Distributed shared memory

Computer Architecture

J. Daniel García Sánchez (coordinator)
David Expósito Singh
Javier García Blas

ARCOS Group
Computer Science and Engineering Department
University Carlos III of Madrid

1 Introduction to distributed shared memory

2 Basics of directory protocols

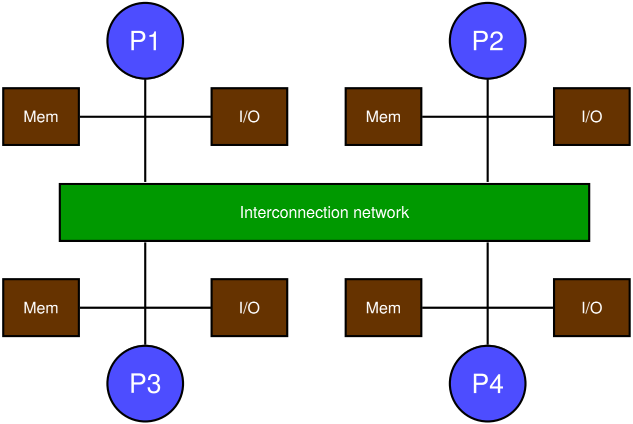
3 Directory based protocol

4 Conclusion

Snooping protocols and scalability

- **Problems** with snooping protocols.
  - Requires communication with all caches:
    - For each cache miss.
    - For each shared data write.
- What is the **advantage** of snooping protocols?
  - No centralized data structure.
    - Low implementation cost.
- What is the **drawback** of snooping protocols?
  - No centralized data structure.
    - Communications limit scalability.

DSM basic model



- **Need to eliminate coherence traffic.**

Kinds of coherence protocols

- **Snooping**
  - Each cache keeps sharing status for each block it holds.
  - Caches accessible through broadcasting medium (bus).
  - All caches monitor if they have a copy of the block.

- **Directory based**:
  - Sharing status kept in a directory.
  - **SMP**: Centralized directory in memory or last level cache (LLC).
  - **DSM**: To avoid bottleneck a distributed directory (more complex) is used.

Directory based protocol

- **Idea**: Keep **status** for each block in cache.
  - Which caches have a block copy?
  - Block state bits.

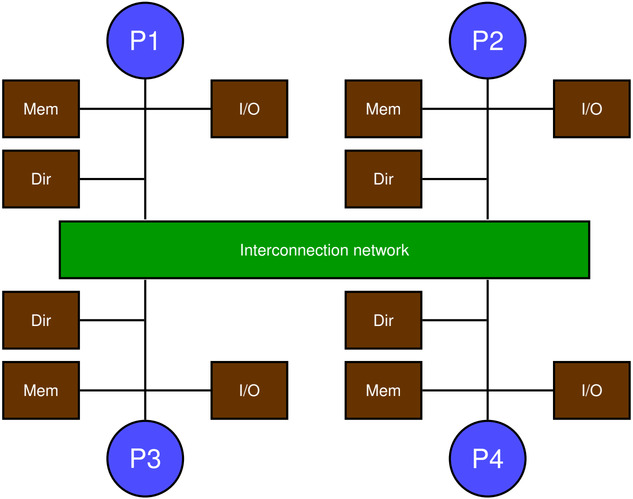
- Multi-cores with external shared cache.
  - **Bit vector** with length equal to number of cores.
    - Signals which private caches many have a copy of block.
    - Only send invalidation to caches marked in bitmap.
  - This scheme works well within a single multi-core.
  - **Example**: **Intel Core i7**.

Centralized directory and scalability

- A centralized directory avoids broadcasting but
  - Becomes a bottleneck.
  - Scalability problem with increasing number of processors.

- **Solution**: **Distributed directory**.
  - Distribute directory with memory.
  - Each directory has information about the associated local memory.
    - Target directory is always known.
  - Different coherence requests go to different directories.

Distributed directory



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Directory

- Basic operations.
    - Handling a read miss.
    - Handling a clean (not modified) shared block write.
- Directory must keep **status for each block**:
    - **Shared**: One or more nodes have a block in cache and its value in memory is updated.
    - **Non cached**: No node has a copy of the block in cache.
    - **Modified**: Only a node has a copy of the block in cache and it has written on it.
        - The block value in memory is not updated.
- **Besides**:
    - Bit map with information of which nodes have a copy of block.

Messages

Message	Source	Target	Content	Function
Read miss	Local cache	Local directory	P,A	P has read miss in A. Request data and P is sharer.
Write miss	Local cache	Local directory	P,A	P has write miss in A. Request data and P is owner.
Invalidation	Local cache	Local directory	A	Invalidate A in all caches.
Invalidation	Local cache	Remote directory	A	Invalidate shared copy.
Fetch	Local directory	Remote cache	A	Fetch block. State to shared.
Fetch/ Invalidation	Local directory	Remote cache	A	Fetch block. Invalidate block.
Response data value	Local directory	Local cache	D	Return value to directory.
Write-back data	Remote cache	Local directory	A,D	Write-back data.

P → **Node**, **A** → **Address**, **D**→ **Data**

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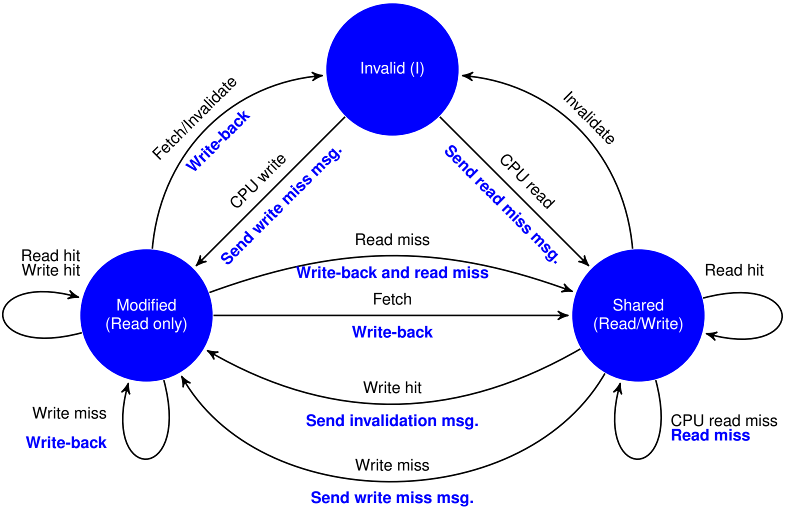
State transition

- **In multi-core chips**:
  - **Internal coherence** is kept through **centralized directory**.
  - **Same directory** may act as **local directory** in **DSM**.

- **Protocol implementation**:
  - State transition in **local cache**.
    - Send requests to **local directory**.
  - State transition in **directory**.

State transition in individual cache



Non cached entry

- Value in memory is updated.
- **Requests**:
  - **Read miss**:
    - Send data in memory to requesting node.
    - Requesting node is the only one in shared state.
    - State transitions to shared.
  - **Write miss**:
    - Send data in memory to requesting node.
    - Block transitions to exclusive state.
    - Requesting node is the owner.

Shared entry

- Value in memory is up to date.
- **Requests**:
  - **Read miss**:
    - Send data from memory to requesting node.
    - Requesting node added to entry nodes set.
  - **Write miss**:
    - Send data from memory to requesting node.
    - Send invalidation messages to entry nodes set.
    - Enable in set only the requesting node.
    - Transition state to exclusive.

Exclusive entry

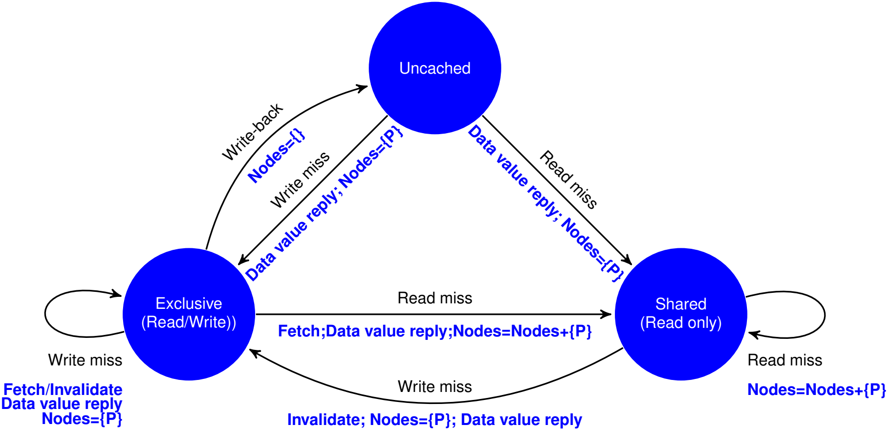
- Block value is in cache in the node identified by the set (owner node).

- **Requests**:
  - **Read miss**:
    - Send fetch message to owner.
    - Write data in memory.
    - Send data to requesting node.
    - Add requesting node to node set.

Exclusive entry

- **Requests**:
  - **Write back**:
    - Happens when owner performs write-back of block.
    - Block transitions to uncached state.
    - Clean entry set.
  - **Write miss**:
    - Block has new owner.
    - Invalidate block in old owner and get value.
    - Send value to requesting node.
    - Enable in set only the new requesting.

Directory state transition



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Summary

- Scalability problems in snooping protocols.
- Alternatives for directory based protocols:
  - Centralized directory in SMP.
  - Distributed directory in DSM.
- In multi-core chips:
  - Internal coherence through centralized directory.
  - Used as local directory in DSM.

References

- **Computer Architecture. A Quantitative Approach**
  5th Ed.
  Hennessy and Patterson.
  Sections: 5.4.

- **Recommended exercises**:
  - 5.9, 5.10, 5.11, 5.12.

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