CS533: Prefetching (I)

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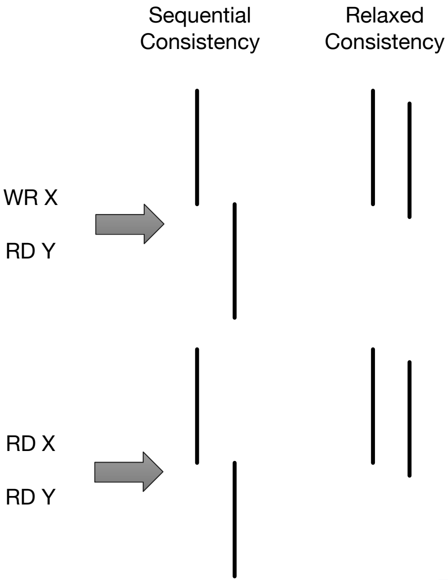
Latency Elimination/Hiding

- Caches and local memories
- Relaxed memory consistency models
- Prefetching/forwarding
- Multithreading

Relaxed Memory Consistency



Prefetching

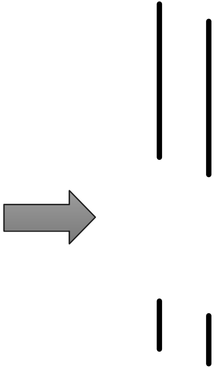
Prefetch X

Prefetch Y

...

RD X

RD Y



Prefetching Classification

Binding vs. Non-binding

- Binding: value of later "real" reference is bound when prefetch is performed
  - Restricts legal prefetch issue: only when no one else can modify value
  - Additional high-speed storage needed (registers)
- Non-binding: prefetch brings data closer, but value not bound until later "real" reference
  - Data remains visible to coherence protocol
  - Prefetch issue not restricted

Prefetching Classification

Code	Binding	Non-Binding

`prefetch(X)`
`lock(L)`
X++
`unlock(L)`
	NO	YES

Choice largely dictated by cache coherence

- HW coherence is a requirement for non-binding

Prefetching Classification

Software-controlled	Prefetching initiated by processor executing a prefetch instruction • Programmer • Compiler
Hardware-controlled	HW prefetches at run-time. No hints from SW. • Instruction lookahead • Long cachelines

HW-Controlled Prefetching

+ Better dynamic information
+ No instruction overhead to issue prefetches
– Difficult to detect memory access patterns
– Lookahead limited by
  - branches
  - buffer size
– Long cachelines have false sharing
– Are "hard-wired" in the processor

SW-Controlled Prefetching

- \+ Extends possible prefetch-reference interval
- \+ Selectiveness based on program knowledge
- \+ Simplifies HW
- − Requires sophisticated software intervention

Benefits of Prefetching

- Prefetch early enough
  - Completely hides latency
- Issue prefetches in blocks
  - Pipelining
  - Only first reference suffers
- Prefetch with ownership
  - Reduce write latency
  - Reduce network traffic

Compiler-Directed Prefetching:Issues

- What to prefetch – need to know what refs are going to hit or miss in the cache (since issuing prefetches has overheads)
  - Often not very difficult for programmer
  - Quite a challenging task for the compiler
- When to prefetch – need to know how to schedule prefetches
  - Not too early (may get displaced from cache)
  - Not too late (data may not arrive in time)
  - Techniques such as software pipelining are critical

Definitions

- **Coverage**: Fraction of the original misses that are eliminated (partially or totally) by the prefetched lines
- **Accuracy**: Fraction of the prefetched lines that eliminate (partially or totally) original misses
- Can we get more misses after prefetching? How?

Compiler-Directed Prefetching: SW

Basic architecture support

- Instructions for read and read-exclusive prefetches (plus exception model)
- Lockup-free caches and associated machinery

Compiler Approach

- First use other tricks to get locality (e.g. blocking). Otherwise not fair.
- Must understand data reuse already in code
  - Temporal, spatial and group reuse (See Mowry paper)
  - Need to understand it within and across loops
  - Determine what to prefetch based on the above
- Optimize code so that address calculations, etc. have little overhead
  - Use loop splitting and loop unrolling
- The above algorithm implemented in Stanford SUIF compiler

Problem: Unnecessary Prefetches

- Overhead of computing address and issuing prefetch
- Increased network traffic

Reuse

Temporal	**DO** j
	  DO i
	    ...
	    =a [j]	

Spatial	**DO** i
	  ...
	  =a [i]
		$\Rightarrow$ Iterations i, $i+1$ use same cache line

Group	**DO** i
	  ...
	  =a [i] [0] + a [i + 5] [0]	

Reducing Overhead: Example

Supposed we need to prefetch four ahead to hide the latency

```
for(i=0;i<n;i++){
   ... = a[i]
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```
prefetch(A[0]);
prefetch(A[1]);
prefetch(A[2]);
prefetch(A[3]);
for(i=0;i<n;i++){
  prefetch(A[i+4]);
  ... = a[i]
```

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1. add prefetches

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```

1. add prefetches
2. use spatial locality

```
prefetch(A[0]);
for(i=0;i<n;i++){
  if(i%4 == 0)
    prefetch(A[i+4]);
  ... = a[i]
```

Reducing Overhead: Example

Supposed we need to prefetch four ahead to hide the latency

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prefetch(A[0]);
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prefetch(A[3]);
for(i=0;i<n;i++){
  prefetch(A[i+4]);
  ... = a[i]
```

1. add prefetches
2. use spatial locality
3. unroll

```
prefetch(A[0]);
for(i=0;i<n;i++){
  if(i%4 == 0)
    prefetch(A[i+4]);
  ... = a[i]
```

```
prefetch(A[0]);
for(i=0;i<n;i+=4){
  prefetch(A[i+4]);
  ... = a[i]
  ... = a[i+1]
  ... = a[i+2]
  ... = a[i+3]
```

Performance

See Fig 3:

- Prefetching applicable to many programs
- Compiler eliminates much of the memory latency
- Increase in the number of instructions
- PF mem overhead:
  - When executing LD/ST and cache tags busy with a PF fill
  - When attempting to issue a PF and PF issue buffer full

Blocking + PF

- Blocking reduces the bandwidth demands of a program, therefore increasing the potential of PF
- However, fewer misses for PF to hide
- See Fig 8: blocking and prefetching together make programs more efficient (different case of GMTRY and VPENTA)