CS 370: OPERATING SYSTEMS
[CPU SCHEDULING]

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Frequently asked questions from the previous class survey

- Could we record burst times in the PCB and use this to inform scheduling?
- Could a higher priority process starve?
- How is SJF implemented if we don't know burst times?

Topics covered in this lecture

- Scheduling Algorithms
  - Wrap-up of SJF
  - Priority Scheduling
  - Round robin scheduling
  - Lottery scheduling
  - Multilevel feedback queues
  - Multiprocessor/core Environments

SHORTEST JOB FIRST (SJF)

Use of SJF in long term schedulers

- Length of the process time limit
  - Used as CPU burst estimate
- Motivate users to accurately estimate time limit
  - Lower value will give faster response times
  - Too low a value?
    - Time limit exceeded error
    - Requires resubmission!

The SJF algorithm and short term schedulers

- **No way to know** the length of the next CPU burst
- So try to **predict** it
- Processes scheduled *based on predicted* CPU bursts

Prediction of CPU bursts: Make estimates based on past behavior

- t_n : Length of the n^{th} CPU burst
- τ_n : Estimate for the n^{th} CPU burst
- α : Controls weight of recent and past history
- $\tau_{n+1} = \alpha t_n + (1-\alpha)\,\tau_n$
- Burst is predicted as an exponential average of the measured lengths of previous CPU bursts

α controls the relative weight of recent and past history

- $\tau_{n+1} = \alpha t_n + (1-\alpha)\,\tau_n$
- Value of t_n contains our most recent information, while τ_n stores the past history
- $\tau_{n+1} = \alpha t_n + (1-\alpha)\,\alpha t_{n-1} + \ldots + (1-\alpha)^j\,\alpha t_{n-j} + \ldots + (1-\alpha)^{n+1}\,\alpha \tau_0$
- α is less than 1, $(1-\alpha)$ is also less than one
  - **Each successive term has less weight than its predecessor**

The choice of α in our predictive equation

- If α=1/2
  - Recent history and past history are **equally weighted**
- With α = ½; successive estimates of τ

  $t_0/2$ $t_0/4 + t_1/2$ $t_0/8 + t_1/4 + t_2/2$ $t_0/16 + t_1/8 + t_2/4 + t_3/2$
  - By the 3rd estimate, weight of what was observed at t_0 has dropped to 1/8.

An example: Predicting the length of the next CPU burst

CPU burst (t_i)		6	4	6	4	13	13	13
"Guess" (τ_i)	10	8	6	6	5	9	11	12

The choice of α in our predictive equation

- $\tau_{n+1} = \alpha t_n + (1-\alpha)\,\tau_n$
- If $\alpha=0$, $\tau_{n+1} = \tau_n$
  - Current conditions are transient
- If $\alpha=1$, $\tau_{n+1} = t_n$
  - Only most recent bursts matter
  - History is assumed to be old and irrelevant

PRIORITY SCHEDULING

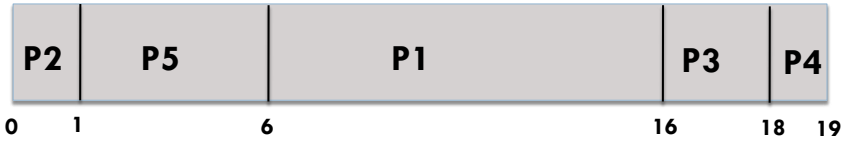
Priority Scheduling

- **Priority** associated with each process
- CPU allocated to process with **highest** priority
- Can be preemptive or nonpreemptive
  - If preemptive: Preempt CPU from a lower priority process when a higher one is ready

Depiction of priority scheduling in action

Process	Burst Time	Priority
P1	10	3
P2	1	1
P3	2	4
P4	1	5
P5	5	2

Here: Lower number means higher priority



Wait time = (6 + 0 + 16 + 18 + 1)/5 = 8.2

How priorities are set

- Internally defined priorities based on:
  - **Measured** quantities
  - Time limits, memory requirements, # of open files, ratio (averages) of I/O to CPU burst
- External priorities
  - Criteria outside the purview of the OS
  - Importance of process, $ paid for usage, politics, etc.

Issue with priority scheduling

- Can leave lower priority processes waiting indefinitely
- Perhaps apocryphal tale:
  - MIT's IBM 7094 shutdown (1973) found processes from 1967!

Coping with issues in priority scheduling: Aging

- **Gradually increase priority** of processes that wait for a long time
- Example:
  - Process starts with a priority of 127 and decrements every 15 minutes
  - Process priority becomes 0 in no more than 32 hours

Can SJF be thought of as a priority algorithm?

- Priority is **inverse** of CPU burst
- The larger the burst, the lower the priority
  - *Note*: The number we assign to represent priority levels may vary from system to system

ROUND ROBIN SCHEDULING

Round-Robin Scheduling

- Similar to FCFS scheduling
  - **Preemption** to enable switch between processes
- Ready queue is implemented as **FIFO**
  - Process Entry: PCB at *tail* of queue
  - Process chosen: From *head* of the queue
- CPU scheduler goes around ready queue
  - Allocates CPU to each process *one after the other*
    - CPU-bound up to a maximum of 1 **quantum**

Round Robin: Choosing the quantum

- Context switch is **time consuming**
  - Saving and loading registers and memory maps
  - Updating tables
  - Flushing and reloading memory cache
- What if quantum is 4 ms and context switch overhead is 1 ms?
  - 20% of CPU time thrown away in administrative overhead

Round Robin: Improving efficiency by increasing quantum

- Let's say quantum is 100 ms and context-switch is 1ms
  - Now wasted time is only 1%
- But what if 50 concurrent requests come in?
  - Each with widely varying CPU requirements
  - 1st one starts immediately, 2nd one 100 ms later, …
  - The last one may have to wait for 5 seconds!
  - A shorter quantum would have given them better service

If quantum is set longer than mean CPU burst?

- **Preemption will not happen very often**
- Most processes will perform a blocking operation before quantum runs out
- Switches happens only when process blocks and cannot continue

Quantum: Summarizing the possibilities

- Too short?
  - Too *many* context switches
  - Lowers CPU efficiency
- Too long?
  - *Poor* responses to interactive requests

A round-robin analogy

- Hyperkinetic student studying for multiple exams simultaneously
  - If you switch between paragraphs of different textbooks? [Quantum is too short]
    - You won't get much done
  - If you never switch? [Quantum is too long]
    - You never get around to studying for some of the courses

LOTTERY SCHEDULING

Lottery scheduling

- Give processes **lottery tickets** for various system resources
  - E.g. CPU time
- When a scheduling decision has to be made
  - Lottery ticket is *chosen at random*
  - Process holding **ticket gets** the resource

All processes are equal, but some processes are more equal than others

- More important processes are given **extra tickets**
  - Increase their odds of winning
- Let's say there are 100 outstanding tickets
  - 1 process holds 20 of these
  - Has 20% chance of winning each lottery
- A process holding a fraction f of tickets
  - Will get about a fraction f of the resource

Lottery Scheduling: Properties [1/2]

- Highly **responsive**
  - Chance of winning is proportional to tickets
- Cooperating processes may **exchange** tickets
  - Process **A** sends request to **B**, and then hands **B** all its tickets for a faster response
- Avoids starvation
  - Each process holds at least one ticket …. Is guaranteed to have a non-zero probability of being scheduled

Lottery Scheduling: Properties [2/2]

- Solves problems that are *difficult to handle* in other scheduling algorithms
- E.g. video server that is managing processes that feed video frames to clients
  - Clients need frames at 10, 20, and 25 frames/sec
  - Allocate processes 10, 20 and 25 tickets
    - CPU divided into approximately 10:20:25

Most commercial OS including Windows, MacOS, and Linux use this scheduling algorithm

MULTI-LEVEL FEEDBACK QUEUES (MFQ)

MFQ is designed to achieve several simultaneous goals

- **Responsiveness**: Run short tasks quickly as in SJF
- **Low Overhead**: Minimize number of preemptions, as in FIFO
  - Minimize time spent making scheduling decisions
- **Starvation-Freedom**
  - All tasks should make progress, as in Round Robin
- **Background tasks**
  - Defer system maintenance tasks, such as defragmentation, so they do not interfere with user work
- **Fairness**

Does MFQ achieve all of these?

- As with any real system that must ***balance*** several, conflicting goals …
  - MFQ does not perfectly achieve any of these goals
- MFQ is intended to be a **reasonable compromise** in most real-world cases

MFQ

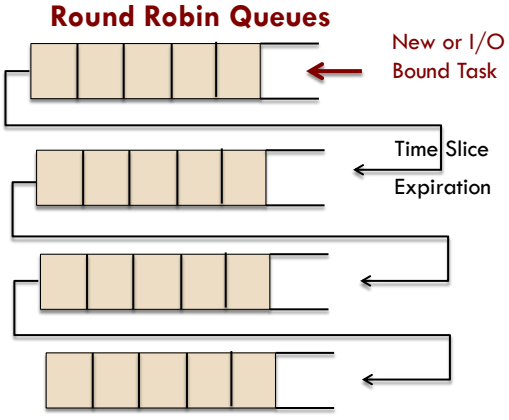
- Extension of round robin
- Instead of only a single queue, MFQ has **multiple round robin queues**
  - Each queue has a **different** *priority level* and *time quanta*

Tasks and priorities

- Tasks at a higher priority **preempt** lower priority tasks
- Tasks at the same priority level are scheduled in **round robin** fashion
- Higher priority tasks have **shorter** time quanta than lower priority tasks

MFQ: Example with 4 priority levels

Priority	Time Slice (ms)
1	10
2	20
3	40
4	60



Task movements and priority

- Tasks are moved between priority levels to favor short tasks over long ones
- Every time a task uses up its time quantum?
  - It **drops** a priority level
- Every time task yields the processor because it is waiting on I/O?
  - It **stays** at the same level, or is **bumped up** a level
- If the task completes … it leaves

Impact on CPU and I/O bound processes

- A **new** CPU bound process will start as *high priority*
  - But it will quickly exhaust its time quantum and fall to the next lower priority, and then the next …
- An I/O bound process with a modest amount of computing
  - Will always be **scheduled quickly**
    - Also, keeps the disk busy
- Compute bound tasks run with a long time quantum to minimize switching overhead while sharing processor

What about starvation and fairness?

- If there are too many I/O bound tasks, the compute bound tasks may receive no time on the processor
- MFQ scheduler **monitors every process** to ensure that it is receiving its fair share
  - For e.g. at each level, Linux actually maintains two queues
    - Tasks whose processes have already reached their fair share are only scheduled if other processes at the same level have also received their fair share
- Periodically, processes not receiving their fair share have their tasks increased in priority
  - Tasks that receive more than their fair share have their priority reduced

Adjusting priority addresses strategic behavior

- From a selfish point of view, a task can keep its priority high by doing a short I/O request just before its quantum expires
  - With MFQ this will be detected, and its priority reduced to its fair level

IDLE THREADS

Dispatcher in Windows XP

- Use a **queue** for each scheduling priority
- **Traverse** the queues from highest to lowest
  - *Until* it finds a thread that is ready to run
- If no ready thread is found?
  - Dispatcher will execute a special thread: **idle thread**

Idle thread in Windows

- Primary purpose is to **eliminate a special case**
  - Cases when no threads are runnable or ready
  - Idle threads are always in a *ready* state
    - If not already running
- Scheduler can always find a thread to execute
- If there are other eligible threads?
  - Scheduler will never select the idle thread

Idle threads in Windows

- Windows thread priorities go from 0-31
  - Idle thread priority can be thought of as -1
- Threads in the system idle process can also implement CPU power saving
  - On x86 processors, run a loop of **halt** instructions
  - Causes CPU to **turn off internal components**
    - Until an interrupt request arrives
  - Recent versions also **reduce the CPU clock speed**

Time consumed by the idle process

- It may seem that the idle process is monopolizing the CPU
  - It is merely acting as a *placeholder during free time*
  - Proof that no other process wants that CPU time

MULTIPROCESSOR/CORE ENVIRONMENTS

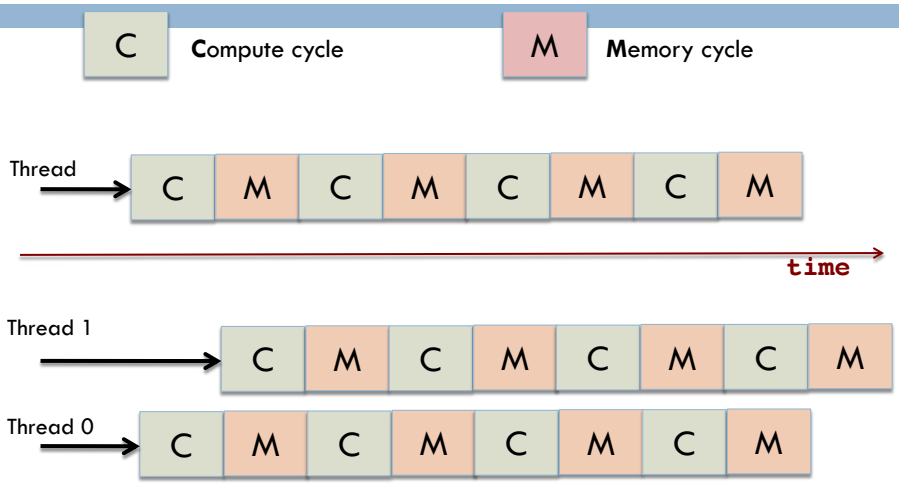
Load balancing: Migration based approaches

- Push migration
  - Specific task periodically checks for *imbalance*
  - Balances load by **pushing** processes from overloaded to less-busy processors.
- Pull migration
  - Idle processor pulls a waiting task from busy processor
- Schemes **not mutually exclusive**: used in parallel
  - Linux: Runs a load-balancing algorithm
    - Every 200 ms (**PUSH** migration)
    - When processor run-queue is empty (**PULL** migration)

Multicore processors place multiple processor cores on same physical chip

- Each core has its own register set
  - Appears to the OS as a separate physical processor
- Recent designs implement 2 or more hardware threads per core
  - If there is a memory stall (due to cache miss) on one thread, **switch** to another hardware thread

Coping with memory stalls



Multithreading a processor

- **Coarse** grained
  - Thread executes on processor till a memory stall
  - Switch to another thread
- Switching between threads
  - *Flush* the instruction pipeline
  - *Refill* pipeline as new thread executes
- **Finer** grained (or interleaved)
  - Switch between threads at the boundary of an instruction cycle
  - Design includes logic for thread switching: overheads are low

Tiered scheduling on multicore processors

- First-level: OS
  - OS chooses which software thread to run on each hardware thread
- Second-level: Core
  - Decides which hardware thread to run
- UltraSPARC T1
  - 8 cores, and 4 hardware threads/core
  - Round robin to schedule hardware threads on core

The contents of this slide-set are based on the following references

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 6]
- *Andrew S Tanenbaum and Herbert Bos. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620.* [Chapter 2]
- *Thomas Anderson and Michael Dahlin. Operating Systems Principles and Practice. 2nd Edition. ISBN: 978-0985673529.* [Chapter 7]