Scheduling

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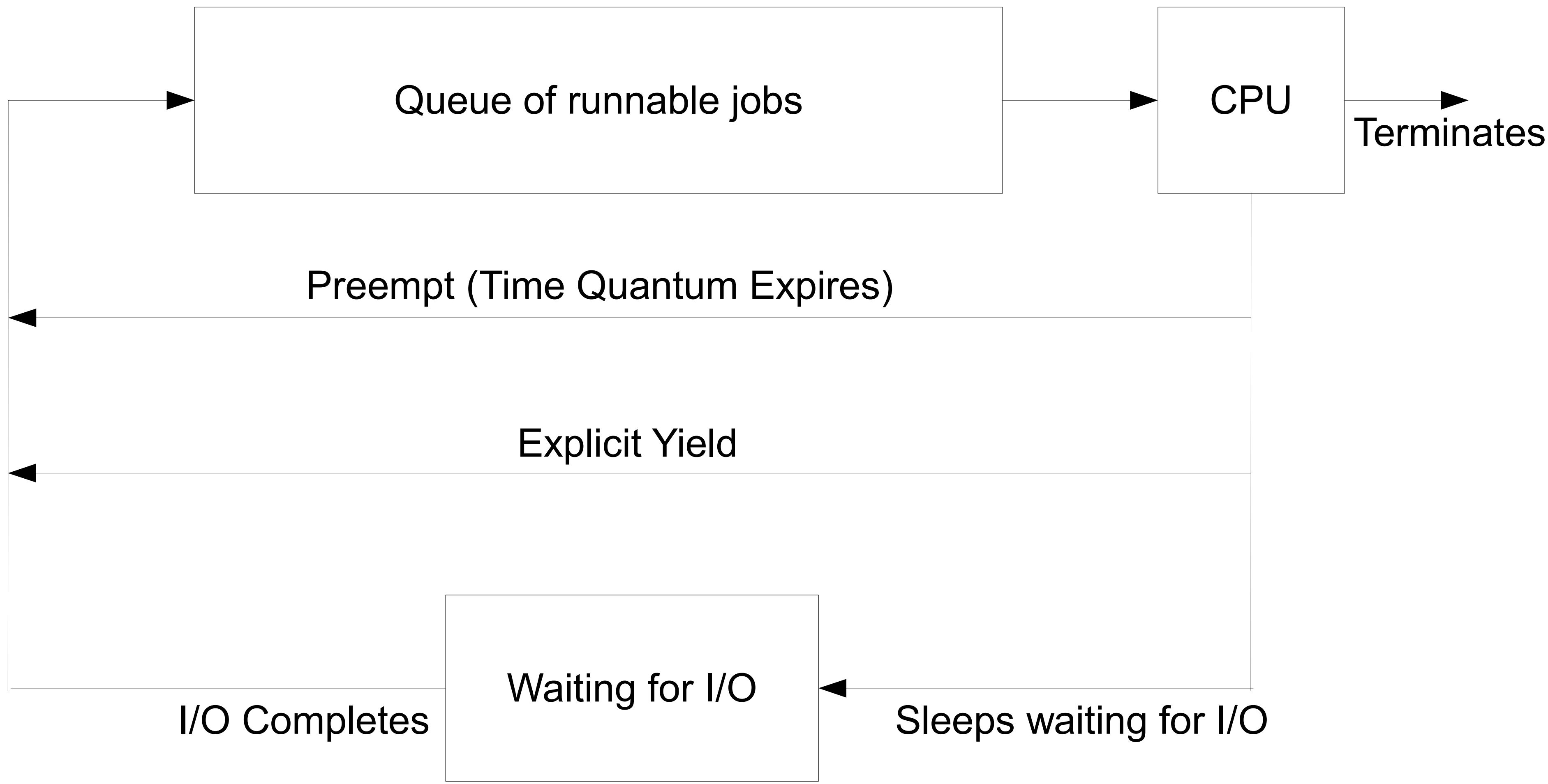
What is Scheduling?

- When a thread is suspended...
  - Kernel must decide which thread gets to run next.
    - *Only runnable threads considered*: most threads are sleeping most of the time.
  - Issues to consider
    - Thread priority
    - Thread history
      - Interactive threads usually given attention ASAP on the theory that they will probably sleep again quickly.
      - This keeps the user interface responsive.
    - Number of processors
      - Often desirable to schedule a thread on the same processor it was using in the past.

CPU vs I/O

- Threads alternate between using the CPU and doing I/O.
  - Here "I/O" also covers the case where a thread waits for another thread.
    - Waiting to acquire a lock.
    - Waiting for another thread to terminate.
  - *CPU Burst*: Time spent running on CPU
  - *I/O Burst*: Time spent waiting for "I/O"
- Scheduling is only concerned with threads that can use the CPU
  - That is, threads involved in or about to start a CPU burst.

Single CPU, Single Queue



Run Queue

- The queue of runnable jobs is called the *run queue* or *wait queue*.
- Scheduling problem:
  - When the CPU is idle...
    - Because executing job terminated
    - Because executing job sleeps on I/O
    - Because executing job is preempted
    - Because executing job explicity yielded the processor
  - ... which job from the run queue should be selected next?
    - This is the essence of the scheduling problem.

Run Queue Empty?

- If the run queue is empty (surprisingly common)
  - CPU idles
  - Most modern systems actually shut it off (in effect)!
    - Conserves energy.
    - Keeps the system cooler.
  - CPU turned back on by the next interrupt.
    - This works...
      - If no jobs can run, the only thing that can happen next is a prior I/O request completing.
      - Hardware will generate an interrupt when that occurs.
      - Interrupt service routine will wake up some process, giving the scheduler something to think about.

Run Queue Not Empty

- If the run queue is not empty...
  - Several algorithms exist for selecting the next job. Basics include...
    - FCFS (First Come First Served; also called FIFO)
      - Executes jobs in the order in which they were entered into the run queue.
    - SJN (Shortest Job Next)
      - Executes the shortest job next regardless of order in run queue.
      - Requries a way to predict which will be the shortest.
    - SRT (Shortest Remaning Time)
      - Similar to SJN.
      - Preempt current job if something shorter arrives on the queue.

Job Time

- Here "Job Time" means the time of the next CPU burst.
  - Example: Jobs A, B, C in the queue in that order.
    - A's next CPU burst will be 3.7 ms
    - B's next CPU burst will be 9.8 ms
    - C's next CPU burst will be 2.5 ms
  - In that case...
    - FCFS chooses A (at the head of the queue)
    - SJN chooses C
    - SRT chooses C as well, but will replace job on the CPU if something shorter is added to the queue while C is running (note: C's burst will be shorter by then too).

CPU Bound

- Some jobs have very long CPU bursts
  - Lasting minutes, days, months...
- Typically split into time quantums and preempted periodically.
  - *For example, every 10 ms.*
  - Some systems adjust time quantum size dynamically.
- Scheduler may assume next CPU burst is the size of the time quantum.
  - But may also take into account history.
    - If a job uses its entire quantum every time it runs, it may be penalized (get a forced priority reduction).

Turn Around Time

- *Normalized Turn Around Time*, T_n
  - T_n = (TimeInQueue + TimeExecuting) / TimeExecuting
  - Example: 18.5 ms in run queue. 2.7 ms executing.
    - $T_n = (18.5 + 2.7)/2.7 = 7.85$
  - Low T_n is good.
    - Ideally $T_n = 1.0$ (zero time in the run queue).
- Average Normalized Turn Around Time...
  - A figure of merit for a scheduler.
    - Average of T_n across every job. You want 1.0.

FCFS

- First Come First Served
  - Easy to implement.
    - Scheduler pulls job from the front of the queue. *Done.*
  - Lousy average T_n
    - Problem: Short jobs that wait experience a huge T_n
      - (250 ms + 1 ms)/1ms = 250
    - McDonalds: You walk in behind a bus load of people who each order a huge meal. You just want a soda.
  - FCFS is fair.
    - Everyone will get a turn... *eventually.*

SJN

- Shortest Job Next
  - Scan the queue looking for the job with the shortest estimated service time. Run it immediately.
  - Much better average T_n
    - Short jobs don't have to wait.
    - *"You just want a soda? Come to the head of the line!"*
  - Long jobs might starve.
    - At McDonald's starvation might be literal!
    - Not always fair.

Estimated Service Time

- SJN requires estimates of a job's service time.
  - Use past behavior.
  - Processes burst on the CPU then sleep.
    - Build up a history of a process's CPU burst durations.
    - Use that history to form guess of future behavior.
    - Not always accurate (of course)
    - Often very close.
  - Different ways to compute estimate can produce different estimates
    - ... can change the performance of basic SJN scheduling.

Real Operating Systems

- *Real systems are more complex.*
  - Multiple queues... one for each priority.
    - Typically pull job from highest priority non-empty queue.
    - Only consult lower priority queues if the high priority queue is empty.
      - Not as bad is it sounds: high priority jobs are typically not CPU bound and usually are waiting for I/O. High priority queues are normally empty.
    - BUT... bump up process priority automatically (to avoid starvation of low priority processes).

Multiple CPUs

- *Real systems have more than one CPU.*
  - This doesn't change things much.
  - Whenever *any* CPU is idle, the scheduler steps in to give it something to do.
    - Can use the same basic algorithms.
    - Sometimes useful to bind a process to the same CPU (to make use of memory cache more efficient).
- Goal: Keep all CPUs busy all the time.
  - Otherwise you are wasting your money!

Linux

- High level overview...
  - Scheduler works with *schedulable entities*.
    - Each such entity needs a `struct sched_entity`.
      - Such a structure is embedded in the `task_struct` of each task.
    - Allows groups of threads to be scheduled as a unit.
      - All threads owned by a particular user.
      - All threads in a particular process.
      - Once the unit is scheduled, then the component tasks can be.
  - Different *scheduling classes* are supported.
    - "Completely fair scheduler" is the default.
    - Also a real-time scheduler to handle `SCHED_RR` and `SCHED_FIFO` policies.
    - Each class works independently of the other(s).

Linux

- High level overview (continued)...
  - Each CPU has a run queue of its own.
    - The CPU run queue tracks total execution time on CPU.
    - Contains class-specific run queues for each class.
  - A task is in exactly one run queue.
    - Waiting on exactly one CPU.
    - Handled by exactly one scheduling class.
  - Under special circumstances tasks can change run queues.
    - Switch to a different scheduling class.
    - Migrate to a different CPU.

Linux

- High level overview (continued)...
  - *Virtual run time* tracked for each task.
    - Updated when task pulled from CPU or at each timer tick.
      - Timer ticks `HZ` times per second. Default is 250 (4 ms tick interval).
      - Only currently executing tasks (on each CPU) needs updating.
    - Weighted by task priority.
      - High priority tasks have virtual run times that advance slowly.
      - Scheduler believes they haven't run very much and runs them again sooner than otherwise.
  - No time quanta in the usual sense.
    - Task preempted from CPU if virtual run time is too high.

Completely Fair Scheduler

- Ensures all tasks get the same (virtual) run time
  - High priority tasks get more real time since their virtual run time advances more slowly.
- Basic idea: *Pick the task with the smallest virtual run time to run next.*
  - Task many not be preempted at each timer interrupt, but it will be preempted eventually.
  - New tasks get more attention because their virtual run times are small initially.
    - Interactive tasks automatically preferred over CPU bound tasks. No special handling of interactive tasks is necessary.

Real Time Scheduler

- Real time class is independent.
  - Threads considered before any CFS threads.
  - `SCHED_FIFO`
    - Thread runs for as long as it wants. All other threads on the system are suspended indefinitely.
      - Of course such threads should sleep quickly!
    - Important if real time deadlines are to be met.
  - `SCHED_RR` (Round Robin)
    - Threads switch among themselves, blocking all other threads on the system indefinitely.
  - BUT... there are real time priorities to consider also.

Real Time Priorities

- CFS threads can be temporarly boosted to real time priority...
  - Using RT Mutexes.
  - Intended to avoid *priority inversion*.
    - See the slide set on locking.
  - Still scheduled by the CFS (as I understand it).

CFS Run Queue

- The CFS uses a *red black tree* for its run queue.
  - Sorted in order of increasing virtual run time.
    - *Okay, not exactly... but this is the general idea.*
  - Next task to run is the leftmost tree node.
- R/B trees have O(log n) running time for most operations.
  - Here 'n' is the number of runnable tasks.
  - Older 2.6.x kernels used an O(1) scheduler.
    - Now obsolete. Required a lot of special case handling and complex heuristics.