Lecture 16/17: Distributed Shared Memory

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Angela Demke Brown

Outline

- Review distributed system basics
- What is distributed shared memory?
- Design issues and tradeoffs

Distributed System Features

- Multiple computers
  - May be heterogenous, or homogeneous
  - May be controlled by a single organization or by distinct organizations or individuals
  - No physical shared memory, no shared clock
- Connected by a communication network
  - Typically a general-purpose network, not dedicated to supporting the distributed system
  - Messages are sent over network for communication
- Co-operating to share resources and services
  - Application processing occurs on more than one machine

Distributed IPC

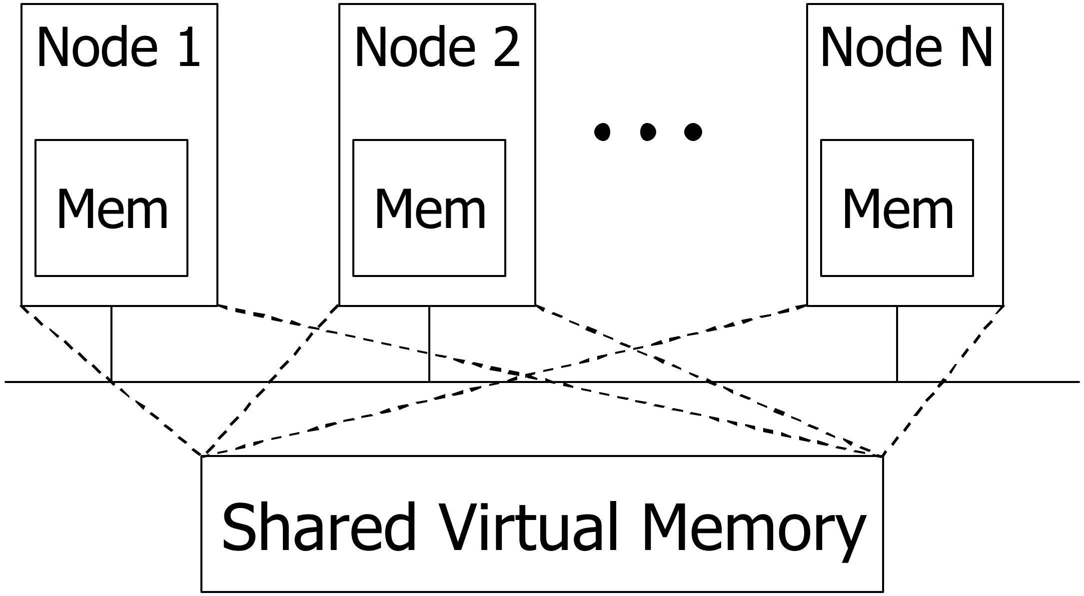
- Option 1: Use message passing primitives
  - E.g. Unix sockets
  - ✓ Good match for underlying structure
  - ✗ programmer has to deal with sending data
- Option 2: Use remote procedure call (RPC)
  - ✓ Familiar programming model
  - ✓ RPC system handles communication details
  - ✗ passing complex data types is hard
  - ✗ model is synchronous, not a good fit for parallel programming

(Local) Shared Memory

- Uniprocessor or SMP systems
- Processes can share part of their address space
  - Threads in a process share entire address space
- IPC provided through access to shared data
  - ✓ Easy to express concurrency, share complex data structures
  - ✗ Synchronization needed to prevent data races
- How is this implemented on single computer?
- Can we achieve same effect on dist. system?

Distributed Shared Memory (DSM)

- Goal: allow processes on networked computers to share physical memory through a single shared virtual address space

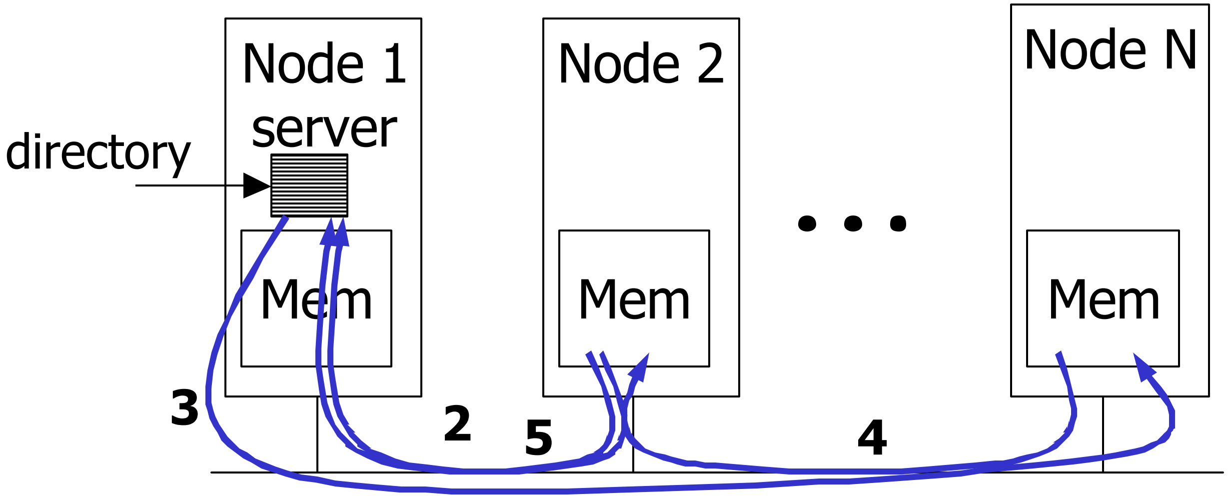


DSM Basics

- Physical memory on each node holds pages of shared virtual address space
  - Local pages are present in current node's memory
  - Remote pages are in some other node's memory
- Exploit MMU hardware to locate pages
  - Page table entry for a page is valid if the page is local
  - Access to non-local page causes a page fault
  - DSM protocol handles page fault, retrieves remote data
  - Operations are transparent to programmer

Locating Remote Data

- Simplest Design: central server maintains directory recording which machine currently holds each page



1. Node 2 pg faults
2. Consult central server to locate
3. Page requested from current owner, Node N
4. Owner invalidates, sends to new location, Node 2
5. Node 2 informs directory of new ownership

Problem 1

- Directory at central server becomes bottleneck
  - All page query requests go to this node
- Solution: Distributed directory
  - Each node is responsible for portion of address space
  - Responsible node = (page #) mod (num nodes)

N1

Page	Locn
0000	N3
0004	N1
0008	N2
000C	N2
…	…

N2

Page	Locn
0001	N1
0005	N3
0009	N4
000D	N1
…	…

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N4

Page	Locn
0003	N4
0007	N2
000B	N3
000F	N3
…	…

Problem 2

- Each virtual page exists on only one machine at time
  - No caching
- Actively shared pages may lead to thrashing
- Solution: allow replication (caching)
  - Read operations become cheaper
    - Simultaneous reads can be executed locally on multiple nodes
  - Write operations become more expensive
    - Cached copies need to be invalidated or updated

Simple Replication

- Multiple Readers, Single Writer (MRSW)
  - One node can be granted a read-write copy
  - **OR** multiple nodes can be granted read-only copies
- On read operation:
  - Acquire read-only copy of the page
  - Set access rights to read-only on any writeable copy on other nodes
- On write operation:
  - Revoke write permission from other writable copy (if any)
  - Get read-write copy of page
  - Invalidate all copies of page at other nodes

Full Replication

- Multiple readers, multiple writers
  - More than one node can have writable copy of page
  - Access to shared data must be controlled to maintain consistency
    - More on this in a minute….

Dealing with replication

- Must keep track of copies of the page
  - Extend directory with copyset
    - The set of all nodes that requested copies
- On request for page copy
  - Add requestor to copyset
  - Send page contents
- On request to invalidate page
  - Send invalidation requests to all nodes in copyset and wait for acknowledgements

Consistency Model

- Defines when modifications to data may be seen at a given processor
- Defines how memory will appear to a programmer
  - Restricts what values can be returned by a read of a memory location
- Must be well-understood
  - Determines how programmer reasons about correctness of program
  - Determines what optimizations are allowed

Recall Sequential Consistency

- All memory operations must execute one at a time
- All operations of a single processor appear to execute in program order
- Interleaving among processors is ok

Achieving Sequential Consistency

- Node must ensure that previous memory operation is complete before proceeding with the next one
  - Must get acknowledgement that write has completed
  - With caching, must sent invalidate or update messages to all copies
  - **ALL** these messages must be acknowledged
- To improve performance we relax the rules

Relaxed (weak) consistency

- Allow reads/writes to different memory locations to be reordered
- Consider operation in critical section:
  - Should be used for all shared data operations
  - One process actively reading/writing
  - Nobody else will access until process leaves c.s.
  - → No need to propagate writes sequentially, or at all, until process leaves critical section!

Synchronization Variables

- Operation for synchronizing memory
  - Analog of fences in shared memory multiprocessors
- All local writes get propagated
- All remote writes are brought in to the local processor
- Block until memory synchronized
- Access to synchronization variables are sequentially consistent

Problems with Weak Consistency

- Inefficiency
  - Synchronization happens at begin and end of a critical section
  - Is process finished memory access? Or is it about to start?
- System must make sure
  - All locally-initiated writes have completed
  - All remote writes have been acquired

Can we do better?

- Separate synchronization into two stages:
- 1. **acquire access**
  - Obtain valid copies of all pages
- 2. **release access**
  - Send invalidations for shared pages that were modified locally to nodes that have copies

- Eager Release Consistency

Can do better still

- Release requires sending invalidations to all nodes with copy
  - And waiting for all to acknowledge
- Delay this process
  - On release, send invalidation to directory
  - On acquire, check with directory to see if new copy is needed
- Reduces message traffic on release

- Lazy Release Consistency

How do you propagate changes?

- Send entire page
  - Easy, but may be a lot of data
- Send only what changed
  - Local system must save original and compute differences