Synchronization

Waiting for other processes, so that they can continue working together

- may repeatedly check to continue
  - sync using spinlocks
- may wait for a signal to continue
  - sync using mutexes and condition vatiables
- waiting hurts performance
  - CPUs wste cycles for checking; cache effects

Limitation of mutextes and condition variables

- Error prone/correctness/ease of use
  - unlock wrong mutex, signal wrong condition variable
- Lack of expressive power
  - helper variables for access or priority control

Low-level support: hardware atmoic instructions

Synchronization constructs

1. Spinlocks (basic sync construct)
   - Spinlock is like a mutex
     - mutual exclusion
     - lock and unlock(free)
   - but, lock == busy => spinning

2. Semaphores
    - common sync construct in OS kernels
    - like a traffic light: Stop and Go
    - like mutex, but more general

Semaphore == integer value

- on init
    - assigned a max value (positive int) => max count
- on try(wait)
    - if non-zero, decrement and proceed => counting semaphore
- if initialized with 1
    - semaphore == mutex(binary semaphore)
- on exit(post)
    - increment

Syncing different types of accesses

Reader/Writer locks

read (don't modify)	write (always modify)
shared access	exclusive access

- RW locks
    - specify type of access, then lock behaves accordingly

Monitors (highlevel construct)

- shared resource
- entry resource
- possible condition variables

- On entry:
    - lock, check
- On exit:
    - unlock, check, signal

More synchroniaztion constructs

- serializers
- path expressions
- barriers

- rendezvous points
- optimistic wait-free sync (RCU) [Read Copy Update]

All need hardware support.

Need for hardware support

- Problem
  - concurrent check/update on different CPUs can overlap

Atomic instructions

Critical section with hardware supported synchronization

Hardware specific

- test-and-set

  - returns(tests) original values and sets new-value!= 1 (busy) automatically
  - first thread: test-and-set(lock) => 0 : free
  - next ones: test-and-set(lock) => 1 busy
    - reset lock to 1, but that's okay
  - **+** : Latency
  - **+** : minimal (Atomic)
  - **+** : Delay potentially min
  - **-** : Contention processors go to memory on each spin - To reduce contention, introduce delay - Static(based on a fixed value) or Dynamic(backoff based, random delay)

- read-and-increment

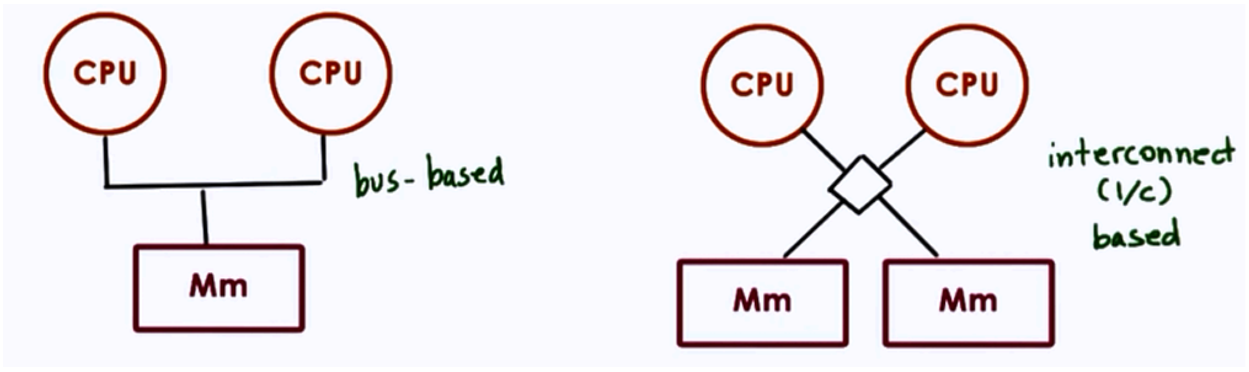
- compare-and-swap

Guarantees

- atomicity
- mutual exclusion
- queue all concurrent instructions but one

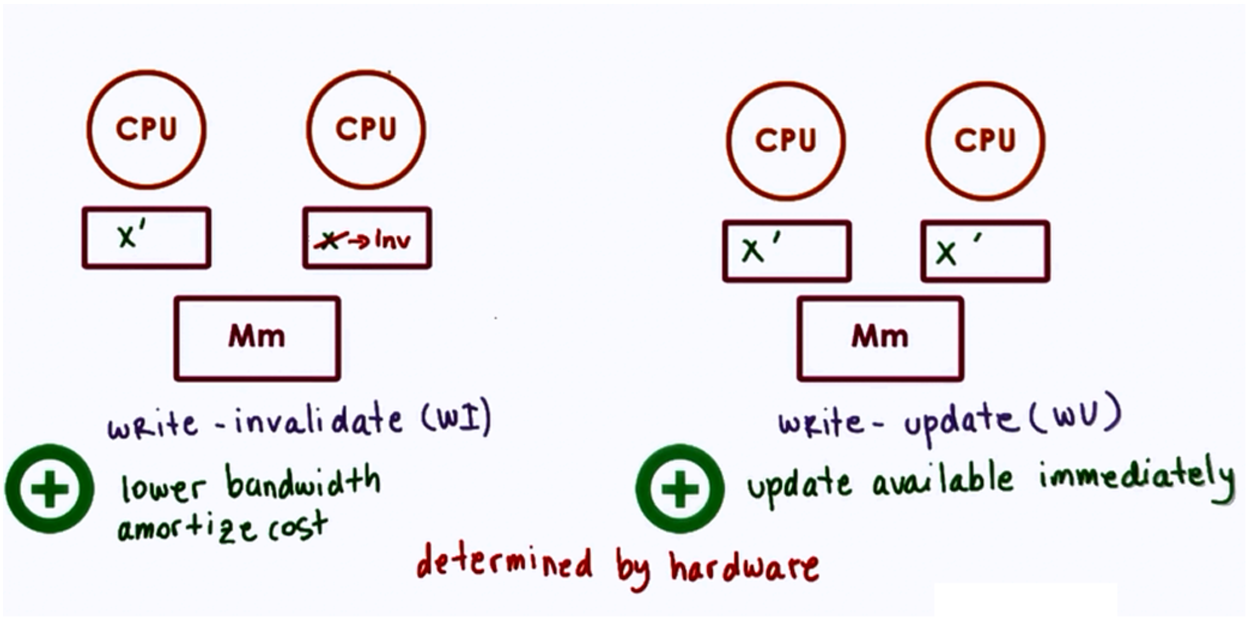
Shared Memory Multiprocessors

Also called symmetric multiprocessors (SMP)



- Caches
  - hide memory latency, "memory" further away due to contention
  - no-write, write-through, write-back

Cache Coherence


CPU
CPU
X'
~~X~~ → Inv
Mm
write - invalidate (WI)
lower bandwidth
amortize cost
CPU
CPU
X'
X'
Mm
write - update (WU)
update available immediately
determined by hardware