Lecture 7:

Processes II: CPU Scheduling

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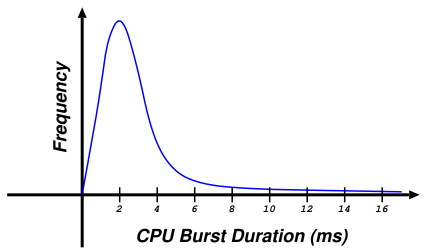
Lecture 7: Friday 19th October 2001

Today's Lecture

Today we'll cover:

- How do we schedule the CPU?
  - Criteria, and
  - Various strategies.

CPU-I/O Burst Cycle



- **CPU-I/O Burst Cycle**: process execution consists of a **cycle** of CPU execution and I/O wait.
- Processes can be described as either:
  1. I/O-bound: spends more time doing I/O than computation; has many short CPU bursts.
  2. CPU-bound: spends more time doing computations; has few very long CPU bursts.
- Observe most processes execute for at most a few milliseconds before blocking

⇒ need multiprogramming to obtain decent overall CPU utilization.

CPU Scheduler

Recall: CPU scheduler selects one of the ready processes and allocates the CPU to it.

- There are a number of occasions when we can/must choose a new process to run:
  1. a running process blocks (`running` → `blocked`)
  2. a timer expires (`running` → `ready`)
  3. a waiting process unblocks (`blocked` → `ready`)
  4. a process terminates (`running` → `exit`)
- If only make scheduling decision under 1, 4 ⇒ have a **non-preemptive** scheduler:

✔ simple to implement
✘ open to denial of service
  – e.g. Windows 3.11, early MacOS.

- Otherwise the scheduler is **preemptive**.

✔ solves denial of service problem
✘ more complicated to implement
✘ introduces concurrency problems. . .

Idle system

What do we do if there is no ready process?

- halt processor (until interrupt arrives)
  - ✔ saves power (and heat!)
  - ✔ increases processor lifetime
  - ✘ might take too long to stop and start.
- busy wait in scheduler
  - ✔ quick response time
  - ✘ ugly, useless
- invent idle process, always available to run
  - ✔ gives uniform structure
  - ✔ could use it to run checks
  - ✘ uses some memory
  - ✘ can slow interrupt response

In general there is a trade-off between responsiveness and usefulness.

Scheduling Criteria

A variety of metrics may be used:

1. CPU utilization: the fraction of the time the CPU is being used (and not for idle process!)
2. Throughput: # of processes that complete their execution per time unit.
3. Turnaround time: amount of time to execute a particular process.
4. Waiting time: amount of time a process has been waiting in the ready queue.
5. Response time: amount of time it takes from when a request was submitted until the first response is produced (in time-sharing systems)

Sensible scheduling strategies might be:

- Maximize throughput or CPU utilization
- Minimize average turnaround time, waiting time or response time.

Also need to worry about **fairness** and **liveness**.

First-Come First-Served Scheduling

- FCFS depends on order processes arrive, e.g.

Process	Burst Time
P_1	25
P_2	4
P_3	7

- If processes arrive in the order P_1, P_2, P_3:

  - Waiting time for P_1=0; P_2=25; P_3=29;
  - Average waiting time: $(0 + 25 + 29)/3 = 18$.

- If processes arrive in the order P_3, P_2, P_1:

  - Waiting time for P_1=11; P_2=7; P_3=0;
  - Average waiting time: $(11 + 7 + 0)/3 = 6$.
  - i.e. three times as good!

- First case poor due to **convoy effect**.

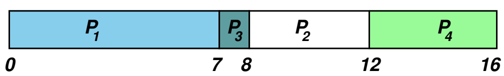
SJF Scheduling

Intuition from FCFS leads us to **shortest job first** (SJF) scheduling.

- Associate with each process the length of its next CPU burst.
- Use these lengths to schedule the process with the shortest time (FCFS can be used to break ties).

For example:

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4



- Waiting time for P_1=0; P_2=6; P_3=3; P_4=7;
- Average waiting time: $(0 + 6 + 3 + 7)/4 = 4$.

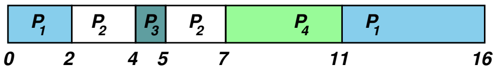
SJF is optimal in that it gives the minimum average waiting time for a given set of processes.

SRTF Scheduling

- SRTF = Shortest Remaining-Time First.
- Just a preemptive version of SJF.
- i.e. if a new process arrives with a CPU burst length less than the *remaining time* of the current executing process, preempt.

For example:

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4



- Waiting time for P_1=9; P_2=1; P_3=0; P_4=2;
- Average waiting time: $(9 + 1 + 0 + 2)/4 = 3$.

What are the problems here?

Predicting Burst Lengths

- For both SJF and SRTF require the next "burst length" for each process ⇒ need to estimate it.
- Can be done by using the length of previous CPU bursts, using exponential averaging:
  1. t_n = actual length of n^{th} CPU burst.
  2. τ_{n+1} = predicted value for next CPU burst.
  3. For $\alpha, 0 \leq \alpha \leq 1$ define:

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

- If we expand the formula we get:

$$\tau_{n+1} = \alpha t_n + \ldots + (1-\alpha)^j \alpha t_{n-j} + \ldots + (1-\alpha)^{n+1}\tau_0$$

  where τ_0 is some constant.
- Choose value of α according to our belief about the system, e.g. if we believe history irrelevant, choose $\alpha \approx 1$ and then get $\tau_{n+1} \approx t_n$.
- In general an exponential averaging scheme is a good predictor if the variance is small.

Round Robin Scheduling

Define a small fixed unit of time called a **quantum** (or **time-slice**), typically 10-100 milliseconds. Then:

- Process at the front of the ready queue is allocated the CPU for (up to) one quantum.
- When the time has elapsed, the process is preempted and appended to the ready queue.

Round robin has some nice properties:

- Fair: if there are n processes in the ready queue and the time quantum is q, then each process gets $1/n^{th}$ of the CPU.
- Live: no process waits more than $(n - 1)q$ time units before receiving a CPU allocation.
- Typically get higher average turnaround time than SRTF, but better average *response time*.

But tricky choosing correct size quantum:

- q too large ⇒ FCFS/FIFO
- q too small ⇒ context switch overhead too high.

Static Priority Scheduling

- Associate an (integer) priority with each process
- For example:

0	system internal processes
1	interactive processes (staff)
2	interactive processes (students)
3	batch processes.

- Then allocate CPU to the highest priority process:
  - 'highest priority' typically means smallest integer
  - get preemptive and non-preemptive variants.
- e.g. SJF is a priority scheduling algorithm where priority is the predicted next CPU burst time.
- Problem: how to resolve ties?
  - round robin with time-slicing
  - allocate quantum to each process in turn.
  - Problem: biased towards CPU intensive jobs.
    - ∗ per-process quantum based on usage?
    - ∗ ignore?
- Problem: starvation. . .

Dynamic Priority Scheduling

Use same scheduling algorithm, but allow priorities to change over time, e.g.

1. Simple aging:
   - processes have a (static) *base priority* and a dynamic *effective priority*.
   - if process starved for k seconds, increment effective priority.
   - once process runs, reset effective priority.
2. Computed priority:
   - first used in Dijkstra's THE
   - time slots: $\ldots, t, t+1, \ldots$
   - in each time slot t, measure the CPU usage of process j: u^j
   - priority for process j in slot $t+1$:

$$\boxed{p^j_{t+1} = f(u^j_t, p^j_t, u^j_{t-1}, p^j_{t-1}, \ldots)}$$

   - e.g. $p^j_{t+1} = p^j_t/2 + ku^j_t$
   - penalises CPU bound $\rightarrow$ supports I/O bound.

Today such computation considered acceptable. . .

Summary

You should now understand:

- What a CPU scheduler does,
- Criteria for scheduling,
- Predicting burst lengths,
- Various strategies:
  1. First-come first-served,
  2. Shortest job first,
  3. Shortest remaining-time first,
  4. Round-robin,
  5. Static and dynamic priorities.

Next lecture: Memory Management

Background Reading:

- Silberschatz et al.: – Chapter 6