Scheduling

Scheduling levels

- **Long-term scheduling**. Selects which jobs shall be allowed to enter the system. Only used in batch systems.
- **Medium-term scheduling.** Performs swapin-swapout operations if the processes do not fit in the primary memory.
- **Short-term scheduling.** Determines which of the processes in the ready queue is selected for execution. The process switch is performed by a *dispatcher*.

Scheduling

Decision to switch the running process can take place under the following circumstances:

1. When a process switches from the *running* state to the *waiting* state.
2. When a process switches from the *running* state to the *ready* state.
3. When a process switches from the *waiting* state to the *ready* state.
4. When a process terminates

When scheduling takes place only under circumstances 1 and 4, we say that the scheduling scheme is **non-preemptive**; otherwise it is **preemptive**.

Scheduling

Possible goals for a scheduling algorithm.

- Be fair.
- Maximize throughput.
- Be predictable.
- Give short response time to interactive processes.
- Avoid starvation.
- Enforce priorities.
- Degrade gracefully under heavy load.

Several of the goals are in conflict with each other.

Scheduling

Criteria for comparing scheduling algorithms.

- **CPU utilization.** We want to keep the CPU as busy as possible.
- **Throughput.** The number of processes completed per time unit.
- **Turnaround time.** Measured from the first time a job enters the system until it is completed. Should be as short as possible. Primarily used for batch systems.
- **Waiting time.** The sum of a the time periods a process spends in the ready queue.
- **Response time.** The time from an event occurs to the first reaction from the system. For example the time from a button is pressed until the character is echoed at the display.

FCFS - First Come First Served

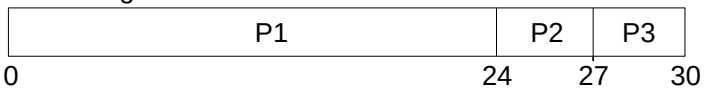
Run the processes in the order they arrives to the ready queue.

Non-preemptive scheduling

Example:

Process	Burst time
P_1	24
P_2	3
P_3	3

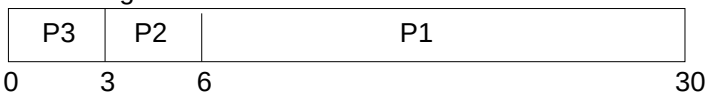
Gantt diagram:



Average waiting time: (0+24+27)/3=17

Different arrival sequence: P3, P2, P1

Gantt diagram:



Average waiting time: (6+3+0)/3=3

SJF - Shortest Job First

- The process with the shortest estimated time to completion is run first.
- Optimal in the sense that it gives the minimum average waiting time for a given set of processes.
- The real problem with SJF is how to know the execution time for the processes.
- In batch systems it is possible to demand users to specify the run time.
- The original version of SJF is non-preemptive.
- A preemptive version of SJF is called Shortest-Remaining-Time-First (SRTF).
- With SRTF the length of the next CPU burst is associated with each process. The process with the shortest next CPU burst is scheduled first.
- The length of the CPU bursts cannot be known, but may be predicted as an exponential average of measured lengths of previous CPU bursts.
- The method may give raise to starvation.

Priority scheduling

A priority number (integer) is associated with each process.

The CPU is allocated to the process with the highest priority.

Two methods:

- **Static priorities**. Each process is assigned a fixed priority that is never changed. May create starvation for low priority processes.
- **Dynamic priorities.** Priorities are dynamically recalculated by the system. Usually a process that have been waiting have it's priority increased. This is called *aging*.

Round Robin Scheduling

Circular queue of runnable processes.

- Every process may execute until it:
  - → Terminates
  - → Becomes waiting due to a blocking operation.
  - → Is interrupted by a clock interrupt.
- Then the execution continues with the next process in the queue.
- All processes have the same priority.

Every time a process is started it may execute no more than one *time quantum*.

- How long should a *time quantum* be?
- With n processes in the ready queue and quantum size q, the maximum response time will be (n-1)q.
- For very big q, the method degenerates to FCFS.
- If the *time quantum* is the same as the time to switch processes, all the CPU time will be used for process switching.
- A rule of thumb is that 80 percent of the CPU bursts should be shorter than the time quantum.

Multilevel Feedback Queues

- Several scheduling queues with different priority are used.
- Then a new process arrives, it is placed the in the highest prioritized queue.
- If the process becomes waiting within one time quanta, it stays in same queue otherwise it is moved down one level.
- A process that does not use the whole of it's time quanta, may be moved up one level.
- Lower priority queues have longer time quanta than the higher priority queues, but processes in these queues only execute if the higher priority queues are empty.
- The lowest prioritized queue is driven according to round-robin.

Multiprocessor/Multicore Hardware

- Several CPU chips shares memory using an external bus
  - → In most cases each CPU has a private high speed cache
- Multicore processors have several CPUs at the same chip
  - → Each processor has private high speed L1 cache
  - → Typically onchip shared L2 cache
  - → Main memory on external bus
- Multithreaded cores
  - → A physical CPU core may have two logical cores
  - → Intel calls this hyperthreading. In this case the L1 cache is shared among the logical cores

Multiprocessor Scheduling

- Asymmetric multiprocessing (Master slave architecture)
  - → Master runs operating system. Slaves run user mode code
  - → Disadvantages:
    - ✯ Master can become a performance bottleneck
    - ✯ Failure of master brings down entire system
- Symmetric multiprocessing (SMP)
  - → Operating system can execute on any processor
  - → Each processor does self-scheduling

Processor Affinity

Recall:

- Processors share main memory
- But have local cache memories
- Recently accessed data populate the caches in order to speed up memory accesses

Processor affinity:

- Most SMP systems try to keep a process running on the same processor
- Quicker to start process on same processor as last time since the cache may already contain needed data

Hard affinity:

Some systems -such as Linux- have a system call to specify that a process shall execute on a specific processor

Assignment of Processes to Processors

Per-processor ready queues:

- Each processor has its own ready queue
  - → Processor affinity kept
    - ✯ A processor could be idle while another processor has a backlog
    - ✯ Explicit load-balancing needed

Global ready queue:

- All processors share a global ready-queue
  - → Ready-queue can become a bottleneck
    - ✯ Task migration not cheap (difficult to enforce processor affinity)
    - ✯ Automatic load-balancing

Load balancing

On SMP systems the load should preferably be divided equally between the processors.

Two methods:

push_migration A surveillance task periodically checks the load on each processor and moves processes from processors with high load to processors with low load if needed.

Pull_migration A processor with empty run queue, tries to fetch a process from another processor.

Linux Scheduler

With Linux kernel version 2.6 a new O(1) scheduler with improved SMP support was introduced.

The ULE scheduler for FreeBSD is built on the same principles as the Linux O(1) scheduler.

Goals:

- Adapted for SMP (Symmetric Multi Processing)
- Give O(1) scheduling. This means that the scheduling time is independent of the number of processes in the system.
- Processor affinity on SMP.
- Tries to give interactive processes high priority.
- Load balancing on SMP.

Linux - Implementation1

- The scheduler uses 140 priority levels. Levels 0-99 are real time priorities and levels 100-140 normal priorities.
- Each processor is independently scheduled and has it's own run queue. Each run queue has two arrays, *active* and *expired*, that points to the scheduling lists for each of the 140 priorities.
- There exists no further priority subdivision within the scheduling lists. All processes on same priority level in the active array are executed in round robin order.
- A process is allocated a certain queue until it blocks or it's time quantum runs out. Then the time quantum runs out, the process is moved to the *expired* array with a recalculated priority.
- Real time processes are allocated a static priority that cannot be changed.
- Normal processes are allocated priority based on nice value and the degree of *interactivity*.
- Processes with high priority are allocated longer time quanta than lower prioritized processes.
- Processes are scheduled in priority order from the *active* array until it becomes empty, then the *expired* and the *active* arrays change place.

Linux - Implementation 2

- A process' interactivity is based on how much time it spends in *sleep* state compared to *running* state.
- Every time a process is awaken, it's *sleep_avg* is increased with the time it has been sleeping.
- At every clock interrupt, the *sleep_avg* for the running process is decreased.
- A process is more interactive if it has a high *sleep_avg*.

Linux Load balancing

Linux uses both **push_migration** and **pull_migration**.

- A load balancing task is executed with an interval of 200 ms.
- If a processor has an empty run queue, processes are fetched from another processor.

Load balancing may be in conflict with processor affinity.

In order not to disturb the caches to much, Linux avoids moving processes with large amounts of cached data.