CACHE OPTIMIZATION

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Overview

- Announcement
  - Homework 4 is due on Mar. 27\textsuperscript{th}

- This lecture
  - Cache replacement policies
  - Cache write policies

- Reducing miss penalty
100,000 loads and stores are generated; L1 cache has 3,000 misses; L2 cache has 1,500 misses. What are various miss rates?
Miss Rates: Example Problem

- 100,000 loads and stores are generated; L1 cache has 3,000 misses; L2 cache has 1,500 misses. What are various miss rates?

  - **L1 miss rates**
    - Local/global: $\frac{3,000}{100,000} = 3\%$
  
  - **L2 miss rates**
    - Local: $\frac{1,500}{3,000} = 50\%$
    - Global: $\frac{1,500}{100,000} = 1.5\%$
Cache Replacement Policies

- Which block to replace on a miss?
  - Only one candidate in direct-mapped cache
  - Multiple candidates in set/fully associative cache

- Ideal replacement (Belady’s algorithm)
  - Replace the block accessed farthest in the future

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- Least recently used (LRU)
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- Most recently used (MRU)
  - Replace the block accessed nearest in the past
Cache Replacement Policies

- Which block to replace on a miss?
  - Only one candidate in direct-mapped cache
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- Ideal replacement (Belady’s algorithm)
  - Replace the block accessed farthest in the future
- Least recently used (LRU)
  - Replace the block accessed farthest in the past
- Most recently used (MRU)
  - Replace the block accessed nearest in the past
- Random replacement
  - hardware randomly selects a cache block to replace
Example Problem

- Blocks A, B, and C are mapped to a single set with only two block storages; find the miss rates for LRU and MRU policies.
Example Problem

- Blocks A, B, and C are mapped to a single set with only two block storages; find the miss rates for LRU and MRU policies.

   - LRU : 100%
   - MRU : 66%

   - LRU : 66%
   - MRU : 44%
Cache Write Policies

- Write vs. read
  - Data and tag are accessed for both read and write
  - Only for write, data array needs to be updated
- Cache write policies

![Diagram of cache write policies]

- Write lookup
  - miss
    - Read lower level?
      - Write no allocate
      - Write allocate
  - hit
    - Write lower level?
      - Write back
      - Write through
Write back

- On a write access, write to cache only
  - write cache block to memory only when replaced from cache
  - dramatically decreases bus bandwidth usage
  - keep a bit (called the *dirty* bit) per cache block
Write through

- Write to both cache and memory (or next level)
  - Improved miss penalty
  - More reliable because of maintaining two copies

- Use write buffer alongside cache
- works fine if
  - rate of stores < 1 / DRAM write cycle
- otherwise
  - write buffer fills up
  - stall processor to allow memory to catch up
Write (No-)Allocate

- **Write allocate**
  - allocate a cache line for the new data, and replace old line
  - just like a read miss

- **Write no allocate**
  - do not allocate space in the cache for the data
  - only really makes sense in systems with write buffers

- How to handle read miss after write miss?
Reducing Miss Penalty

- Some cache misses are inevitable
  - when they do happen, want to service as quickly as possible
- Other miss penalty reduction techniques
  - Multilevel caches
  - Giving read misses priority over writes
  - Sub-block placement
  - Critical word first
Victim Cache

- How to reduce conflict misses
  - Larger cache capacity
  - More associativity

- Associativity is expensive
  - More hardware; longer hit time
  - More energy consumption

- Observation
  - Conflict misses do not occur in all sets
  - Can we increase associativity on the fly for sets?
Victim Cache

- Small fully associative cache
  - On eviction, move the victim block to victim cache
Cache Inclusion

- How to reduce the number of accesses that miss in all cache levels?
  - Should a block be allocated in all levels?
    - Yes: inclusive cache
    - No: non-inclusive or exclusive
  - Non-inclusive: only allocated in L1

- Modern processors
  - L3: inclusive of L1 and L2
  - L2: non-inclusive of L1 (large victim cache)