ECE 259 / CPS 221
Advanced Computer Architecture II
(Parallel Computer Architecture)

Shared Memory MPs - Directories

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Slides are derived from work by
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Thanks!
Outline

• Directory-Based Cache Coherence
  – Motivation
  – Basic Idea
  – Some Variations

• Stanford DASH Case Study

• SGI Origin Case Study

• Advanced Directory Systems
Why Snooping Doesn’t Scale

• Limitations of snooping
  – Broadcasting uses lots of “bus” bandwidth
  – Snooping every transaction uses lots of controller bandwidth

• Snooping is great for small-medium size machines
  – Largest current snooping system has 128 processors

• Snooping hits bottleneck for large machines
  – Even with tricks like Multicast Snooping

• So how do we overcome this bottleneck?
  – Get rid of protocol that requires:
    » Broadcasting
    » Logical bus
Large Scale Shared Memory Multiprocessors

- 100s to 1000s of nodes (processors) with single shared physical address space

- Use general purpose interconnection network
  - Still have cache coherence protocol
  - Use messages instead of bus transactions
  - No hardware broadcast
Directory Based Cache Coherence

- Avoid broadcast request to all nodes on a miss
- Maintain directory of which nodes have cached copies of the block (directory controller + directory state)
- On a miss, cache controller sends message to directory
- Directory determines what (if any) protocol action is required
  - E.g., invalidations of Shared nodes
- Directory waits for protocol actions to finish and then responds to the original request

Directory is new serialization point (instead of bus)
Centralized Directory

- **Single directory** that contains a copy of all nodes’ cache tags

**Disadvantages**
- Bottleneck (1000s of processors...)
- Directory structure changes with number of nodes

**Advantages**
- Only send invalidates/updates to those nodes that have copy of block
Flat, Memory-Based Distributed Directory

- Distribute directory among memory modules
- Maintain directory for each memory block
  - Block’s home node = node with directory info for that block

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Directory Nomenclature

- \( \text{Dir}_{i \times} \) -- 2 variables (i and X)

- Directory of \( i \) pointers (\( i \leq \) total number of nodes)

- X specifies what to do on Shared to Modified transition
  - B = Broadcast
  - NB = No Broadcast
  - SW = Software

- \( \text{Dir}_N \) = full-map directory
  - Bit vector per memory block
  - Bit per node in system
  - No need to broadcast (unless all nodes are sharers)

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Limited Pointer Directory

• Each directory entry contains < N pointers
  – Not bit vector, but instead pointers to nodes
• Less overhead than full-map directory
• What to do when run out of pointers depends on what we want to do on S→M transition

Broadcast (Dir,B)
• Just give out another copy of block
• Modify state to indicate broadcast
• If S→M, then broadcast invalidation

No Broadcast (Dir,NB)
• Never allow more than i Sharers
  – If another request for shared, then invalidate a current sharer
Replacement Notification

- Should the directory be notified for blocks that are replaced from Shared state?

**Reasons to do this**
- Can avoid broadcast, clear bit/pointer when notified

**Reasons not to do this**
- Read-only data that will never be invalidated
- Notifications may cause unnecessary traffic
Coarse Vector and Sparse Directories

Coarse Vector

• Instead of full-map or broadcast, indicate a set of nodes that may have the block
• Reduces space requirements
• Many applications have near neighbor sharing

Sparse Directory (aka Directory Caching)

• Not all of memory is in processor caches
  – Size of memory $\gg$ sum of cache sizes
• Cache of directory entries at memory
Software Assistance

- Trap to software if we run out of pointers
- Limitless Directory (MIT Alewife)
- Dir₃SW (Wisconsin Wind Tunnel Group)

Why software assistance?
- Cost (less hardware)
- Flexibility

Actually, can do *everything* in software = Software DSM
- Page-based DSM
- Blizzard-S
- Shasta
Flat, Cache-Based Distributed Directory (SCI)

- Also known as “chaining directory”
- Build linked list of nodes containing cache block
- Store pointers in cache with block of data
- Home node points to start of list

Issues/Drawbacks
- Replacements
- Time to send invalidations