Scheduling in Kernel 2.6

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Agenda

* Scheduling
  o Process Scheduling
    - O(1) scheduler – design, performance
    - Pre-emption
  o I/O Scheduling
    - Deadline I/O scheduler
    - Anticipatory I/O scheduler
    - Comparison
Considerations in Scheduler design

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

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

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

* Full O(1) scheduling
  o Great shift away from O(n) scheduler
* Perfect SMP scalability
  o Per CPU runqueues and locks
  o No global lock/runqueue
  o 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
  o The lower the value, higher is the priority
  o Eg: Priority level 110 will have a higher priority than 130.
* Two priority-ordered 'priority-arrays' per CPU
  o 'Active' array: tasks which have timeslices left
  o 'Expired' Array: tasks which have run
  o 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 its own RunQueue

- **RunQueue**
  - **Active**
    - Task 1 → Task 2 → ... → Task N
      - [Priority: 1]
      - [Priority: 140]
  - **Expired**
    - ... → ...
  - **Migration Thread**

From kernel/sched.c
O(1) Algorithm (Constant time algorithm)

* The highest priority level, with at-least ONE task in it, is selected
  o This takes a fixed time (say $t_1$)
* The first task (head of the doubly-linked list) in this priority level is allowed to run
  o This takes a fixed time (say $t_2$)
* Total time taken for selecting a new process is
  o $t = t_1 + t_2$ (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.
  o All CPUs had to wait for other CPUs to finish execution.

* An O(n) scheduler.
  o In 2.4, the scheduler used to go through the entire “global runqueue” to determine the next task to be run.
  o 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
  o 1-100: RT prio (MAX_RT_PRIO = 100)
  o 101-140: User task Prio (MAX_PRIO = 140)

* Three different scheduling policies
  o One for normal tasks
  o Two for Real time tasks

* Normal tasks
  o Each task assigned a “Nice” value
  o PRIO = MAX_RT_PRIO + NICE + 20
  o Assigned a time slice
  o Tasks at the same prio are round-robined.
    - Ensures Priority + Fairness
Policies ( contd ... )

* RT tasks ( Static priority )
  o FIFO RT tasks
    - Run until they relinquish the CPU voluntarily
    - Priority levels maintained
    - Not pre-empted !!
  o 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 its 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.
  o 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 its priority level.
* Also, priority recalculation happens every 20ms.
For programmers

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

* void schedule()
  o The main scheduling function.
  o Upon return, the highest priority process will be active

* Data
  o struct runqueue()
    - The main per-CPU runqueue data structure
  o 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 its 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 imbalanced
    - 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
* Along with a queue sorted seek-wise, two additional queues are implemented.
  o FIFO read queue with a deadline of 500ms
  o 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
  o Doesn't proceed to the next request
  o Waits for a few milliseconds (6ms) to see if the application submits another read request.
    - Eg: an app reading an Image file in 1024 byte buffers.
  o If a new read request happens then the scheduler process this request.
* This small wait prevents a lot of seek operations.
  o If the app doesn't issue any read request the waiting period is wasted!!
Performance Comparison

* Read operations
  o Deadline I/O
    - Comparable during streaming writes.
    - Performs 10 times better during streaming reads.
  o Anticipatory I/O ( w.r.t 2.4 )
    - 10 times better during streaming writes
    - 100 times better during streaming reads.

* Write operations
  o Perform almost same as 2.4 (2.4 may be better)
  o 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
Thankyou

* Special thanks to
  - Robert Love & Rusty Russel for their excellent documentation efforts
    - This presentation is based on a paper presented by Robert Love at “LinuxSymoposium/2003”
  - The Linux Kernel Team for commenting the code and giving it a story-book feeling !!
  - The Infosys OpenSource Community for clarifying most of my doubts.
  - The Bangalore LUG for giving me a chance to speak at their monthly meet !!