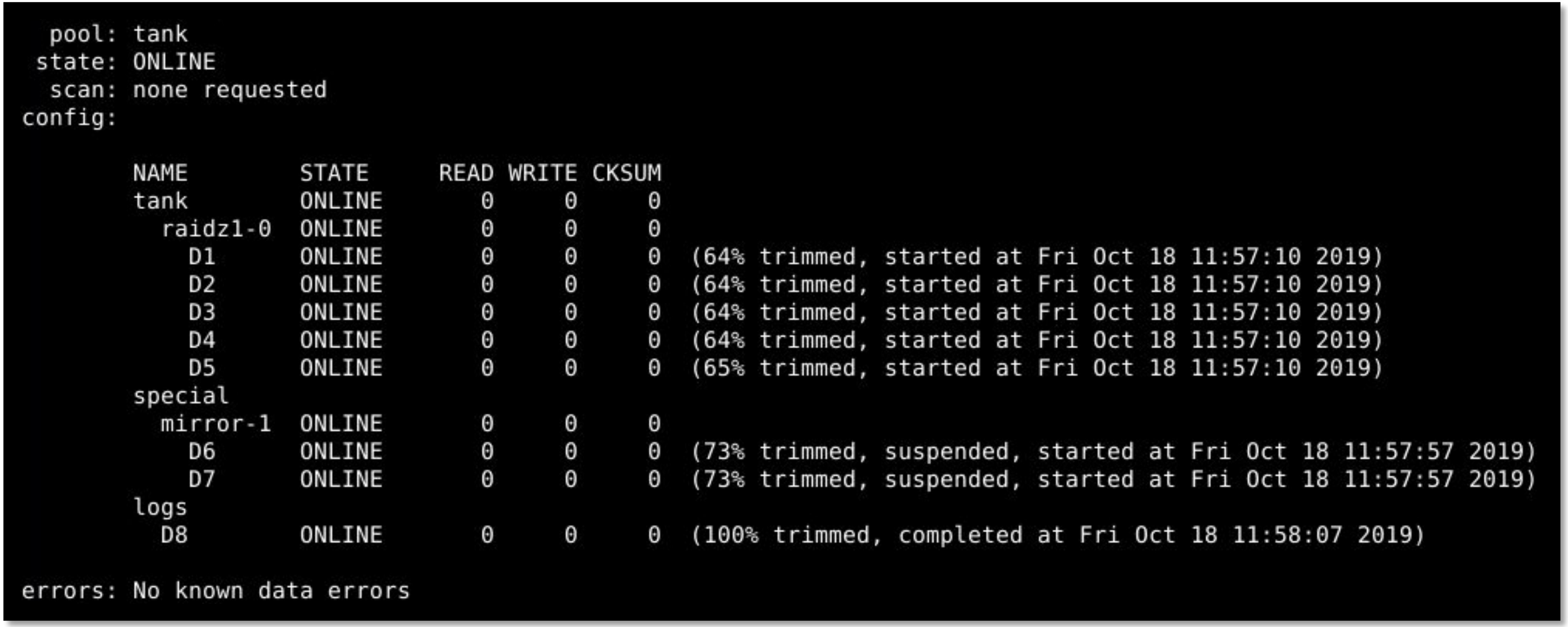


```
  pool: tank
 state: ONLINE
  scan: none requested
config:

        NAME        STATE     READ WRITE CKSUM
        tank        ONLINE       0     0     0
          raidz1-0  ONLINE       0     0     0
            D1      ONLINE       0     0     0  (trimming)
            D2      ONLINE       0     0     0  (trimming)
            D3      ONLINE       0     0     0  (trimming)
            D4      ONLINE       0     0     0  (trimming)
            D5      ONLINE       0     0     0  (trimming)
        special
          mirror-1  ONLINE       0     0     0
            D6      ONLINE       0     0     0  (trimming)
            D7      ONLINE       0     0     0  (trimming)
        logs
          D8        ONLINE       0     0     0  (trimming)

errors: No known data errors
```

“zpool status –t”



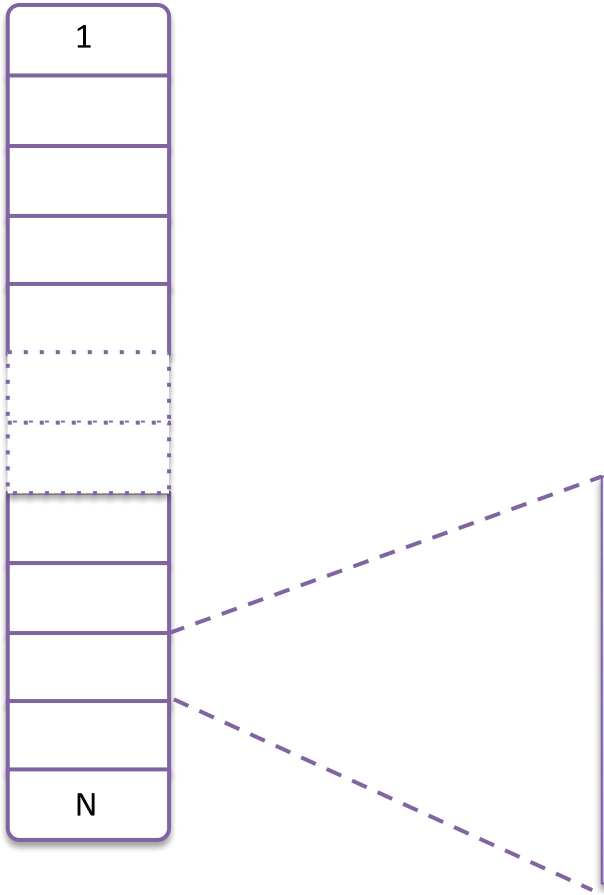
```
  pool: tank
 state: ONLINE
  scan: none requested
config:

        NAME        STATE     READ WRITE CKSUM
        tank        ONLINE       0     0     0
          raidz1-0  ONLINE       0     0     0
            D1      ONLINE       0     0     0  (64% trimmed, started at Fri Oct 18 11:57:10 2019)
            D2      ONLINE       0     0     0  (64% trimmed, started at Fri Oct 18 11:57:10 2019)
            D3      ONLINE       0     0     0  (64% trimmed, started at Fri Oct 18 11:57:10 2019)
            D4      ONLINE       0     0     0  (64% trimmed, started at Fri Oct 18 11:57:10 2019)
            D5      ONLINE       0     0     0  (65% trimmed, started at Fri Oct 18 11:57:10 2019)
        special
          mirror-1  ONLINE       0     0     0
            D6      ONLINE       0     0     0  (73% trimmed, suspended, started at Fri Oct 18 11:57:57 2019)
            D7      ONLINE       0     0     0  (73% trimmed, suspended, started at Fri Oct 18 11:57:57 2019)
        logs
          D8        ONLINE       0     0     0  (100% trimmed, completed at Fri Oct 18 11:58:07 2019)

errors: No known data errors
```

Metaslabs

- ms_allocatable is used to track the allocatable space
- metaslab_enable() / metaslab_disable()
  - Unavailable for new allocations
  - Up to max_disable_ms metaslabs disabled concurrently
  - Multiple threads may disable the same metaslab



```
struct metaslab {
        …
        range_tree_t        *ms_freed;                      /* already freed this syncing txg */
        range_tree_t        *ms_defer[TXG_DEFER_SIZE];      /* freed in a previous txg */
        range_tree_t        *ms_allocatable;                /* allocatable / free space */
        range_tree_t        *ms_trim;                       /* autotrim ranges */
        …
        uint64_t            ms_disabled;
}
```

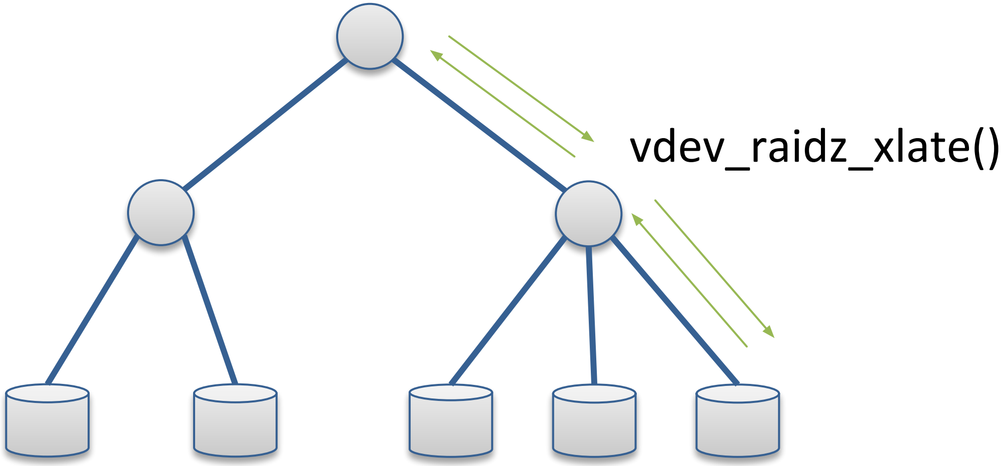
vdev_xlate()

- Translates a logical range to a physical range for the specified vdev

```
void vdev_xlate(vdev_t *vd, const range_seg64_t *logical_rs, range_seg64_t *physical_rs);
```

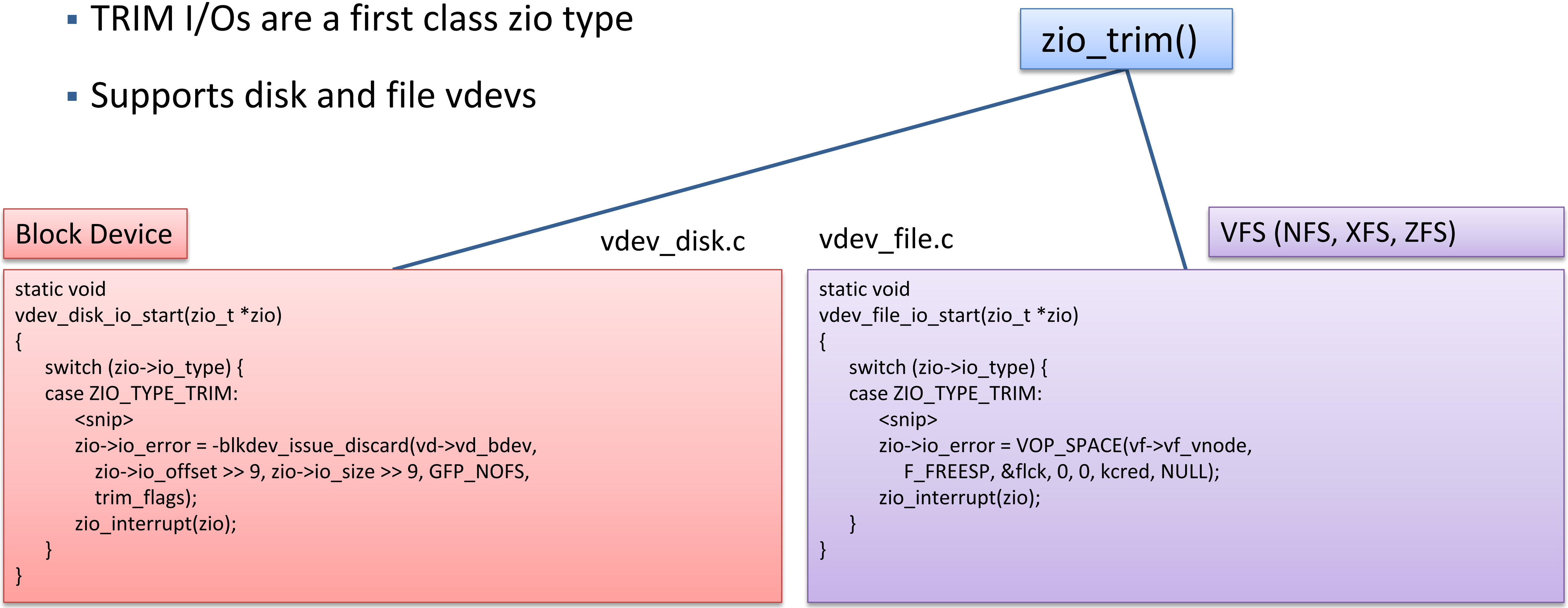
- Strategy:
  - Walks up each parent to the top-level vdev
  - Unwinds calling each parent's translation function
  - Returns the physical range for the vdev

- Translation Functions:
  - Callback: "vdev_ops->vdev_op_xlate()"
    - vdev_raidz_xlate()
    - vdev_default_xlate()



ZIO_TYPE_TRIM

- TRIM I/Os are a first class zio type
- Supports disk and file vdevs

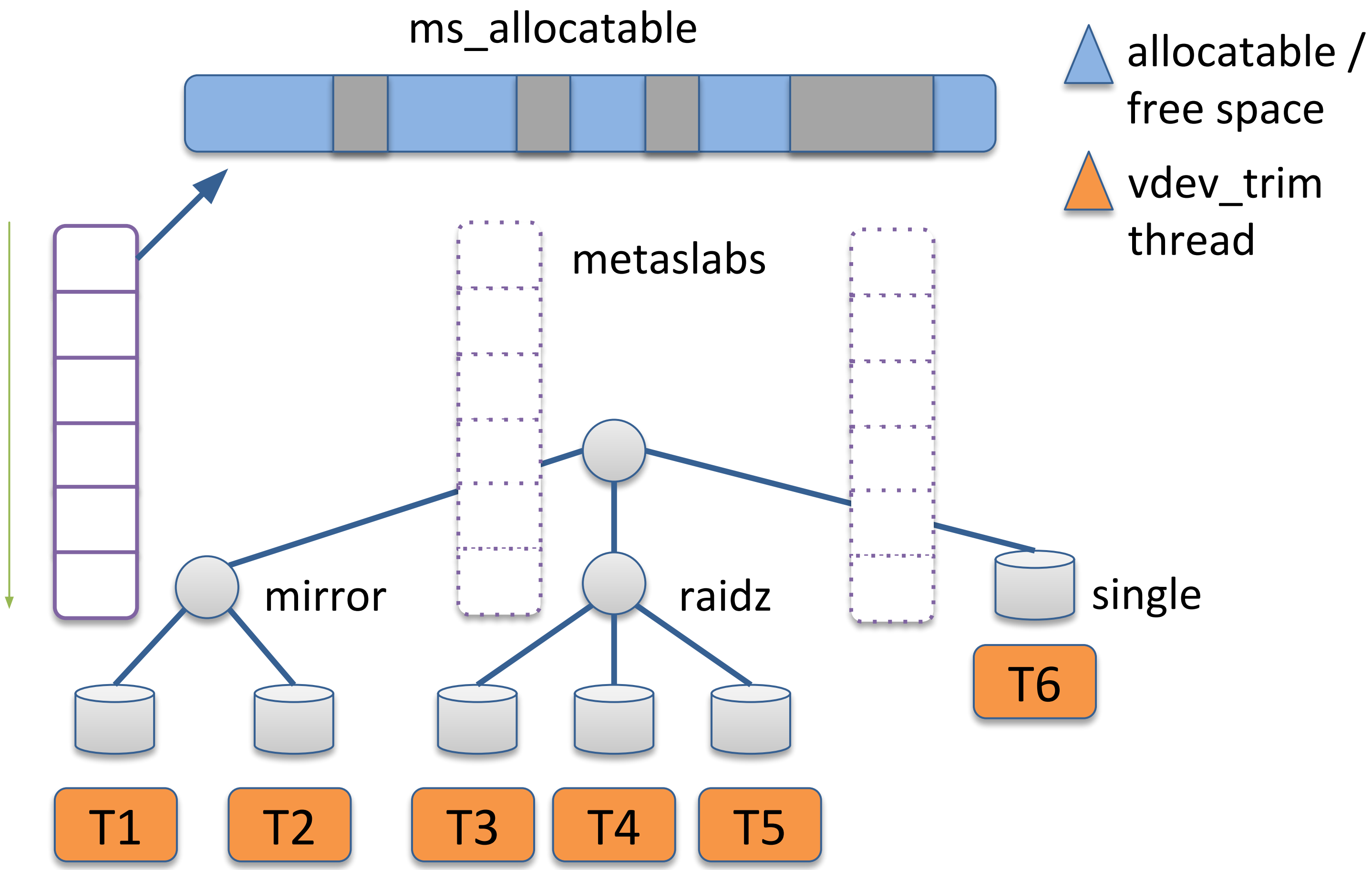


```
static void
vdev_disk_io_start(zio_t *zio)
{
    switch (zio->io_type) {
    case ZIO_TYPE_TRIM:
        <snip>
        zio->io_error = -blkdev_issue_discard(vd->vd_bdev,
           zio->io_offset >> 9, zio->io_size >> 9, GFP_NOFS,
           trim_flags);
        zio_interrupt(zio);
    }
}
```

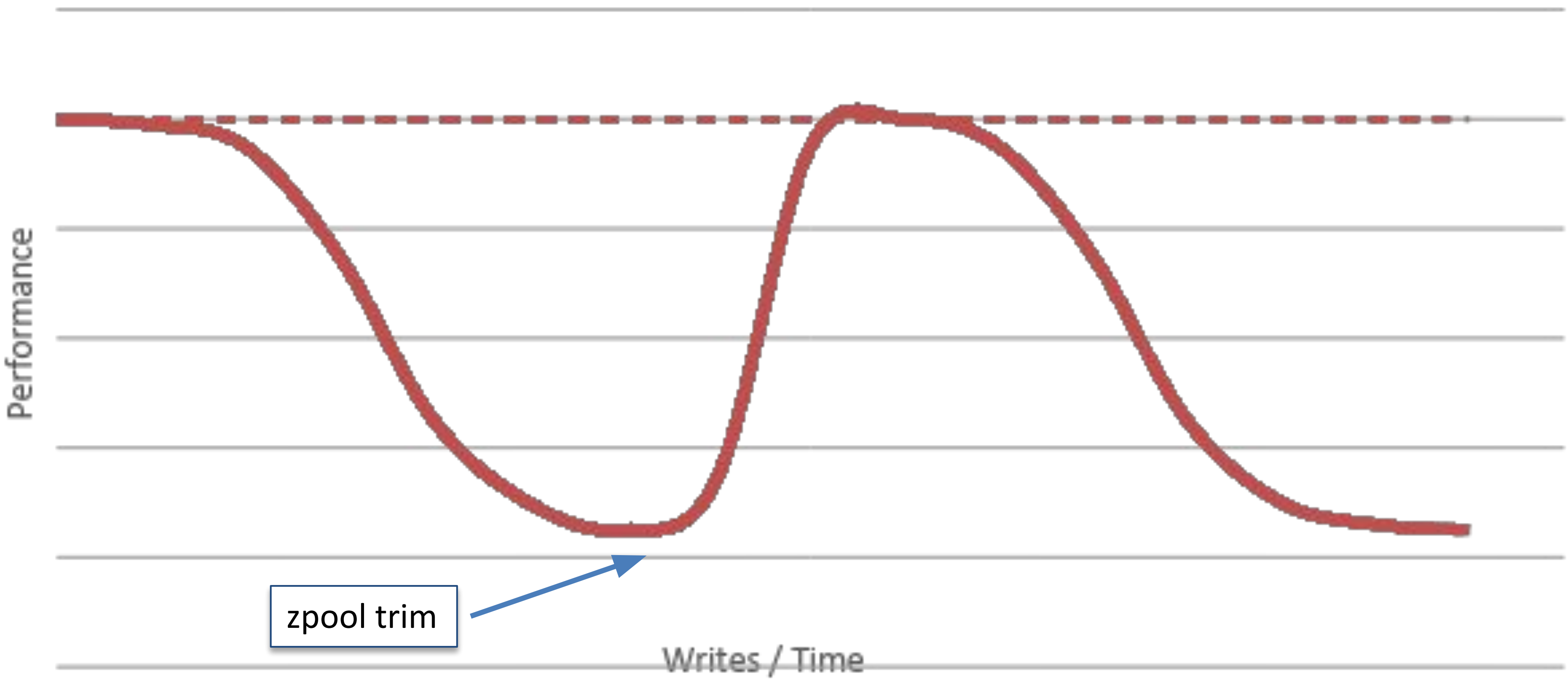
```
static void
vdev_file_io_start(zio_t *zio)
{
    switch (zio->io_type) {
    case ZIO_TYPE_TRIM:
        <snip>
        zio->io_error = VOP_SPACE(vf->vf_vnode,
            F_FREESP, &flck, 0, 0, kcred, NULL);
        zio_interrupt(zio);
    }
}
```

Manual TRIM – “zpool trim”

- One thread per leaf vdev
  - Relatively short lived
- Iterates sequentially over all of the metaslabs:
  - Disable metaslab allocations
  - Issues TRIM I/Os to leaf for all ranges in ms_allocatable
  - Wait for TRIM completion
  - Enable metaslab allocations
- Progress is saved in leaf-ZAP
- Can cancel / suspend / resume



Expected SSD Performance: “zpool trim”



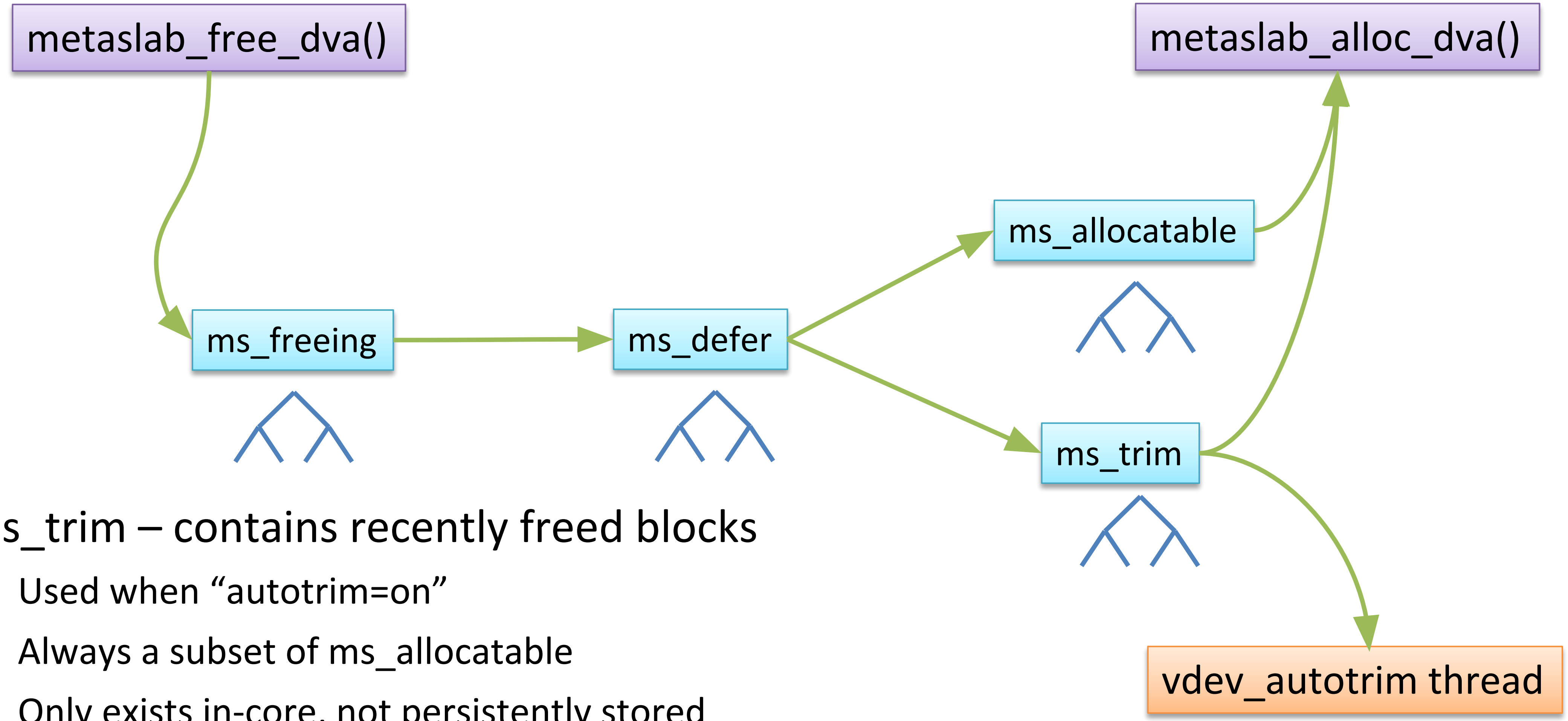
zpool trim

Performance Recovers but Degrades Again

Automatic TRIM

- Continuous background TRIM of all recently freed blocks
- Ensures underlying store always has an up to date mapping of allocated blocks
- Controlled by “autotrim=<on|off>” pool property

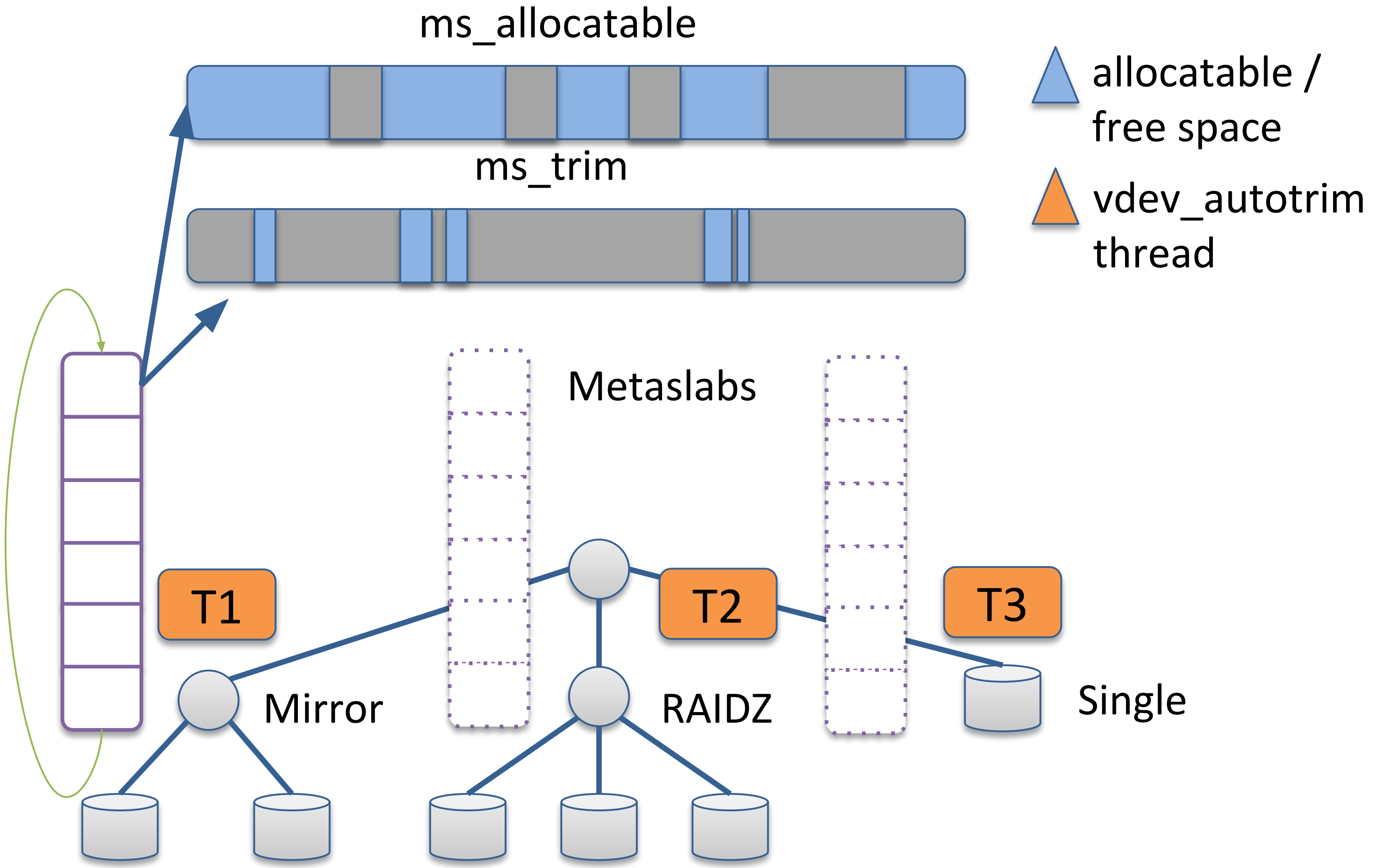
Free Block Life Cycle



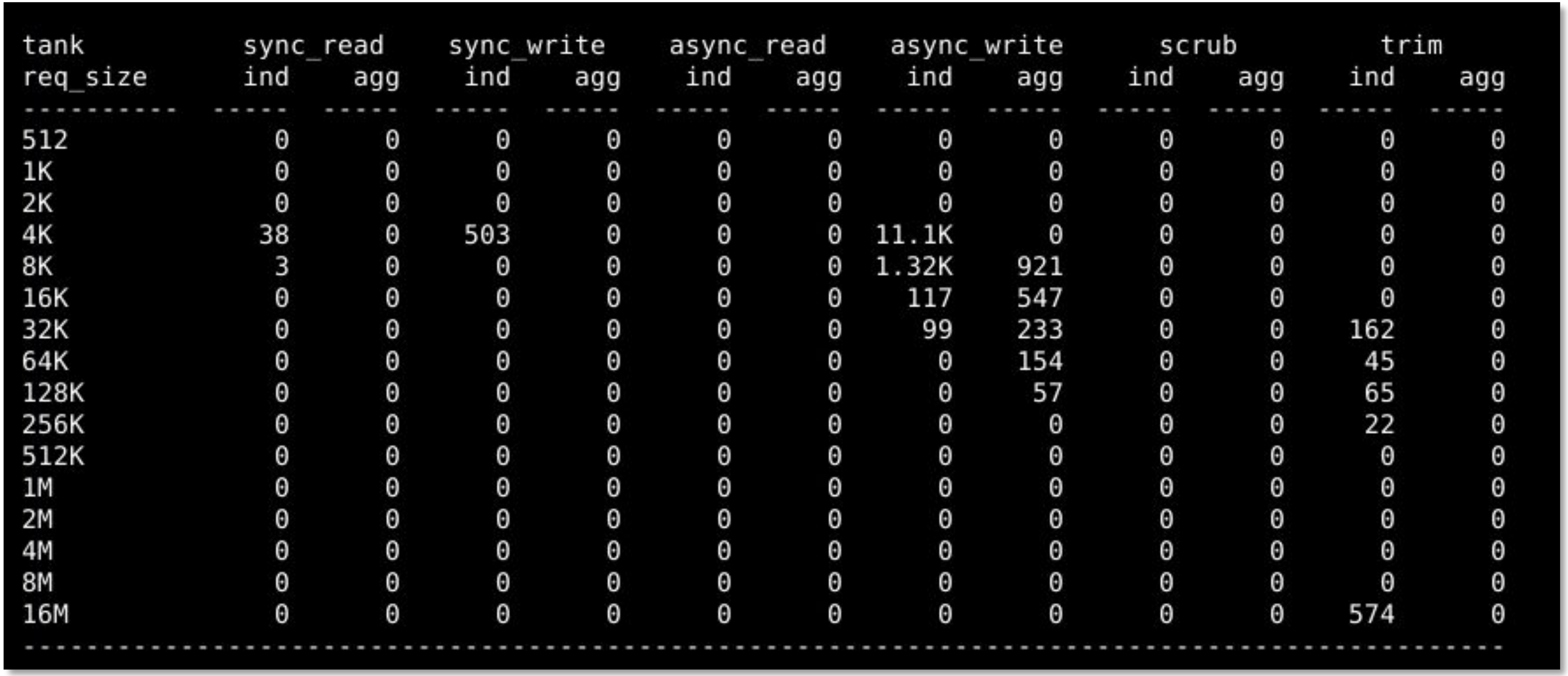
- ms_trim – contains recently freed blocks
  - Used when “autotrim=on”
  - Always a subset of ms_allocatable
  - Only exists in-core, not persistently stored

Automatic TRIM: “autotrim=on”

- One thread per top-level vdev
  - Long running
  - Only disables one metaslab a time
- Continuously iterates over metaslabs
  - Disable allocations
  - Swap and consume ms_trim
  - Issues TRIM I/Os to the children for all ranges in ms_trim
  - Wait for TRIM completion
  - Enable allocations
- Metaslab groups
  - Rate limiting; never forces a txg sync
  - At most one group processed per-txg
  - Allows time for freed block to be merged
  - Controlled by zfs_trim_txg_batch=32

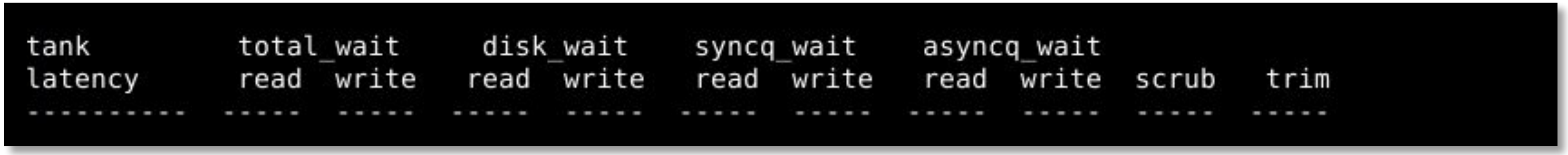


zpool iostat -r

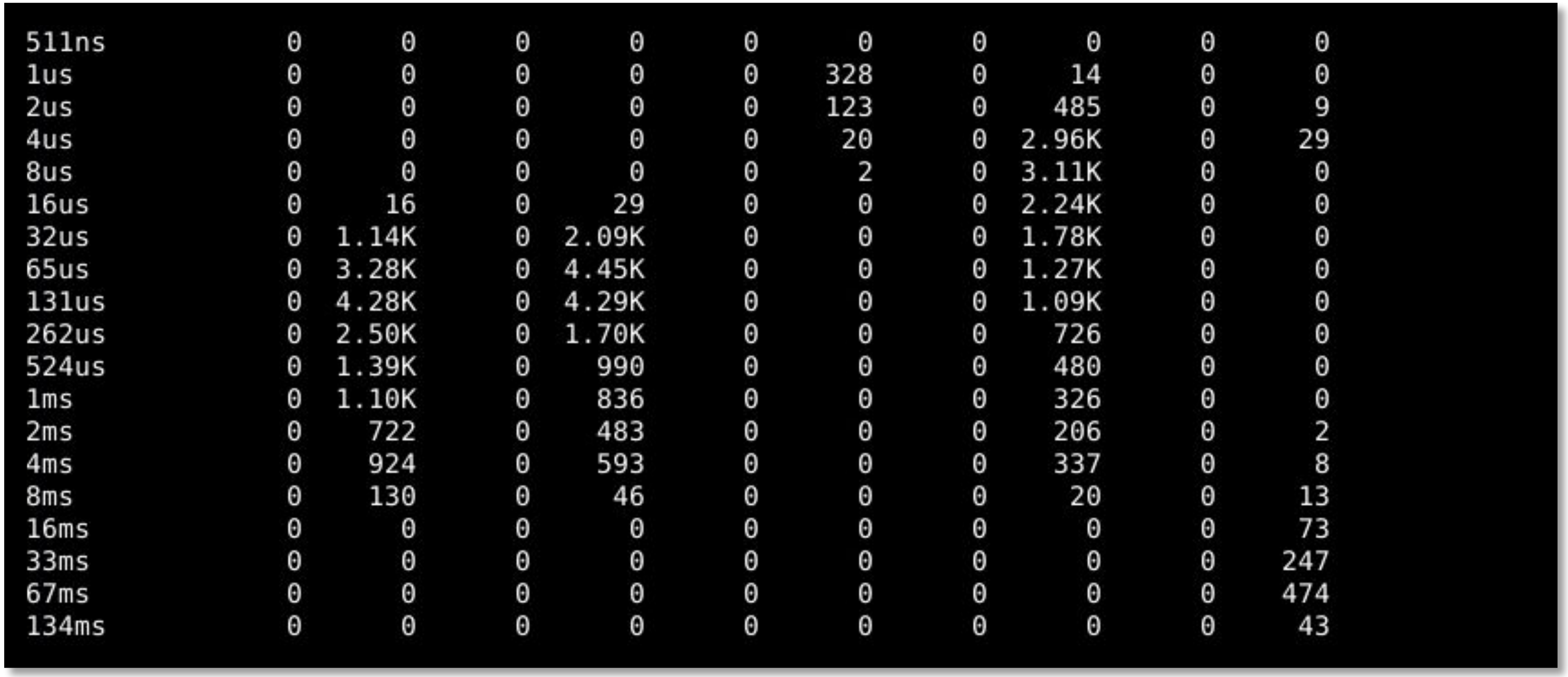


```
tank           sync_read    sync_write    async_read    async_write      scrub         trim
req_size       ind    agg    ind    agg    ind    agg    ind    agg    ind    agg    ind    agg
----------  -----  -----  -----  -----  -----  -----  -----  -----  -----  -----  -----  -----
512             0      0      0      0      0      0      0      0      0      0      0      0
1K              0      0      0      0      0      0      0      0      0      0      0      0
2K              0      0      0      0      0      0      0      0      0      0      0      0
4K             38      0    503      0      0      0  11.1K      0      0      0      0      0
8K              3      0      0      0      0      0  1.32K    921      0      0      0      0
16K             0      0      0      0      0      0    117    547      0      0      0      0
32K             0      0      0      0      0      0     99    233      0      0    162      0
64K             0      0      0      0      0      0      0    154      0      0     45      0
128K            0      0      0      0      0      0      0     57      0      0     65      0
256K            0      0      0      0      0      0      0      0      0      0     22      0
512K            0      0      0      0      0      0      0      0      0      0      0      0
1M              0      0      0      0      0      0      0      0      0      0      0      0
2M              0      0      0      0      0      0      0      0      0      0      0      0
4M              0      0      0      0      0      0      0      0      0      0      0      0
8M              0      0      0      0      0      0      0      0      0      0      0      0
16M             0      0      0      0      0      0      0      0      0      0    574      0
----------------------------------------------------------------------------------------------
```

zpool iostat -w

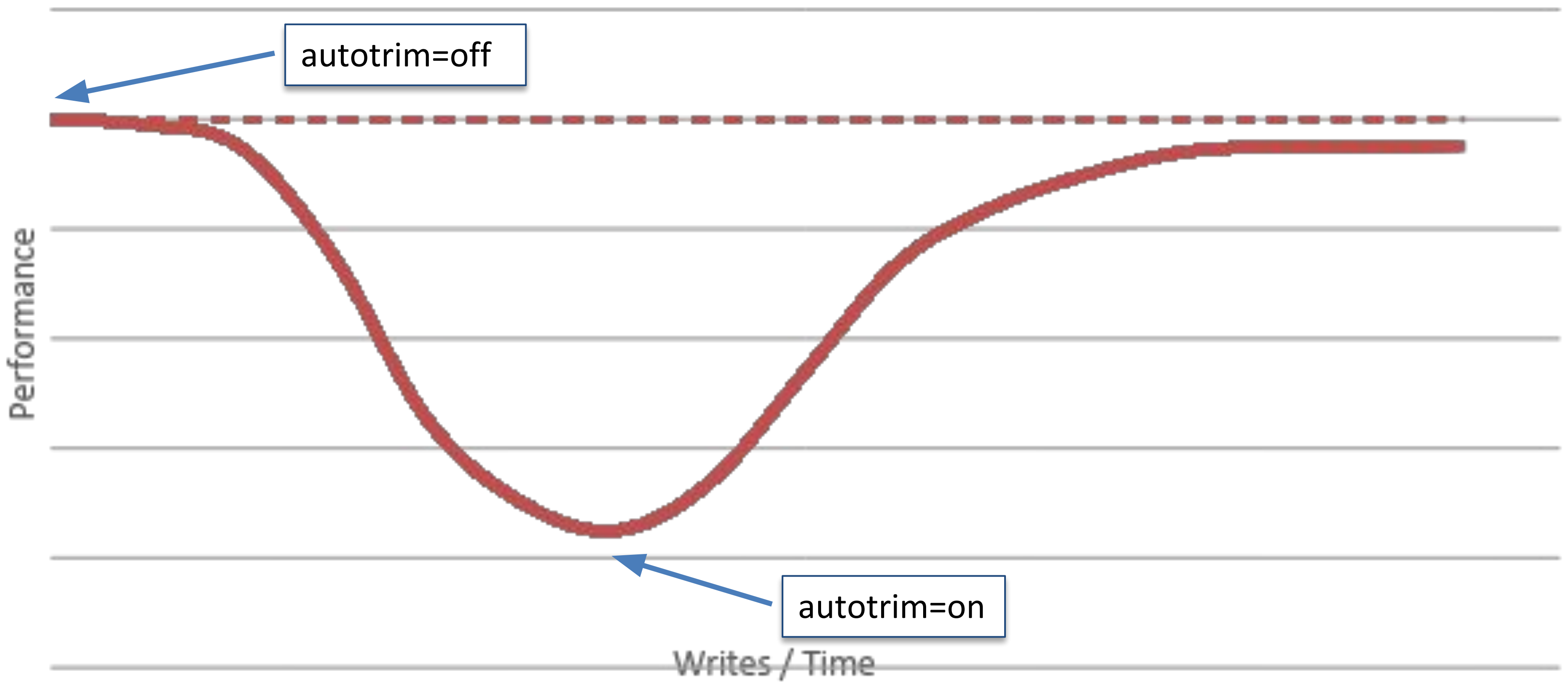


```
tank          total_wait     disk_wait    syncq_wait    asyncq_wait
latency        read  write   read  write   read  write   read  write  scrub   trim
----------  -----  -----  -----  -----  -----  -----  -----  -----  -----  -----
```



```
511ns           0      0      0      0      0      0      0      0      0      0
1us             0      0      0      0      0    328      0     14      0      0
2us             0      0      0      0      0    123      0    485      0      9
4us             0      0      0      0      0     20      0  2.96K      0     29
8us             0      0      0      0      0      2      0  3.11K      0      0
16us            0     16      0     29      0      0      0  2.24K      0      0
32us            0  1.14K      0  2.09K      0      0      0  1.78K      0      0
65us            0  3.28K      0  4.45K      0      0      0  1.27K      0      0
131us           0  4.28K      0  4.29K      0      0      0  1.09K      0      0
262us           0  2.50K      0  1.70K      0      0      0    726      0      0
524us           0  1.39K      0    990      0      0      0    480      0      0
1ms             0  1.10K      0    836      0      0      0    326      0      0
2ms             0    722      0    483      0      0      0    206      0      2
4ms             0    924      0    593      0      0      0    337      0      8
8ms             0    130      0     46      0      0      0     20      0     13
16ms            0      0      0      0      0      0      0      0      0     73
33ms            0      0      0      0      0      0      0      0      0    247
67ms            0      0      0      0      0      0      0      0      0    474
134ms           0      0      0      0      0      0      0      0      0     43
```

Expected SSD Performance: “autotrim=on”

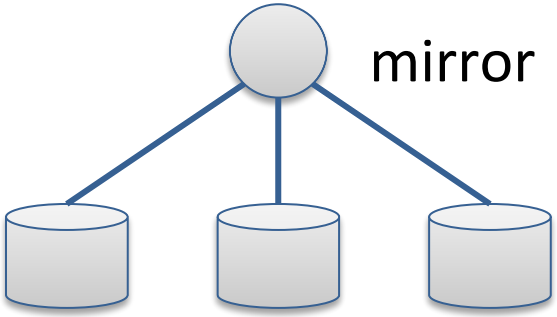


Performance Recovers and is Maintained

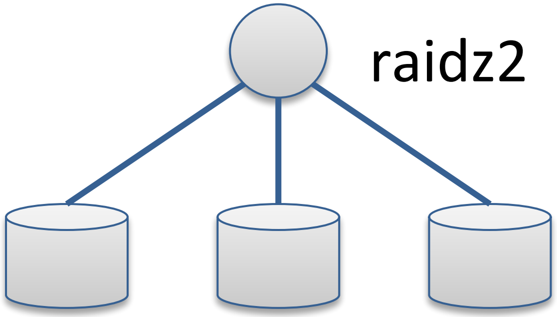
Real Performance Results

- Test case – Total time to copy the Linux kernel source

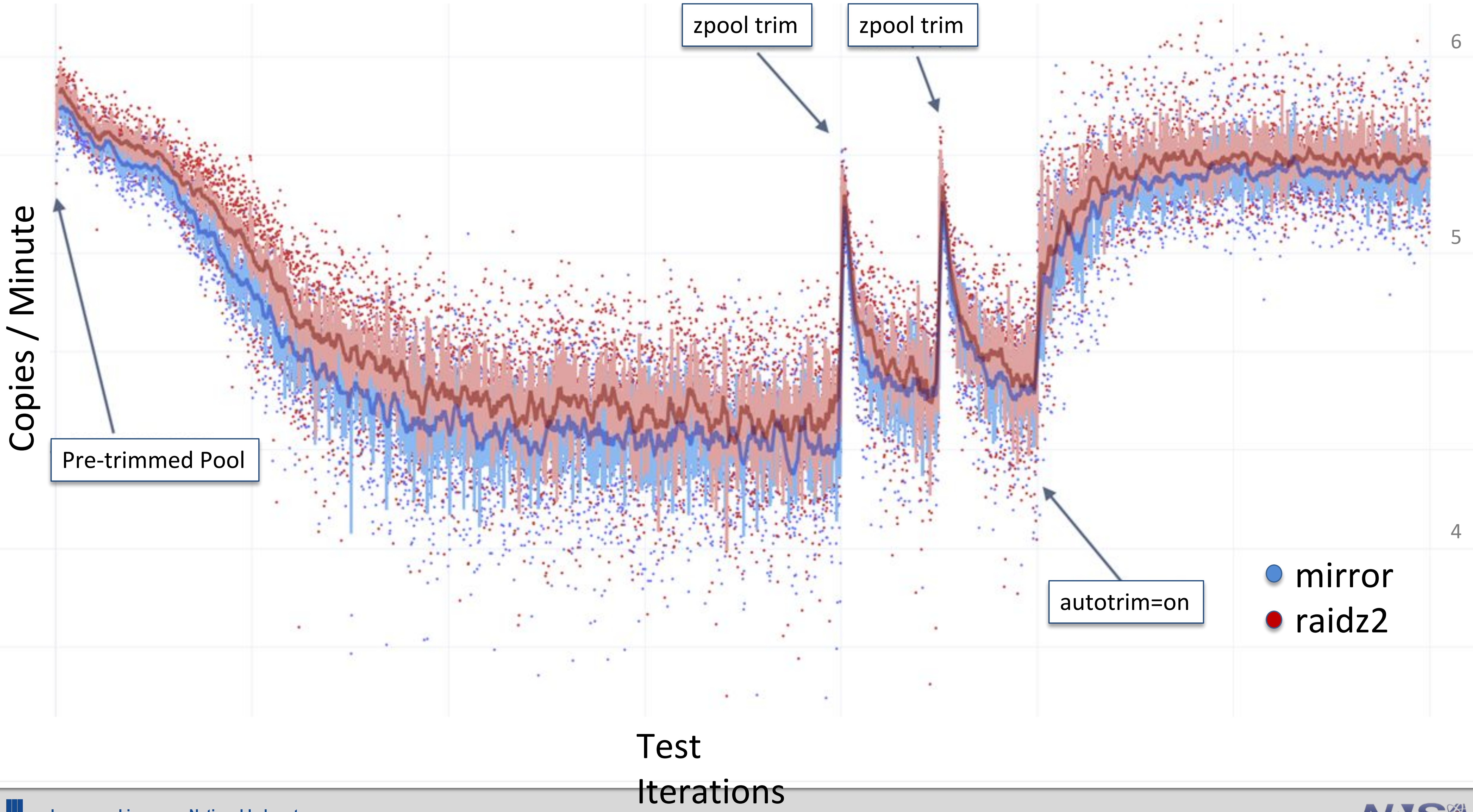
```
Repeat:
    N=$((RANDOM % 200))
    rm -r /testpool/fs/linux-$N
    time (cp -a /tmp/linux /testpool/fs/linux-$N; sync)
```



- Configuration
  - Target pool capacity ~80%
  - RHEL 7.6 - 3.10.0-957.0.0 kernel
  - Mirror (3-devices)
  - RAIDZ2 (1d+2p)



- Hardware
  - 3 Seagate ST800FM0173 devices
  - Dual 12Gb/s SAS attached



zpool trim

zpool trim

Pre-trimmed Pool

autotrim=on

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- Thank You:
  - Tim Chase
  - George Wilson
  - Matt Ahrens

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