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FlashCache

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FlashCache at Facebook

- What
  - We want to use some Flash storage on existing servers
  - We want something that is simple to deploy and use
  - Our IO access patterns benefit from a cache
- Who
  - Mohan Srinivasan – design and implementation
  - Paul Saab – platform and MySQL integration
  - Mark Callaghan - benchmarketing

Introduction

- Block cache for Linux - write back and write through modes
- Layered below the filesystem at the top of the storage stack
- Cache Disk Blocks on fast persistent storage (Flash, SSD)
- Loadable Linux Kernel module, built using the Device Mapper (DM)
- Primary use case InnoDB, but general purpose
- Based on dm-cache by Prof. Ming

Caching Modes

Write Back

- Lazy writing to disk
- Persistent across reboot
- Persistent across device removal

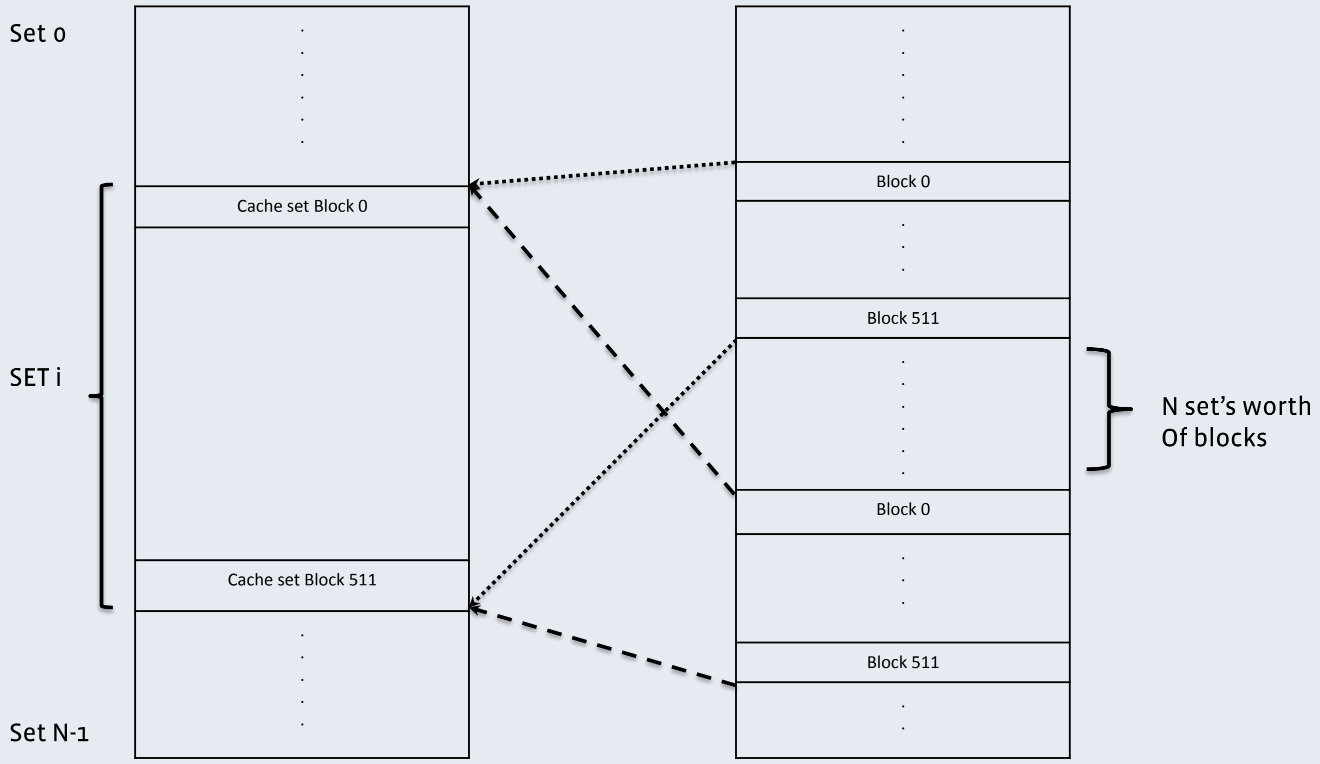
Write Through

- Non-persistent
- Are you a pessimist?

Cache Structure

- Set associative hash
- Hash with fixed sized buckets (sets) with linear probing within a set
- 512-way set associative by default
- dbn: Disk Block Number, address of block on disk
- Set = (dbn / block size / set size) mod (number of sets)
- Sequential range of dbns map onto a single sets

Cache Structure



Write Back

- Replacement policy is FIFO (default) or LRU within a set
- Switch on the fly between FIFO/LRU (sysctl)
- Metadata per cache block: 24 bytes in memory, 16 bytes on ssd
- On ssd metadata per-slot
  - <dbn, block state>
- In memory metadata per-slot:
  - <dbn, block state, LRU chain pointers, misc>

Write Through

- Replacement policy is FIFO
- Metadata per slot
    - 17 bytes (memory), no metadata stored on ssd
- In memory metadata per-slot
    - ‹dbn, block state, checksum›

Reads

- Compute cache set for dbn
- Cache Hit
  - Verify checksums if configured
  - Serve read out of cache
- Cache Miss
  - Find free block or reclaim block based on replacement policy
  - Read block from disk and populate cache
  - Update block checksum if configured
  - Return data to user

Write Through - writes

- Compute cache set for dbn
- Cache hit
    - Get cached block
- Cache miss
    - Find free block or reclaim block
- Write data block to disk
- Write data block to cache
- Update block checksum

Write Back - writes

- Compute cache set for dbn
- Cache Hit
  - Write data block into cache
  - If data block not DIRTY, synchronously update on-ssd cache metadata to mark block DIRTY
- Cache miss
  - Find free block or reclaim block based on replacement policy
  - Write data block to cache
  - Synchronously update on-ssd cache metadata to mark block DIRTY

Small or uncacheable requests

- First invalidate blocks that overlap the requests
  - There are at most 2 such blocks
  - For Write Back, if the overlapping blocks are DIRTY they are cleaned first then invalidated
- Uncacheable full block reads are served from cache in case of a cache hit.
- Perform disk IO
- Repeat invalidation to close races which might have caused the block to be cached while the disk IO was in progress

Write Back policy

- Default expiration of 30 seconds (work in progress)
- When dirty blocks in a set exceeds configurable threshold, clean some blocks
  - Blocks selected for writeback based on replacement policy
  - Default dirty threshold 20%. Set higher for write heavy workloads
- Sort selected blocks and pickup any other blocks in set that can be contiguously merged with these
- Writes merged by the IO scheduler

Write Back – cache metadata overhead

- In-Memory cache metadata memory footprint
  - 300GB/4KB cache -> ~1.8GB
  - 160GB/4KB cache -> ~960MB
- Cache metadata writes/file system write
  - Worst case is 2 cache metadata updates per write
    - (VALID->DIRTY, DIRTY->VALID)
  - Average case is much lower because of cache write hits and batching of cache metadata updates

Write Through – cache metadata overhead

- In-Memory Cache metadata footprint
  - 300GB/4KB cache -> ~1.3GB
  - 160GB/4KB cache -> ~700MB
- Cache metadata writes per file system write
  - 1 cache data write per file system write

Write Back – metadata updates

- Cache (on-ssd) metadata only updated on writes and block cleanings (VALID->DIRTY or DIRTY->VALID)
- Cache (on-ssd) metadata not updated on cache population for reads
- Reload after an unclean shutdown only loads DIRTY blocks
- Fast and Slow cache shutdowns
  - Only metadata is written on fast shutdown. Reload loads both dirty and clean blocks
  - Slow shutdown writes all dirty blocks to disk first, then writes out metadata to the ssd. Reload only loads clean blocks.
- Metadata updates to multiple blocks in same sector are batched

Torn Page Problem

- Handle partial block write caused by power failure or other causes
- Problem exists for Flashcache in Write Back mode
- Detected via block checksums
  - Checksums are disabled by default
  - Pages with bad checksums are not used
- Checksums increase cache metadata writes and memory footprint
  - Update cache metadata checksums on DIRTY->DIRTY block transitions for Write Back
  - Each per-cache slot grows by 8 bytes to hold the checksum (a 33% increase from 24 bytes to 32 bytes for the Write Back case).

Cache controls for Write Back

- Work best with O_DIRECT file access
- Global modes – Cache All or Cache Nothing
    - Cache All has a blacklist of pids and tgids
    - Cache Nothing has a whitelist of pids and tgids
- tgids can be used to tag all pthreads in the group as cacheable
- Exceptions for threads within a group are supported
- List changes done via FlashCache ioctls
- Cache can be read but is not written for non-cacheable tgids and pids
- We modified MySQL and scp to use this support

Cache Nothing policy

- If the thread id is whitelisted, cache all IOs for this thread
- If the tgid is whitelisted, cache all IOs for this thread
- If the thread id is blacklisted do not cache IOs

Cache control example

- We use Cache Nothing mode for MySQL servers
- The mysqld tgid is added to the whitelist
  - All IO done by it is cacheable
  - Writes done by other processes do not update the cache
- Full table scans done by mysqldump use a hint that directs mysqld to add the query's thread id to the blacklist to avoid wiping FlashCache
  - select /* SQL_NO_FCACHE */ pk, col1, col2 from foobar

Utilities

- flashcache_create
    - flashcache_create -b 4k -s 10g mysql /dev/flash /dev/disk
- flashcache_destroy
    - flashcache_destory /dev/flash
- flashcache_load

sysctl –a | grep flash

```
dev.flashcache.cache_all = 0               dev.flashcache.do_pid_expiry = 0

dev.flashcache.fast_remove = 0             dev.flashcache.max_clean_ios_set = 2

dev.flashcache.zero_stats = 1              dev.flashcache.max_clean_ios_total = 4

dev.flashcache.write_merge = 1             dev.flashcache.debug = 0

dev.flashcache.reclaim_policy = 0          dev.flashcache.dirty_thresh_pct = 20

dev.flashcache.pid_expiry_secs = 60        dev.flashcache.stop_sync = 0

dev.flashcache.max_pids = 100              dev.flashcache.do_sync = 0
```

Removing FlashCache

- umount /data
- dmesetup remove mysql
- flashcache_destroy /dev/flash

cat /proc/flashcache_stats

```
reads=4 writes=0 read_hits=0 read_hit_percent=0 write_hits=0
  write_hit_percent=0 dirty_write_hits=0 dirty_write_hit_percent=0
  replacement=0 write_replacement=0 write_invalidates=0
  read_invalidates=0 pending_enqueues=0 pending_inval=0
  metadata_dirties=0 metadata_cleans=0 cleanings=0 no_room=0
  front_merge=0 back_merge=0 nc_pid_adds=0 nc_pid_dels=0
  nc_pid_drops=0 nc_expiry=0 disk_reads=0 disk_writes=0 ssd_reads=0
  ssd_writes=0 uncached_reads=169 uncached_writes=128
```

Future Work

- Cache mirroring
  - SW RAID 0 block device as a cache
- Online cache resize
  - No shutdown and recreate
- Support for ATA trim
  - Discard blocks no longer in use
- Fix the torn page problem
  - Use shadow pages

Resources

- GitHub : facebook/flashcache
- Mailing list : flashcache-dev@googlegroups.com
- http://facebook.com/MySQLatFacebook
- Email :
  - mohan@facebook.com (Mohan Srinivasan)
  - ps@facebook.com (Paul Saab)
  - mcallaghan@facebook.com (Mark Callaghan)

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