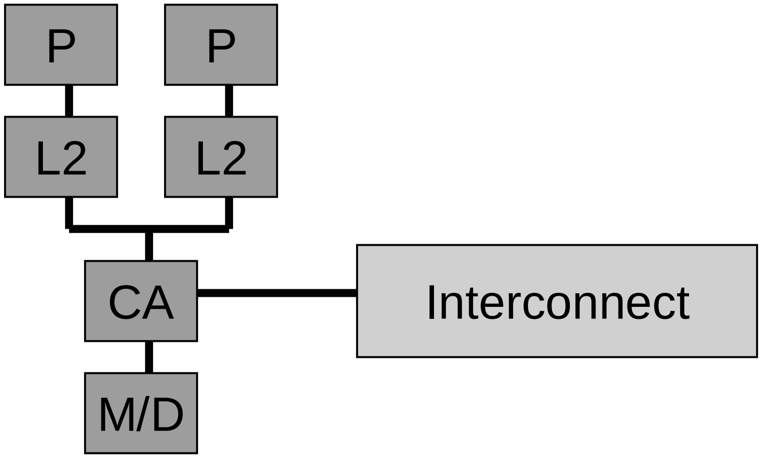
Lecture 8: Directory-Based Examples

- Topics: SGI Origin 2000 case study

SGI Origin 2000

- Flat memory-based directory protocol
- Uses a bit vector directory representation
- Two processors per node, but there is no snooping protocol within a node – combining multiple processors in a node reduces cost



Protocol States

- Each memory block has seven states
- Three stable states: unowned, shared, exclusive (either dirty or clean)
- Three busy states indicate that the home has not completed the previous request for that block (read, read-excl or upgrade, uncached read)
- Poison state – used for lazy TLB shootdown

Handling Reads

- When the home receives a read request, it looks up memory (speculative read) and directory in parallel

- Actions taken for each directory state:
    - shared or unowned: memory copy is clean, data is returned to requestor, state is changed to excl if there are no other sharers
    - busy: a NACK is sent to the requestor
    - exclusive: home is not the owner, request is fwded to owner, owner sends data to requestor and home

Inner Details of Handling the Read

- The block is in exclusive state – memory may or may not have a clean copy – it is speculatively read anyway

- The directory state is set to busy-exclusive and the presence vector is updated

- In addition to fwding the request to the owner, the memory copy is speculatively forwarded to the requestor
  - ➢ Case 1: excl-dirty: owner sends block to requestor and home, the speculatively sent data is over-written
  - ➢ Case 2: excl-clean: owner sends an ack (without data) to requestor and home, requestor waits for this ack before it moves on with speculatively sent data

Inner Details II

- Why did we send the block speculatively to the requestor if it does not save traffic or latency?
  - ➢ the R10K cache controller is programmed to not respond with data if it has a block in excl-clean state
  - ➢ when an excl-clean block is replaced from the cache, the directory need not be updated – hence, directory cannot rely on the owner to provide data and speculatively provides data on its own

Handling Write Requests

- The home node must invalidate all sharers and all invalidations must be acked (to the requestor), the requestor is informed of the number of invalidates to expect

- Actions taken for each state:
    - shared: invalidates are sent, state is changed to excl, data and num-sharers is sent to requestor, the requestor cannot continue until it receives all acks (Note: the directory does not maintain busy state, subsequent requests will be fwded to new owner and they must be buffered until the previous write has completed)

Handling Writes II

- Actions taken for each state:
  - unowned: if the request was an upgrade and not a read-exclusive, is there a problem?
  - exclusive: is there a problem if the request was an upgrade? In case of a read-exclusive: directory is set to busy, speculative reply is sent to requestor, invalidate is sent to owner, owner sends data to requestor (if dirty), and a “transfer of ownership” message (no data) to home to change out of busy
  - busy: the request is NACKed and the requestor must try again

Handling Write-Back

- When a dirty block is replaced, a writeback is generated and the home sends back an ack

- Can the directory state be shared when a writeback is received by the directory?

- Actions taken for each directory state:
    - ➢ exclusive: change directory state to unowned and send an ack
    - ➢ busy: a request and the writeback have crossed paths: the writeback changes directory state to shared or excl (depending on the busy state), memory is updated, and home sends data to requestor, the intervention request is dropped

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

Serialization - II

- Assume that a dirty block is being passed from P1 to another writer P2, the “ownership transfer” message from P1 to home takes a long time, P2 receives its data and carries on, P2 does a writeback, directory moves from busy to exclusive (P2) and sends data back to P2, P2 will drop it – hence, writebacks from outstanding request needs to be handled differently (with a NACK)

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

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