CIS 505: Software Systems
OS Overview -- CPU Scheduling

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CPU SCHEDULING

- How can OS schedule the allocation of CPU cycles to processes/threads to achieve "good performance"?
- Overview of topics
  - Issues in scheduling
  - Basic scheduling algorithms
    - First-come First-served
    - Round Robin
    - Shortest Job First
    - Priority based
  - Scheduling in Unix
  - Real-time scheduling (Priority Inheritance)

Scheduling Issues

- Application Profile:
  - A program alternates between CPU usage and I/O
  - Relevant question for scheduling: is a program compute-bound (mostly CPU usage) or I/O-bound (mostly I/O wait)
- Multi-level scheduling (e.g., 2-level in Unix)
  - Swapper decides which processes should reside in memory
  - Scheduler decides which ready process gets the CPU next
- When to schedule
  - When a process is created
  - When a process terminates
  - When a process issues a blocking call (I/O, semaphores)
  - On a clock interrupt
  - On I/O interrupt (e.g., disk transfer finished, mouse click)
  - System calls for IPC (e.g., up on semaphore, signal, etc.)

Scheduling Issues

- Is preemption allowed?
  - Non-preemptive scheduler does not use clock interrupts to stop a process
- What should be optimized?
  - CPU utilization: Fraction of time CPU is in use
  - Throughput: Average number of jobs completed per time unit
  - Turnaround Time: Average time between job submission (or command issue) and completion
  - Waiting Time: Average amount of time a process is ready but waiting
  - Response Time: in interactive systems, time until the system responds to a command
  - Response Ratio: (Turnaround Time)/(Execution Time) -- long jobs should wait longer

Scheduling Issues

- Different applications require different optimization criteria
  - Batch systems (throughput, turnaround time)
  - Interactive system (response time, fairness, user expectation)
  - Real-time systems (meeting deadlines)
- Overhead of scheduling
  - Context switching is expensive (minimize context switches)
  - Data structures and book-keeping used by scheduler
- What's being scheduled by OS?
  - Processes in Unix, but Threads in Linux or Solaris

Basic Scheduling Algorithm: FCFS

- FCFS - First-Come, First-Served
  - Non-preemptive
  - Ready queue is a FIFO queue
  - Jobs arriving are placed at the end of queue
  - Dispatcher selects first job in queue and this job runs to completion of CPU burst
- Advantages: simple, low overhead
- Disadvantages: inappropriate for interactive systems, large fluctuations in average turnaround time are possible.

Example of FCFS

- Workload (Batch system)
  Job 1: 24 units, Job 2: 3 units, Job 3: 3 units
- FCFS schedule:

```
  | Job 1 |  Job 2  |  Job 3  |
 0       24        27        30
```

- Total waiting time: 0 + 24 + 27 = 51
- Average waiting time: 51/3 = 17
- Total turnaround time: 24 + 27 + 30 = 81
- Average turnaround time: 81/3 = 27

SJF - Shortest Job First

- Non-preemptive
- Ready queue treated as a priority queue based on smallest CPU-time requirement
  - arriving jobs inserted at proper position in queue
  - dispatcher selects shortest job (1st in queue) and runs to completion
- Advantages: provably optimal w.r.t. average turnaround time
- Disadvantages: in general, cannot be implemented. Also, starvation possible!
- Can do it approximately: use exponential averaging to predict length of next CPU burst
  ==> pick shortest predicted burst next!

Example of SJF

- Workload (Batch system)
  Job 1: 24 units, Job 2: 3 units, Job 3: 3 units
- SJF schedule:

```
  | Job 2 |  Job 3  |  Job 1  |
  0       3         6         30
```

- Total waiting time: 6 + 0 + 3 = 9
- Average waiting time: 3
- Total turnaround time: 30 + 3 + 6 = 39
- Average turnaround time: 39/3 = 13
- SJF always gives minimum waiting time and turnaround time

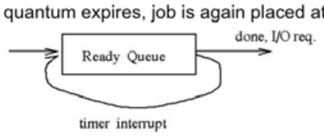
Exponential Averaging

$$\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\, \tau_n$$

- τ_{n+1} : predicted length of next CPU burst
- t_n : actual length of last CPU burst
- τ_n : previous prediction
- $\alpha = 0$ implies make no use of recent history
  $(\tau_{n+1} = \tau_n)$
- $\alpha = 1$ implies $\tau_{n+1} = t_n$ (past prediction not used).
- $\alpha = 1/2$ implies weighted (older bursts get less and less weight).

RR - Round Robin

- Preemptive version of FCFS
- Treat ready queue as circular
  - o arriving jobs are placed at end
  - o dispatcher selects first job in queue and runs until completion of CPU burst, or until time quantum expires
  - o if quantum expires, job is again placed at end



Example of RR

- Workload (Batch system)
  Job 1: 24 units, Job 2: 3 units, Job 3: 3 units
- RR schedule with time quantum=3:

```
  | Job 1 |  Job 2  |  Job 3  |    Job 1    |
  0       3         6         9             30
```

- Total waiting time: 6 + 3 + 6 = 15
- Average waiting time: 5
- Total turnaround time: 30 + 6 + 9 = 45
- Average turnaround time: 15
- RR gives intermediate wait and turnaround time (compared to SJF and FCFS)

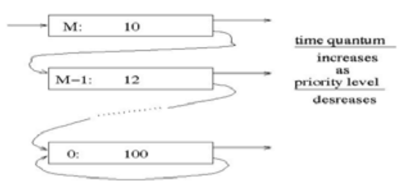
Properties of RR

- Advantages: simple, low overhead, works for interactive systems
- Disadvantages:
  - o if quantum is too small, too much time wasted in context switching
  - o if too large (i.e., longer than mean CPU burst), approaches FCFS
- Typical value: 20 – 40 msec
- **Rule of thumb:** Choose quantum so that large majority (80 – 90%) of jobs finish CPU burst in one quantum
- RR makes the assumption that all processes are equally important

HPF - Highest Priority First

- General class of algorithms ==> priority scheduling
- Each job assigned a priority which may change dynamically
- May be preemptive or non-preemptive
- Key Design Issue: how to compute priorities?

Multi-Level Feedback (FB)

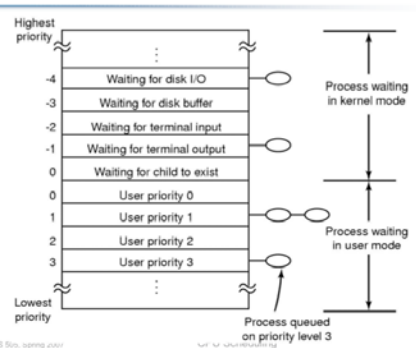


- Each priority level has a ready queue, and a time quantum
- process enters highest priority queue initially, and (next) lower queue with each timer interrupt (penalized for long CPU usage)
- bottom queue is standard Round Robin
- process in a given queue are not scheduled until all higher queues are empty

FB Discussion

- I/O-bound processes tend to congregate in higher-level queues. (Why?)
- This implies greater device utilization
- CPU-bound processes will sink deeper (lower) into the queues.
- Large quantum occasionally versus small quanta often
- Quantum in top queue should be large enough to satisfy majority of I/O-bound processes
- Can assign a process a lower priority by starting it at a lower-level queue
- Can raise priority by moving process to a higher queue, thus can use in conjunction with aging
- To adjust priority of a process changing from CPU-bound to I/O-bound, can move process to a higher queue each time it voluntarily relinquishes CPU.

UNIX Scheduler



Process Scheduling in Unix

- Based on multi-level feedback queues
- Priorities range from -64 to 63 (lower number means higher priority)
- Negative numbers reserved for processes waiting in kernel mode
  - o (that is, just woken up by interrupt handlers)
  - o (why do they have a higher priority?)
- Time quantum = 1/10 sec (empirically found to be the longest quantum that could be used without loss of the desired response for interactive jobs such as editors)
  - o short time quantum means better interactive response
  - o long time quantum means higher overall system throughput since less context switch overhead and less processor cache flush.
- Priority dynamically adjusted to reflect
  - o resource requirement (e.g., blocked awaiting an event)
  - o resource consumption (e.g., CPU time)

Unix CPU Scheduler

- Two values in the PCB
  - p_cpu: an estimate of the recent CPU use
  - p_nice: a user/OS settable weighting factor (-20..20) for flexibility; default = 0; negative increases priority; positive decreases priority
- A process' priority calculated periodically

  priority = base + p_cpu + p_nice

  and the process is moved to appropriate ready queue
- CPU utilization, p_cpu, is incremented each time the system clock ticks and the process is found to be executing.
- p_cpu is adjusted once every second (time decay)
  - Possible adjustment: divide by 2 (that is, shift right)
  - Motivation: Recent usage penalizes more than past usage
  - Precise details differ in different versions (e.g. 4.3 BSD uses current load (number of ready processes) also in the adjustment formula)

Example (exercise)

- Suppose p_nice is 0, clock ticks every 10msec, time quantum is 100msec, and p_cpu adjustment every sec
- Suppose initial base value is 4. Initially, p_cpu is 0
- Initial priority is 4.
- Suppose scheduler selects this process at some point, and it uses all of its quantum without blocking. Then, p_cpu will be 10, priority recalculated to 10, as new base is 0.
- At the end of a second, p_cpu, as well as priority, becomes 5 (more likely to scheduled)
- Suppose again scheduler picks this process, and it blocks (say, for disk read) after 30 msec. p_cpu is 8
- Process is now in waiting queue for disk transfer
- At the end of next second, p_cpu is updated to 4
- When disk transfer is complete, disk interrupt handler computes priority using a negative base value, say, -10. New priority is -6
- Process again gets scheduled, and runs for its entire time quantum. p_cpu will be updated to 14

Summary of Unix Scheduler

- Commonly used implementation with multiple priority queues
- Priority computed using 3 factors
  - PUSER used as a base (changed dynamically)
  - CPU utilization (time decayed)
  - Value specified at process creation (nice)
- Processes with short CPU bursts are favored
- Processes just woken up from blocked states are favored even more
- Weighted averaging of CPU utilization
- Details vary in different versions of Unix