Directory-Based Cache Coherence

Review – Bus-based MP Architectures

- Centralized Memory
- Uniform Memory Access Time
- Bus as point of serialization and broadcast

Review – Network-based Multiprocessors

- “Scalable” network interconnect
- No broadcast medium
- Serialization at memory

Large-scale MPs

- Separate memory per processor
- No broadcast mechanism
- Use a directory, per memory block, that tracks the state of every block in every cache (why?)
- Accounting per cache block, or per memory block?
  - Pro (per memory) – less complex – one entry per block
  - Minus – memory much bigger than caches
- Distribute directories with memories to prevent single directory as bottleneck
Example (simple!) Directory Protocol

- Similar to snoopy: each block could be:
  - Shared
  - Uncached
  - Exclusive

- In addition to state, must keep track of who is sharing (when shared), or who owns (when exclusive).

- Terminology
  - Local node (where the request [load] originates)
  - Home node (where the memory location permanently resides)
  - Remote node (a node that has a copy of the block)

Directory Messages

<table>
<thead>
<tr>
<th>Type</th>
<th>Source</th>
<th>Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read miss</td>
<td>Local</td>
<td>Home</td>
</tr>
<tr>
<td>Write miss</td>
<td>Local</td>
<td>Home</td>
</tr>
<tr>
<td>Invalidate</td>
<td>Home</td>
<td>Remote</td>
</tr>
<tr>
<td>Fetch</td>
<td>Home</td>
<td>Remote</td>
</tr>
<tr>
<td>Fetch/invalidate</td>
<td>Home</td>
<td>Remote</td>
</tr>
<tr>
<td>Data value</td>
<td>Home</td>
<td>Local</td>
</tr>
<tr>
<td>Data write back</td>
<td>Remote</td>
<td>Home</td>
</tr>
</tbody>
</table>
Cache Block Actions

- Cache must also track state (ESI)

Directory Actions

Example

P1: write 10 to A1
P1: read A1
P2: read A1
P2: write 20 to A1
P2: write 40 to A2 (same block)

Coherence Summary

- Snoopy vs. Directory
- Directory keeps track of state of line and of all sharers
- Snoopy cost is function of cache size
- Directory cost is function of memory size (* number of nodes?)
- Coherence misses can be significant part of miss rate