Scheduling policy

Reference: ULK3e 7.1

Goals

- fast process response time
- good throughput for background jobs
- avoidance of process starvation
- reconciliation of needs of low- and high-priority processes

Scheduling policy

Reference: ULK2e 11.1

Scheduling policy is based on a combination of

- Multi-level queues
  - different queues for *real-time* and *conventional* processes
- Priority scheduling
  - low numbers $\Rightarrow$ high priority
  - priorities are dynamic (change with time)
    - priority of waiting process increases
    - priority of processes running for a long time decreases

implicitly uses aging

- Round robin scheduling
  - process preempted on expiry of quantum
  - but duration of quantum typically varies from process to process
- FCFS: only for breaking ties

Scheduling policy (contd.)

Scheduling policy is preemptive

- When a process enters the TASK_RUNNING state, kernel checks priority
- If priority of new task is greater than priority of current process, scheduler is invoked

2.4 Scheduler

Priorities

- Static priority (`rt_priority`)
  - assigned to real-time processes only
  - ranges from 1 to 99; 0 for conventional processes
  - never changed by the scheduler
- Dynamic priority
  - applies only to conventional processes
  - dynamic priority of conventional process is always less than static priority of real-time process

Scheduling algorithm

Reference: ULK2e 11.2

- CPU time is divided into *epochs*
- In each epoch, every process gets a specified time quantum
  - quantum = maximum CPU time assigned to the process in that epoch
  - duration of quantum computed when epoch begins
  - different processes may have different time quantum durations
  - when process forks, remainder of parent's quantum is split / shared between parent and child
- Epoch ends when all *runnable* processes have exhausted their quanta
- At end of epoch, scheduler algorithm recomputes the time-quantum durations of *all processes*; new epoch begins

Implementation

Scheduling related fields in *proc* structure

- `counter`: contains quantum alloted to a process when new epoch begins
  - decremented for current process by 1 at every tick
- `nice`: contains values ranging between -20 and +19
  - negative values $\Rightarrow$ high priority processes
  - positive values $\Rightarrow$ low priority processes
  - 0 (default value) $\Rightarrow$ normal processes.

Scheduling algorithm

- Process selection:

```
c = -1000;
list_for_each(tmp, &runqueue_head) {
   p = list_entry(tmp, struct task_struct, run_list);
   if (p->cpus_runnable & p->cpus_allowed & (1 << this_cpu)) {
       int weight = goodness(p, this_cpu, prev->active_mm);
       if (weight > c)
           c = weight, next = p; // break ties using FCFS
   }
}
```

- Best candidate may be the current process
- `c == 0` $\Rightarrow$ new epoch begins

```
for_each_task(p) // all EXISTING processes
    p->counter = (p->counter >> 1) + (20 - p->nice) / 4 + 1;
```

goodness()

- **Case I:**
  - `p` is a conventional process that has exhausted its quantum (`p->counter` is zero)
  - `weight = 0`
- **Case II:**
  - `p` is a conventional process that has not exhausted its quantum
  - ```
    weight = p->counter + 20 - p->nice;
    if (p->processor == this_cpu) weight +=15;
    if (p->mm == this_mm || !p->mm) weight += 1;
    /* 2 <= weight <= 77 */
    ```
- **Case III:**
  - `p` is a real-time process
  - `weight = p->counter + 1000 // weight >= 1000`
    ```

Limitations

Reference: ULK2e 11.2.3

- Scalability: if # of existing/runnable processes is large
  - inefficient to recompute all dynamic priorities
  - I/O bound processes are boosted only at the end of an epoch $\Rightarrow$ interactive applications have longer response time if number of runnable processes is large
- I/O-bound process boosting strategy:
  - batch programs with almost no user interaction may be I/O-bound e.g. database search engine, network application that collects data from a remote host on a slow link

2.6 Scheduler

Ingredients

- Static priority: inherited from parent
- Dynamic priority: function of
  - static priority
  - average sleep time
- Nature of process: interactive or batch

Priorities

Reference: ULK3e 7.2

- Static priority (`static_prio`)
  - low value $\Rightarrow$ high priority
  - 0 – 99: real-time processes
  - 100 – 139: conventional process
  - default value is 120
  - may be changed via `nice()`
  - new process inherits static priority of its parent
- Base time quantum
  - time (ms) allocated to a process when it has exhausted its previous time quantum

```
if (static_prio < 120) base = (140-static_prio) * 20;
else if (static_prio >= 120) base = (140-static_prio)*5;
```

Priorities

- "Average" sleep time: depends on
  - whether process is sleeping in `TASK_INTERRUPTIBLE` state
  - whether process is sleeping in `TASK_UNINTERRUPTIBLE` state
  - decreases while a process is running
  - maximum value = 1 second
- Dynamic priority (`prio`)
  - Used by scheduler when selecting new process to run
  - `prio = MAX(100, MIN(static_prio - bonus + 5, 139))` where `bonus = MIN(sleep_avg / 100, 10)`

roughly, user input

roughly, disk I/O

interactive tasks receive a prio bonus
CPU bound tasks receive a prio penalty

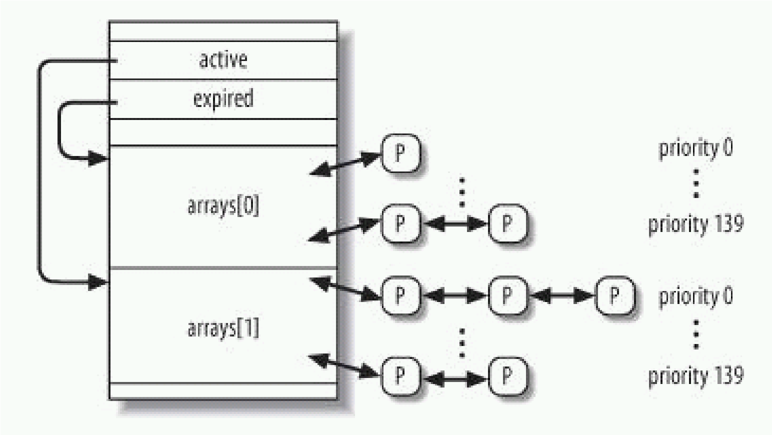
Active vs. expired processes

- Active processes: runnable processes that have not yet exhausted their time quantum
- Expired processes: runnable processes that have exhausted their time quantum
- Time quantum is recalculated on expiry (cf. base time quantum)
- Active <u>batch</u> processes that finish time quantum $\rightarrow$ expire
- Active <u>interactive</u> processes that finish time quantum:
  - if the eldest expired process has already waited for a long time, or if an expired process has higher static priority than the interactive process $\rightarrow$ expire
  - otherwise, time quantum is refilled and process remains in the set of active processes
- Process is interactive if

```
bonus - 5 >= static_prio / 4 - 28
```

Data structures

Reference: ULK3e 7.3



- Bitmap keeps track of which process lists are non-empty

scheduler_tick()

- Invoked once every tick
- Steps
  1. Decrease the ticks left in the allocated time of the process. (`p->counter` (2.4), or `p->time_slice` (2.6))
  2. Update dynamic priority using `sleep_avg`.
  3. If necessary, refill the time allocation for the process with the base quantum.
  4. Insert process in expired queue / active queue based on
     (a) whether the task is interactive,
     (b) whether the expired tasks are starving,
     (c) relative priority of the process w.r.t. expired processes.

Real-time processes

Preemptible kernel 2.6

- Non-premptible kernel (e.g., 2.4): scheduler can only interrupt process running in user mode
  $\Rightarrow$ ready to run high-priority process may be blocked for long periods of time by a low-priority process inside a slow system call
- Pre-emptible kernel: scheduler can interrupt *all* processes

Scheduling classes

- `SCHED_FIFO`
  1. Pick highest priority `SCHED_FIFO` queue that is non-empty.
  2. Schedule first process on this queue.
  3. Preempted only if higher priority real-time process becomes runnable.
- `SCHED_RR`: process is preempted on expiry of time quantum if there are other ready processes with same priority
- `SCHED_NORMAL` or `SCHED_OTHER`: conventional processes
- May be set using `sched_setscheduler()` system call, or from command line using `chrt`