Scheduling in Kernel 2.6

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Agenda

- Scheduling
  - Process Scheduling
    - O(1) scheduler – design, performance
    - Pre-emption
  - I/O Scheduling
    - Dealine I/O scheduler
    - Anticipatory I/O scheduler
    - Comparison

Considerations in Scheduler design

- Fairness
  - Prevent starvation of tasks
- Scheduling latency
  - Reduction in delay between a task waking up and actually running
  - Time taken for the scheduler decisions
- Interrupt latency
  - Delay in processing h/w interrupts
- Scheduler decisions

Process Scheduler

- Goals
  - Good interactive performance during high load
  - Fairness
  - Priorities
  - SMP efficiency
  - SMP affinity
    - Issues of random bouncing taken care
    - No more 'timeslice squeeze'
  - RT Scheduling

(From /usr/src/linux-2.6.x/Documentation/sched-design.txt)

Goals (contd ....)

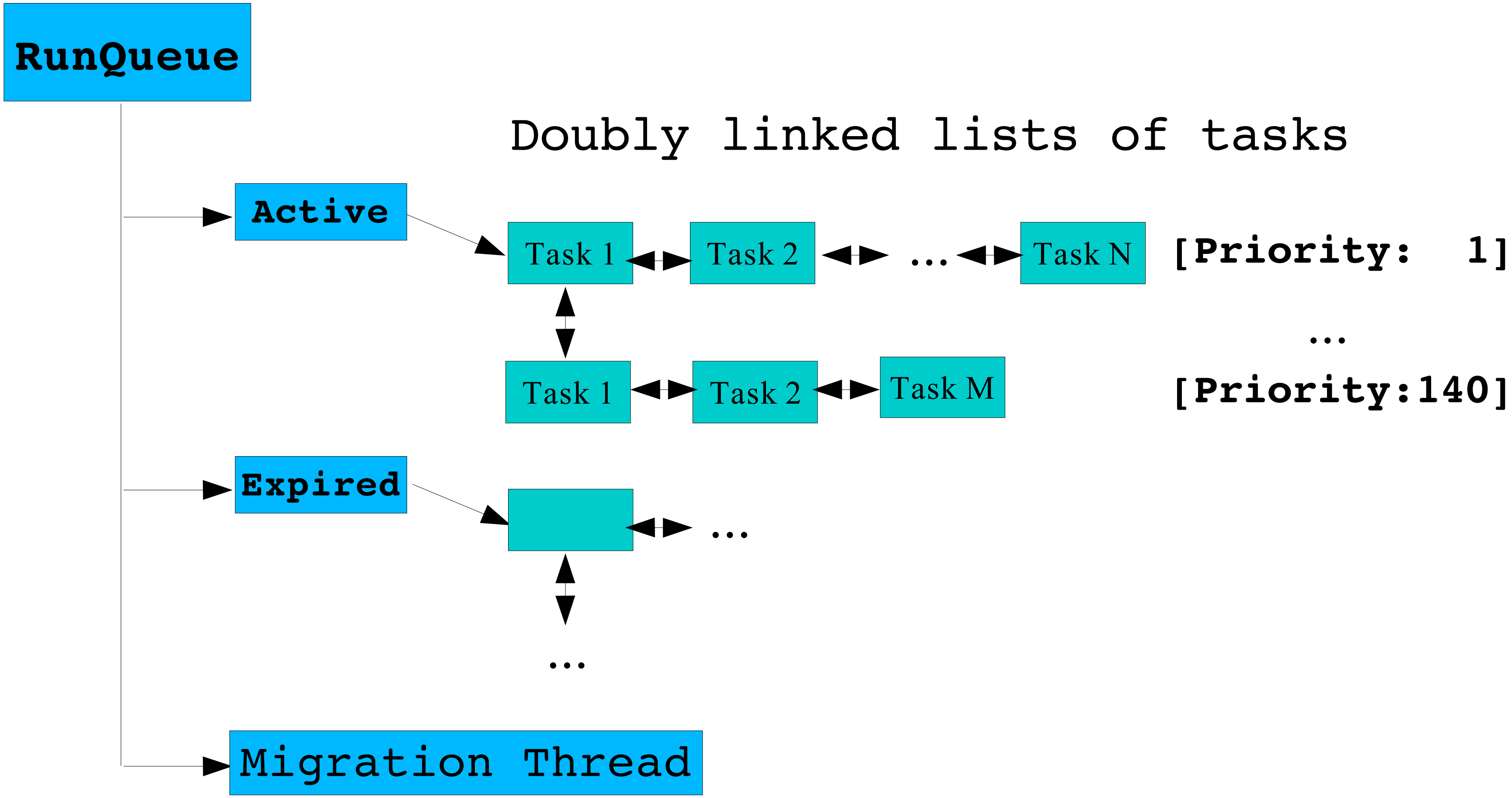
- Full O(1) scheduling
  - Great shift away from O(n) scheduler
- Perfect SMP scalability
  - Per CPU runqueues and locks
  - No global lock/runqueue
  - All operations like wakeup, schedule, context-switch etc. are in parallel
- Batch scheduling (bigger timeslices, RR)
- No scheduling storms
- O(1) RT scheduling

Design

- 140 priority levels
  - The lower the value, higher is the priority
  - Eg : Priority level 110 will have a higher priority than 130.
- Two priority-ordered 'priority-arrays' per CPU
  - 'Active' array : tasks which have timeslices left
  - 'Expired' Array : tasks which have run
  - Both accessed through pointers from per-CPU runqueue
- They are switched via a simple pointer swap

Per-CPU runqueue

Each CPU on the system has it's own RunQueue



From kernel/sched.c

O(1) Algorithm (Constant time algorithm)

- The highest priority level, with at-least ONE task in it, is selected
  - This takes a fixed time (say `t1`)
- The first task (head of the doubly-linked list) in this priority level is allowed to run
  - This takes a fixed time (say `t2`)
- Total time taken for selecting a new process is
  - `t = t1 + t2` (Fixed)
- The time taken for selecting a new process will be fixed (constant time irrespective of number of tasks)
- Deterministic algorithm !!

2.6 v/s 2.4

Kernel 2.4 had

- A Global runqueue.
  - All CPUs had to wait for other CPUs to finish execution.
- An O(n) scheduler.
  - In 2.4, the scheduler used to go through the entire “ global runqueue” to determine the next task to be run.
  - This was an O(n) algorithm where 'n' is the number of processes. The time taken was proportional to the number of active processes in the system.
- This lead to large performance hits during heavy workloads.

Scheduling policies in 2.6

- 140 Priority levels
  - 1-100 : RT prio (MAX_RT_PRIO = 100)
  - 101-140 : User task Prio (MAX_PRIO = 140)
- Three different scheduling policies
  - One for normal tasks
  - Two for Real time tasks
- Normal tasks
  - Each task assigned a "Nice" value
  - PRIO = MAX_RT_PRIO + NICE + 20
  - Assigned a time slice
  - Tasks at the same prio are round-robined.
    - Ensures Priority + Fairness

Policies (contd ...)

- RT tasks (Static priority)
  - FIFO RT tasks
    - Run until they relinquish the CPU voluntarily
    - Priority levels maintained
    - Not pre-empted !!
  - RR RT tasks
    - Assigned a timeslice and run till the timeslice is exhausted.
    - Once all RR tasks of a given prio level exhaust their timeslices, their timeslices are refilled and they continue running.
    - Prio levels are maintained
- The above can be unfair !! - Sane design expected !!

Interactivity estimator

- Dynamically scales a tasks priority based on it's interactivity
- Interactive tasks receive a prio bonus [-5]
  - Hence a larger timeslice
- CPU bound tasks receive a prio penalty [+5]
- Interactivity estimated using a running sleep average.
  - Interactive tasks are I/O bound. They wait for events to occur.
  - Sleeping tasks are I/O bound or interactive !!
  - Actual bonus/penalty is determined by comparing the sleep average against a constant maximum sleep average.
- Does not apply to RT tasks

Recalculation of priorities

When a task finishes it's timeslice :

- It's interactivity is estimated
- Interactive tasks can be inserted into the 'Active' array again.
- Else, priority is recalculated
- Inserted into the NEW priority level in the 'Expired' array.

Re-inserting interactive tasks

- To avoid delays, interactive tasks may be re-inserted into the 'active' array after their timeslice has expired.
- Done only if tasks in the 'expired' array have run recently.
  - Done to prevent starvation of tasks
- Decision to re-insert depends on the task's priority level.

Finegrained timeslice distribution

- Priority is recalculated only after expiring a timeslice.
- Interactive tasks may become non-interactive during their LARGE timeslices, thus starving other processes.
- To prevent this, time-slices are divided into chunks of 20ms.
- A task of equal priority may preempt the running task every 20ms.
- The preempted task is requeued and is round-robined in it's priority level.
- Also, priority recalculation happens every 20ms.

For programmers

From `/usr/src/linux-2.6.x/kernel/sched.c`

- `void schedule()`
  - The main scheduling function.
  - Upon return, the highest priority process will be active
- Data
  - `struct runqueue()`
    - The main per-CPU runqueue data structure
  - `struct task_struct()`
    - The main per-process data structure

For programmers (contd....)

Process Control methods

- `void set_user_nice ( ... )`
  - Sets the nice value of task p to given value
- `int setscheduler( ... )`
  - Sets the scheduling policy and parameters for a given pid
- `rt_task( pid )`
  - Returns true if pid is real-time, false if not.
- `yield()`
  - Place the current process at the end of the runqueue and call schedule().

Handling SMP (multiple CPUs)

- A run-queue per CPU
  - Each CPU handles it's own processes and do not have to wait till other CPU tasks finish their timeslices.
- A 'migration' thread runs for every CPU.
- `void load_balance()`
  - This function call attempts to pull tasks from one CPU to another to balance CPU usage if needed.
  - Called
    - Explicitly if runqueues are inbalanced
    - Periodically by the timer tick
- Processes can be made affine to a particular CPU.

I/O Schedulers

I/O Scheduler

- Kernel 2.4 I/O scheduler
  - One request queue, which is sorted seek-wise.
  - Reduces seek-time for the disk head.
  - This type of sorting can lead to starvation of requests far away from the current seek position.
  - Write – starving – reads.
    - Write requests are asynchronous and non-blocking
      - Most apps are not bothered about write commits
    - Read requests are blocking, as apps need the data to continue (synchronous)
    - Read requests have to be prioritised over write requests to improve responsiveness.

Deadline I/O scheduler

- Assigns tasks an expiration time
- Alongwith a queue sorted seek-wise, two additional queues are implemented.
  - FIFO read queue with a deadline of 500ms
  - FIFO write queue with a deadline of 5 seconds.
- A request is submitted to the sorted queue and the appropriate deadline queue (at the tail of the queue)
- Requests are scheduled from the sorted queue.
- If a request in the FIFO queue expires then the scheduler begins dispatching from FIFO queues.

Deadline I/O scheduler (contd...)

- Ensures that seeks are minimised
- At the same time, makes sure that requests are not starved.
- Read requests are given a better deadline than write requests (10 times)
  - Interactivity is improved.
  - Applications are not blocked by read requests.
  - Improved performance in case of dependent read requests.
    - Eg : `$ cat *`
- Can result in a seek-storm, because the sorted queue can get neglected !!

Anticipatory I/O scheduler

- Same algorithm, but anticipates future read requests in case of dependent read requests.
- After a read-request is completed
  - Doesn't proceed to the next request
  - Waits for a few milliseconds (6ms) to see if the application submits another read request.
    - Eg : an app reading an Image file in 1024byte buffers.
  - If a new read request happens then the scheduler process this request.
- This small wait prevents a lot of seek operations.
  - If the app doen't issue any read request the waiting period is wasted !!

Performance Comparison

- Read operations
  - Deadline I/O
    - Comparable during streaming writes.
    - Performs 10 times better during streaming reads.
  - Anticipatory I/O (w.r.t 2.4)
    - 10 times better during streaming writes
    - 100 times better during streaming reads.
- Write operations
  - Perform almost same as 2.4 (2.4 may be better)
  - Deadline I/O scheduler performs slightly better than Anticipatory I/O scheduler.

Resources

- Kernel documentation
  - /usr/src/linux-2.6.x/Documentation/
    - sched-design.txt, sched-coding.txt
    - preempt-locking.txt
    - as-iosched.txt
- Scheduler
    - http://kerneltrap.org/node/view/464
    - http://kerneltrap.org/node/view/657
    - http://www.arstechnica.com/etc/linux/index.html
- http://kerneltrap.org
- The Linux Mailing List Archives

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