Improving Block Discard Support throughout the Linux Storage Stack

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What the heck are discards? - A very brief history of block I/O

- The traditional block interface simply was reads and writes of blocks.
- That’s nice and good for disks.
  - *Well sorta..*
- But Flash SSDs can not just overwrite existing data
  - So they must write out of place
  - And manage a block mapping
- Also enter under provisioned Arrays into the game

What the heck are discards? - A very brief history of block I/O

- We need a way to tell the device blocks aren’t in use anymore..
  - Linux calls this a discard
  - Every storage protocol has a different name for it

Different implementations of the discard concept: ATA TRIM

- ATA supports the *TRIM* operation in the **DSM** command
  - Supports up to 64 ranges
  - 16 bits worth of blocks per range
  - The **DSM** command is not queued
- Newer versions support queued TRIM
  - I’ve not actually seen a working implementation in the field

Different implementations of the discard concept: SCSI UNMAP

- SBC supports the **UNMAP** command
  - Supports an implementation specific number of ranges
  - 32 bits worth of blocks per range
  - All SCSI commands are queued

Different implementations of the discard concept: SCSI WRITE SAME

- SBC supports the **WRITE SAME 10/16/32** commands to write a LBA sized buffer to many LBAs
  - If the *UNMAP* bit is set **WRITE SAME** ask the device to unmap the blocks covered
  - Buffer must be all zeros for the *UNMAP* bit to work.
  - Future reads from the LBAs must return all zeros

Different implementations of the discard concept: NVMe Deallocate

- NVMe supports the *Deallocate* operation in the **DSM** command
  - Supports up to 256 ranges, 32 bits worth of blocks per range
  - All NVMe commands are queued

When does the OS issue a discard?

1. Explicit through an ioctl:
   - e.g. mkfs time - trivial
2. Walk the free space information and discard everything that isn’t used:
   - (**FITRIM** ioctl, or horrible hacks in hdparm)
3. Whenever the file system actually frees previously space:
   - online discard (mount -o discard)

History of discard in Linux

- Support for **REQ_DISCARD** added in Linux 2.6.28 (2008):
  - Intended as a pure hint
  - Discards are issued asynchronously as “barriers”
  - Only single ranges supported
  - No payload in the bio / request
  - Exposed as *BLKDISCARD* ioctl
  - fat and ext4 support limited online discard
  - Implemented by MTD (raw flash)

History of discard in Linux (2)

- SCSI and ATA support added in Linux 2.6.33 (2009):
  - libata parses a SCSI **WRITE SAME** and translates it to an ATA **TRIM**
  - new discard_zeroes_data, discard_granularity, discard_alignment flags
  - Discard now carries a single page payload that the driver can use for its purposes
- Linux 2.6.36 (2010) adds support for secure erase into the discard code, and leaves payload allocation to the driver

History of discard in Linux (3)

- Linux 2.6.37 (2011) removes the barrier semantics and makes discard synchronous
- Linux 2.6.38 (2011) adds the **FITRIM** ioctl to discard all free space in a file systems
- Each release more file systems start issuing online discards

Online discard in XFS

- How do file systems free blocks?
  - Needs to be atomic vs deleting them from the extent list

    → *Atomic transaction that logs the intent to free, actual freeing delayed*
  - Transactions might be asynchronous

    → **Must only reuse or discard blocks once actually committed**

The busy extent list

- Tracks all extents that have their deletion intent committed but the transaction not safely on disk yet
  - Red / Black tree per allocation group
  - Allocations try to skip busy extents when possible
  - If not the transaction freeing them has to be forcibly written to disk

The busy extent list - discards

- Reuses the busy extent list:
  - Once the transaction committing the deletion is on disk, issue a discard for all deleted extents
  - Extents stay on the busy extent list
  - Only get removed once the discard completes
  - Initially discards were issued synchronously

    → blocks the log write completion thread
- As part of discard support the busy extent list was improved:
  - Scalable and bulletproof *(at least we thought..)*

Asynchronous discards in the file systems

- Do not wait for the discards from the log write completion handler
  - Instead attach a completion handler that removes them from the busy extent list
  - Forces us to wait for discards in various places, including the near ENOSPC allocator code
  - Ended up finding lots of bugs in this code

Recent discard improvements

- Linux 4.7 adds usable asynchronous discards supports
  - Allows for attaching a completion callback
- Linux 4.10 improves the way they payloads for **TRIM** / **UNMAP** / **WRITE SAME** are allocated
  - Doesn’t pretend to be the normal I/O path
  - Special drivers overrides the payload path now

Ranged TRIM support

- Linux so far only allowed a single discard range
- Linux block I/O requests generally are LBA -contiguous, although multiple bios can be merged into one
  - Ranged discard uses this linkage to allow linking non-contiguous bios for discard if the driver allows it
  - Driver then walks the list of bios and generates the payload
  - Multiple ranges only happen when issued asynchronously
- Linux 4.11 supports ranged deallocated for NVMe

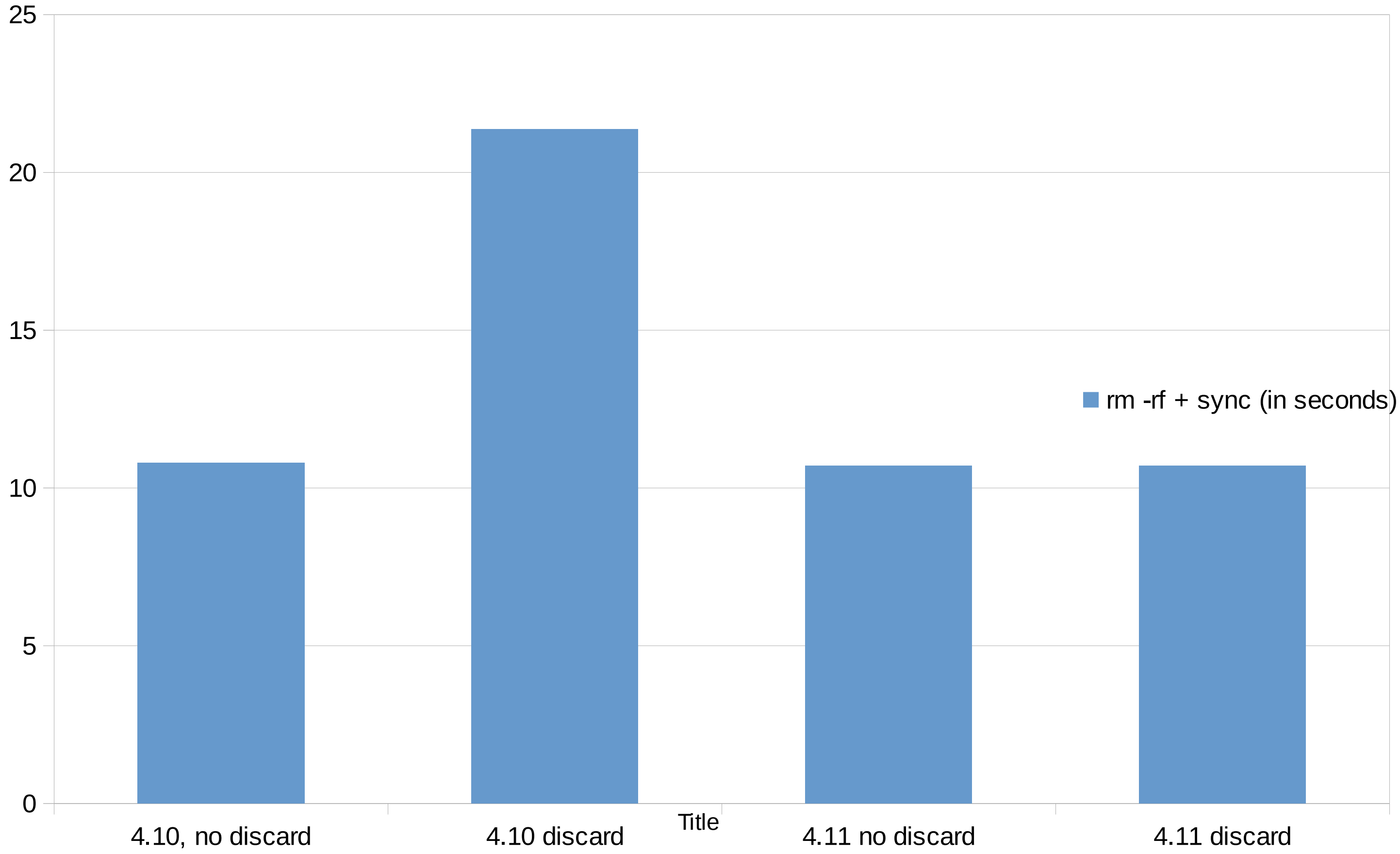
ATA ranged TRIM support

- Libata translated SCSI into ATA commands
- For discards it advertises **WRITE SAME** support and builds **TRIM** commands
  - **WRITE SAME** only supports a single range
  - TRIM supports multiple small ranges
  - In SCSI **UNMAP** would support multiple ranges, but the semantics don’t match very well
  - Rewriting the payload in place corrupts user data for SCSI pass through

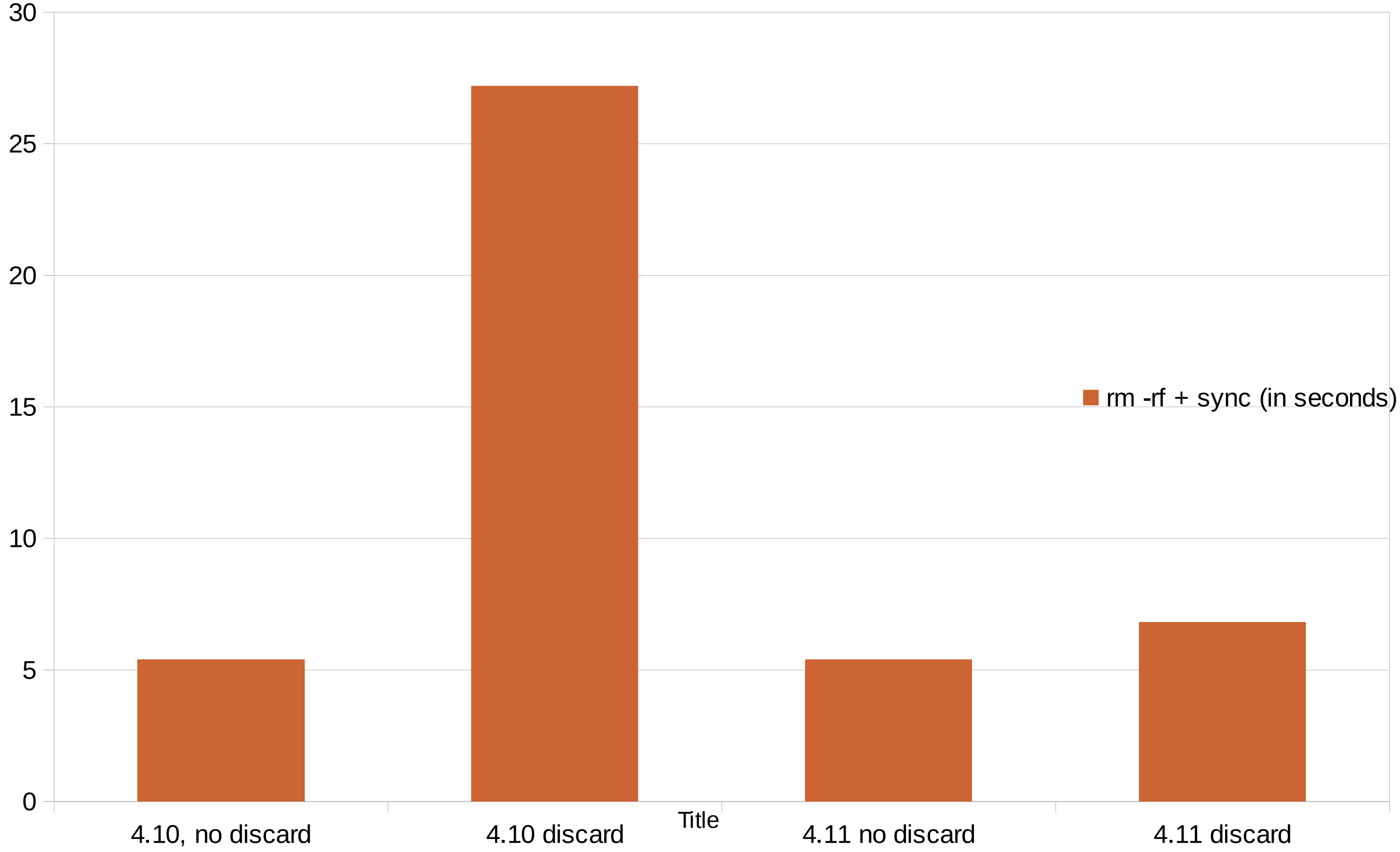
ATA ranged TRIM support (2)

- *Maybe we should get out the command rewriting business?*
  - Add a new Vendor Specific SCSI command with the ATA **TRIM** payload
  - Greatly simplifies the libata code
  - Discard can now use the zero page as **WRITE SAME** payload
- Submitted for Linux 4.12, not merged yet

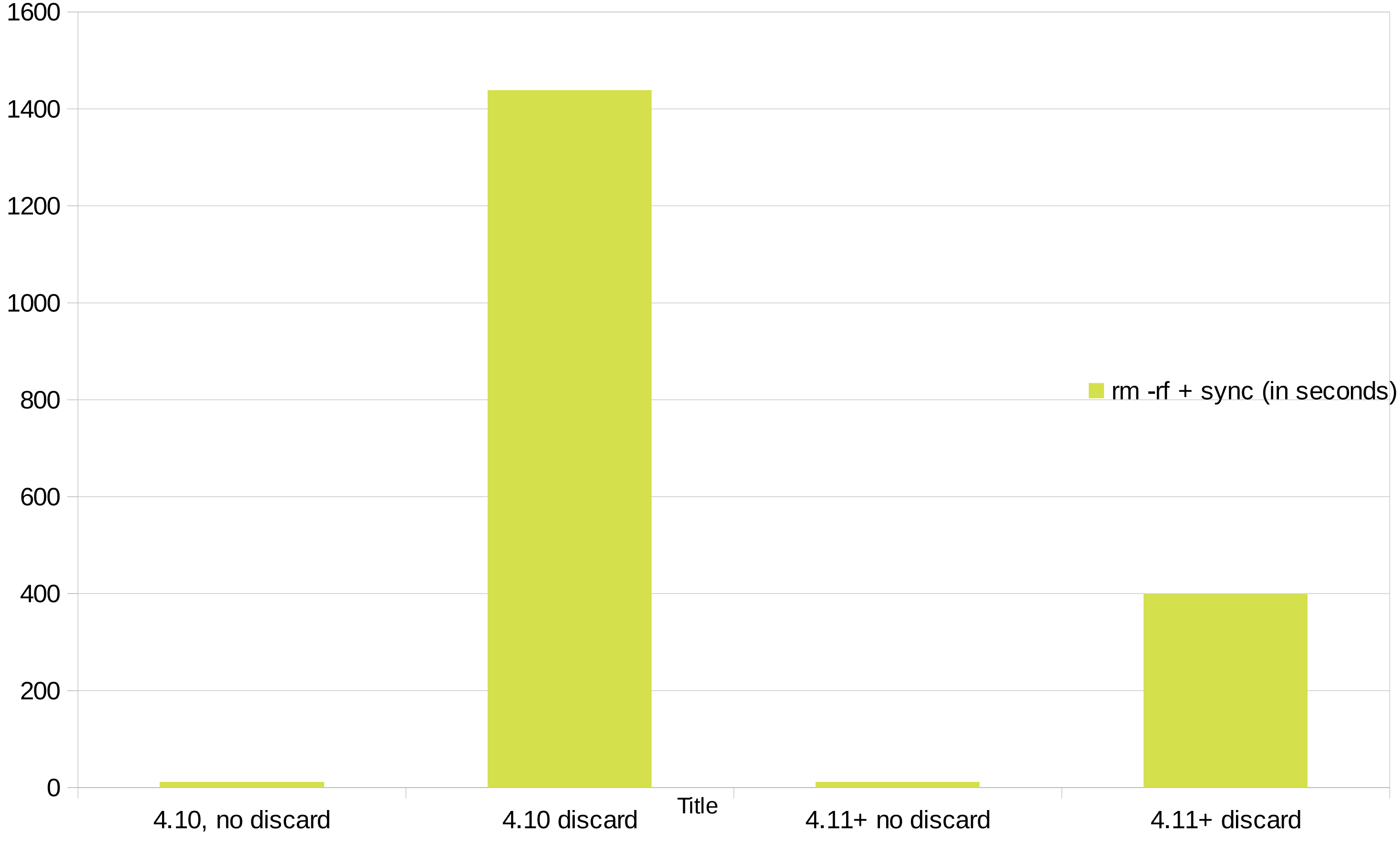
NVMe enterprise SSD (Vendor A)



NVMe enterprise SSD (Vendor B)



SATA SSD (non-queued TRIM)



(Ab)using discard for zeroes

- WRITE SAME guarantees that future reads return all zeros.
  - *Wouldn’t it be nice to use that for zeroing?*
- Keyed off the discard_zeros_data flag
  - Works perfect for WRITE SAME
  - But now discard isn’t just a hint any more
  - Failure reporting becomes important now, e.g. for too small or unaligned requests

More Zeroing offload

- Linux 3.7 (2012) adds support for explicit **WRITE SAME** operations
  - can be used for zeroing without the UNMAP bit
- Linux 4.10 (2017) adds an explicit zeroing operation (***REQ_OP_WRITE_ZEROES***)
  - No payload (same as discard)
  - Can be implemented directly (NVMe)
  - Or by adding a payload (e.g. SCSI)

Questions?