Multiprocessor OS

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Multiprocessor Applications

- Multiprogramming
  - Multiple regular applications running concurrently

- Concurrent servers
  - Web servers, ... ...

- Parallel programs
  - Utilizing multiple processors to complete one task (parallel matrix multiplication, Gaussian elimination)
  - Strong synchronization

Single-processor OS vs. Multi-processor OS

- Single-processor OS
  - easier to support kernel synchronization
    - fine-grained locking vs. coarse-grained locking
    - disabling interrupts to prevent concurrent executions
  - easier to perform scheduling
    - which to run, not where to run

- Multi-processor OS
  - evolution of OS structure
  - synchronization
  - scheduling

Multiprocessor Hardware

- A computer system in which two or more CPUs share full access to the main memory
- Each CPU might have its own cache and the coherence among multiple cache is maintained
  - write operation by a CPU is visible to all other CPUs
  - writes to the same location is seen in the same order by all CPUs (also called write serialization)
  - bus snooping and cache invalidation

Cache
CPU
Cache
CPU
Memory bus
Memory

A x B = C

x = A B C

Multiprocessor OS

Each CPU has its own operating system
  - quick to port from a single-processor OS
Disadvantages
  - difficult to share things (processing cycles, memory, buffer cache)

Multiprocessor OS – Master/Slave

All operating system functionality goes to one CPU
  - no multiprocessor concurrency in the kernel
Disadvantage
  - OS CPU consumption may be large so the OS CPU becomes the bottleneck (especially in a machine with many CPUs)

Multiprocessor OS – Shared OS

A single OS instance may run on all CPUs
The OS itself must handle multiprocessor synchronization
  - multiple OS instances from multiple CPU may access shared data structure

Synchronization (Fine/Coarse-Grain Locking)

Fine-grain locking – only locking necessary critical section
Coarse-grain locking – locking large piece of code, much of which is unnecessary
  - simplicity, robustness
  - prevent simultaneous execution

Simultaneous execution is not possible anyway on uniprocessor anyway.
Synchronization (Spin Locking)

- Protecting short critical region - busy waiting is OK
- Disabling interrupts does not work
- Software spin locks
- Hardware spin locks
  - using TSL

```assembly
entry_section:
  TSL R1, LOCK   | copy lock to R1 and set lock to 1
  CMP R1, #0    | was lock zero?
  JNE entry_section | if it wasn’t zero, lock was set, so loop
  RET | return; critical section entered

exit_section:
  MOV LOCK, #0  | store 0 into lock
  RET | return; out of critical section
```

TSL on Multiprocessor

- TSL involves two actions (reading the value and writing 1) and it needs to be atomic
- On uniprocessor, we simply need to make the two actions unbreakable
- On multiprocessor, the TSL implementation is more complex, usually it has to monopolize the memory bus

More on TSL Locks

- TSL is a heavy operation, imagine multiple CPUs are busy waiting on one lock, there will be a lot of load on the bus
- Precede each TSL lock will a trylock (basically a simple read)
  - only when trylock shows the lock is not locked, a TSL lock will be applied

Multiprocessor Scheduling

- Timesharing
  - similar to uni-processor scheduling - one queue of ready tasks (protected by synchronization), a task is dequeued and executed when a processor is available
- cache affinity
  - affinity-based scheduling - try to run each process on the processor that it last ran on
- caching sharing and synchronization of parallel/concurrent applications
  - gang/cohort scheduling - utilize all CPUs for one parallel/concurrent application at a time
Resource Contention-Aware Scheduling I

- Hardware resource sharing/contention in multi-processors
  - SMP processors share memory bus bandwidths
  - Multi-core processors share L2 cache
  - SMT processors share a lot more stuff
- An example: on an SMP machine
  - A web server benchmark delivers around 6300 reqs/sec on one processor, but only around 9500 reqs/sec
- Contention-reduction scheduling
  - Co-scheduling tasks with complementing resource needs (a computation-heavy task and a memory access-heavy task)
  - In [Fedoreva et al. USENIX2005], IPC is used to distinguish computation-heavy task and memory access-heavy task

Resource Contention-Aware Scheduling II

- What if contention on a resource is unavoidable?
- Two evils of contention
  - High contention ⇒ performance slowdown
  - Fluctuating contention ⇒ uneven application progress over the same amount of time ⇒ poor fairness
- [Zhang et al. HotOS2007] Scheduling so that:
  - Very high contention is avoided
  - The resource contention is kept stable

Multiprocessor Scheduling in Linux 2.6

- One ready task queue per processor
  - Scheduling within a processor and its ready task queue is similar to single-processor scheduling
- One task tends to stay in one queue
  - For cache affinity
- Tasks move around when load is unbalanced
  - E.g., when the length of one queue is less than one quarter of the other
  - Which one to pick?
- No native support for gang/cohort scheduling or resource-contention-aware scheduling

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