Lecture 10: Directory-Based Examples II

- Topics: SGI Origin wrap-up, Sequent NUMA-Q case study

Serialization

- Note that the directory serializes writes to a location, but does not know when a write/read has completed at any processor

- For example, a read reply may be floating on the network and may reach the requestor much later – in the meantime, the directory has already issued a number of invalidates, the invalidate is overwritten when the read reply finally shows up – hence, each node must buffer its requests until outstanding requests have completed

Directory Structure

- The system supports either a 16-bit or 64-bit directory (fixed cost)
- For small systems, the directory works as a full bit vector representation
- For larger systems, a coarse vector is employed – each bit represents p/64 nodes
- State is maintained for each node, not each processor – the communication assist broadcasts requests to both processors

Page Migration

- Each page in memory has an array of counters to detect if a page has more misses from a node other than home

- When a page is moved to a different physical memory location, the virtual address remains the same, but the page table and TLBs must be updated

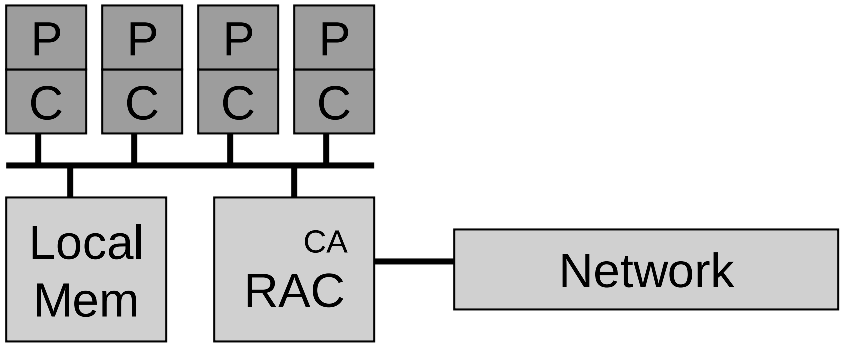
- To reduce the cost of TLB shootdown, the old page sets its directory state to poisoned – if a process tries to access this page, the OS intervenes and updates the translation

Sequent NUMA-Q

- Employs a flat cache-based directory protocol between nodes – IEEE standard SCI (Scalable Coherent Interface) protocol

- Each node is a 4-way SMP with a bus-based snooping protocol

- The communication assist includes a large "remote access cache" – the directory protocol tries to keep the remote caches coherent, while the snooping protocol ensures that each processor cache is kept coherent with the remote access cache



Directory Structure

- The physical address identifies the home node – the home node directory stores a pointer to the head of a linked list – each cache stores pointers to the next and previous sharer

- A main memory block can be in three directory states:
  - Home: (similar to unowned) the block does not exist in any remote access cache (may be in the home node's processor caches, though)
  - Fresh: (similar to shared) read-only copies exist in remote access caches and memory copy is up-to-date
  - Gone: (similar to exclusive) writeable copy exists in some remote cache

Cache Structure

- 29 stable states and many more pending/busy states!

- The stable states have two descriptors:
  - position in linked list: ONLY, HEAD, TAIL, MID
  - state within cache: dirty, clean, fresh, etc.

- SCI defines and implements primitive operations to facilitate linked list manipulations:
  - List construction: add a new node to the list head
  - Rollout: remove a node from a list
  - Purging: invoked by the head to invalidate all other nodes

Handling Read Requests

- On a read miss, the remote cache sets up a block in busy state and other requests to the block are not entertained

- The requestor sends a “list construction request” to the home and the steps depend on the directory state:
  - ➢ Home: state updated to fresh, head updated to requestor, data sent to requestor, state at requestor is set to ONLY_FRESH
  - ➢ Fresh: head updated to requestor, home responds with data and pointer to old head, requestor moves to a different busy state, sends list construction request to old head, old head moves from HEAD_FRESH to MID_VALID, sends ack, requestor → HEAD_FRESH

Handling Read Requests II

- Gone: home does not reply with data, it remains in Gone state, sends old head pointer to requestor, requestor moves to a different busy state, asks old head for data and “list construction”, old head moves from HEAD_DIRTY to MID_VALID, returns data, requestor moves to HEAD_DIRTY (note that HEAD_DIRTY does not mean exclusive access; the head can write without talking to the home, but sharers must be invalidated)

- Home keeps forwarding requests to head even if head is busy – this results in a pending linked list that is handled as transactions complete

Handling Write Requests

- At all times, the head of a list is assumed to have the latest copy and only the head is allowed to write
- The writer starts by moving itself to the head of the list; actions depend on the state in the cache:
    - HEAD_DIRTY: the home is already in GONE state, so home is not informed, sharing list is purged (each list element invalidates itself and informs the requestor of the next element – simple, but slow – works well for small invalidation sizes)

Handling Write Requests II

- HEAD_FRESH: home directory is updated from FRESH to GONE, sharing list is purged; if the home directory is not in FRESH state, some other node’s request is in flight – the requestor will have to move to the head again and retry

- ONLY_DIRTY: the write happens without generating any interconnect traffic

Writeback & Replacement

- Replacements are no longer "quiet" as the linked lists have to be updated – the "rollout" operation is used

- To rollout, a node must set itself to pending, inform the neighbors, and set itself to invalid – to prevent deadlock in the case of two neighbors attempting rollout, the node closer to the tail is given priority

- If the node is the head, it makes the next element the head and informs home

Writeback & Replacement II

- If the head is attempting a rollout, it sends a message home, but the home is pointing to a different head: the old head will eventually receive a request from the new head – at this point, the writeback is complete, and the new head is instead linked with the next node

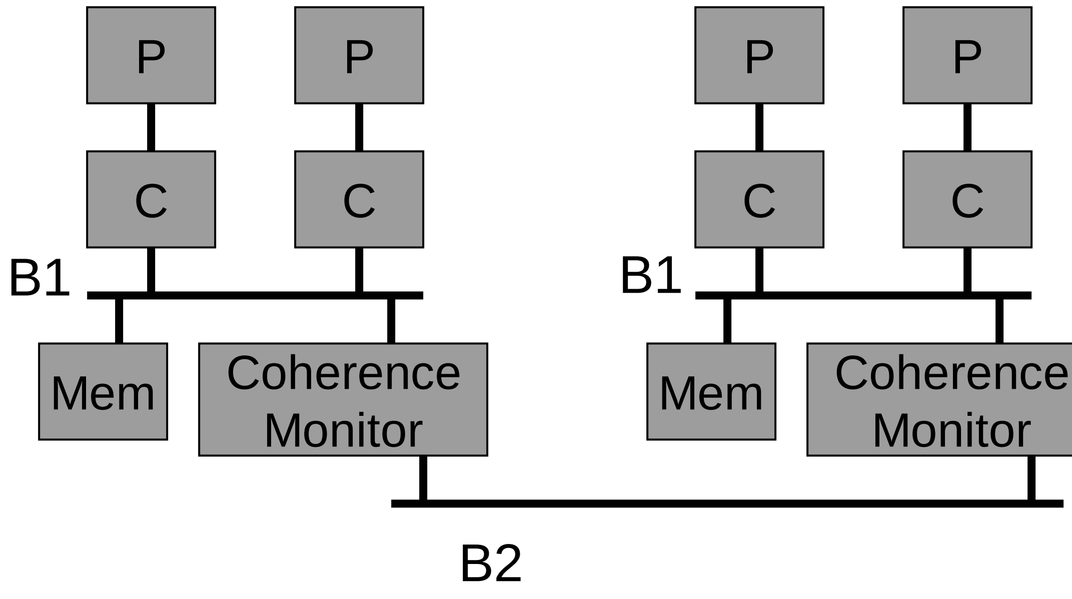
- To reduce buffering needs, the writeback happens before the new block is fetched

Serialization

- The home serves as the point of serialization – note that requests are almost never NACKed – requests are usually re-directed to the current head – helps avoid race conditions

- Since requests get queued in a pending list and buffers are rarely used, the protocol is less prone to starvation, unfairness, deadlock, and livelock problems

Hierarchical Snooping



Coherence Monitor:

- Tracks remotely allocated, locally cached data (by using a remote access cache)
- Tracks locally allocated, remotely cached data (by using a local state monitor)

Title

- Bullet