Solaris and Linux scheduling

Self study material

Module 3

Operating systems 2018

1DT044 and 1DT096

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Scheduling

Solaris is a Unix operating system originally developed by Sun Microsystems. It superseded their earlier SunOS in 1993. Oracle Solaris, as it is now known, has been owned by Oracle Corporation since Oracle's acquisition of Sun in January 2010

Solaris Dispatch Table

By default, there is an inverse relationship between priorities and time slices. The higher the priority, the smaller the time slice.

Interactive processes typically have a higher priority: CPU-bound processes, a lower priority.

New priority when returning from sleep, such as waiting for I/O.

New priority when time quantum expires.

low priority

priority	time quantum	time quantum expired	return from sleep
0	200	0	50
5	200	0	50
10	160	0	51
15	160	5	51
20	120	10	52
25	120	15	52
30	80	20	53
35	80	25	54
40	40	30	55
45	40	35	56
50	40	40	58
55	40	45	58
59	20	49	59

higher priority

This scheduling policy give good response times for interactive processes and good throughput for CPU-bound processes.

Schedulers

Linux 2.6 scheduling

In versions of the Linux kernel 2.6 prior to 2.6.23, the scheduler used is an **O(1) scheduler** by Ingo Molnár.

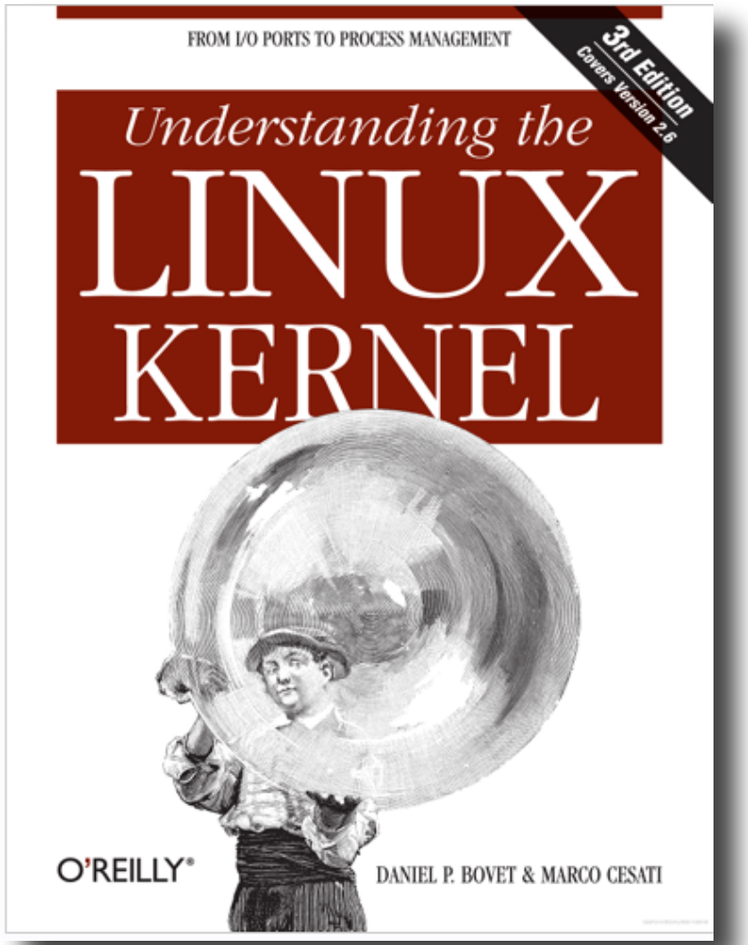
The scheduler used thereafter is the **Completely Fair Scheduler**, also by Ingo Molnár.

- Runs in **O(log N)** time where N is the number of tasks in the runqueue.
- Choosing a task can be done in constant time, but reinserting a task after it has run requires O(log N) operations, because the runqueue is implemented as a **red-black tree**.
- A red–black tree is a type of **self-balancing binary search tree** data structure.

O(1) Scheduler

kernel 2.6 (2003-12-17) — kernel 2.6.22 (2007-07-08)

Linux O(1) scheduler (prior to 2.6.23)



The scheduling algorithm of Linux 2.6 is much more sophisticated. By design, it scales well with the number of runnable processes, because it selects the process to run in constant time, independently of the number of runnable processes. It also scales well with the number of processors because each CPU has its own queue of runnable processes. Furthermore, the new algorithm does a better job of distinguishing interactive processes and batch processes. As a consequence, users of heavily loaded systems feel that interactive applications are much more responsive in Linux 2.6 than in earlier versions.

Goals of the O(1) scheduler

Maximise overall CPU utilisation while also maximising interactive performance.

- ★ Implement fully **O(1) scheduling**. Every algorithm in the new scheduler completes in constant-time, regardless of the number of running processes.
- ★ Implement perfect **SMP scalability**. Each processor has its own locking and individual runqueue.
- ★ Implement improved **SMP affinity**. Attempt to group tasks to a specific CPU and continue to run them there. Only migrate tasks from one CPU to another to resolve imbalances in runqueue sizes.
- ★ Provide **good interactive performance**. Even during considerable system load, the system should react and schedule interactive tasks immediately.
- ★ Provide **fairness**. No process should find itself starved of timeslice for any reasonable amount of time. Likewise, no process should receive an unfairly high amount of timeslice.
- ★ Optimize for the common case of only one or two runnable processes, yet scale well to multiple processors, each with many processes.

Priority levels and values

High priority level ⟷ Low priority value

Low priority level ⟷ High priority value

Interactivity and dynamic priority

The Linux scheduler favours interactive processes.

Interactivity heuristic

A task’s interactivity is determined by how long it has been suspended waiting for I/O.

Dynamic priority

A task’s priority is recalculated when the task has exhausted its time quantum.

Rewarding I/O bound processes

To prevent tasks from hogging the CPU and thus starving other tasks that need CPU access, the Linux 2.6 scheduler can **dynamically alter a task's priority**.

Because **I/O-bound** tasks are viewed as **altruistic** for CPU access they are **rewarded** by having their **priority level raised** by up to five steps.

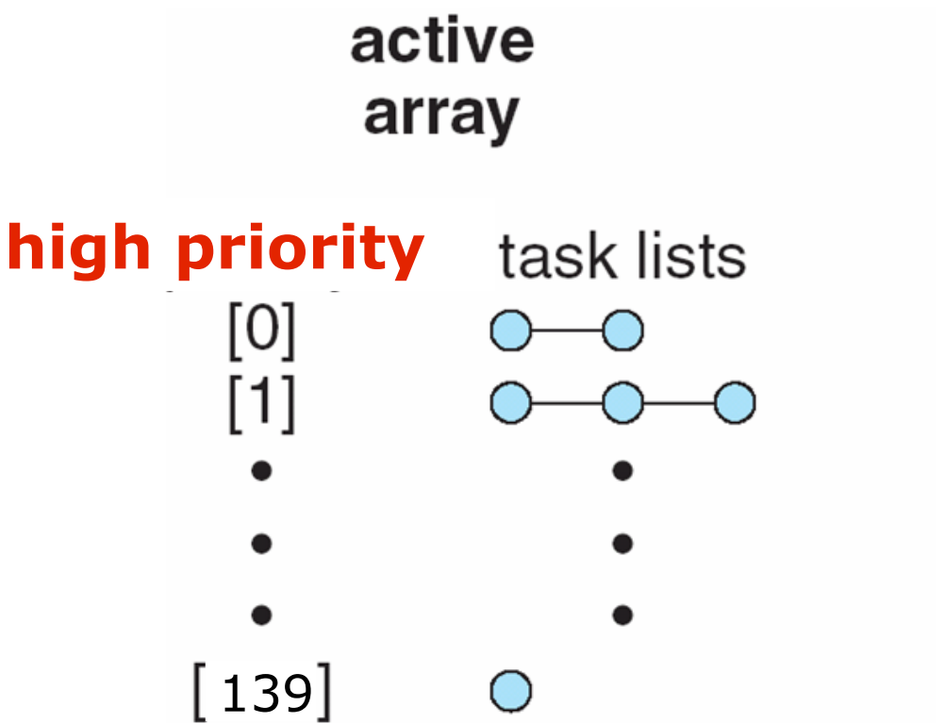
I/O-bound tasks commonly use the CPU to set up I/O and then sleep awaiting the completion of the I/O. This type of behaviour gives other tasks access to the CPU.

CPU-bound tasks are **punished** by having their **priority level lowered** by up to five steps.

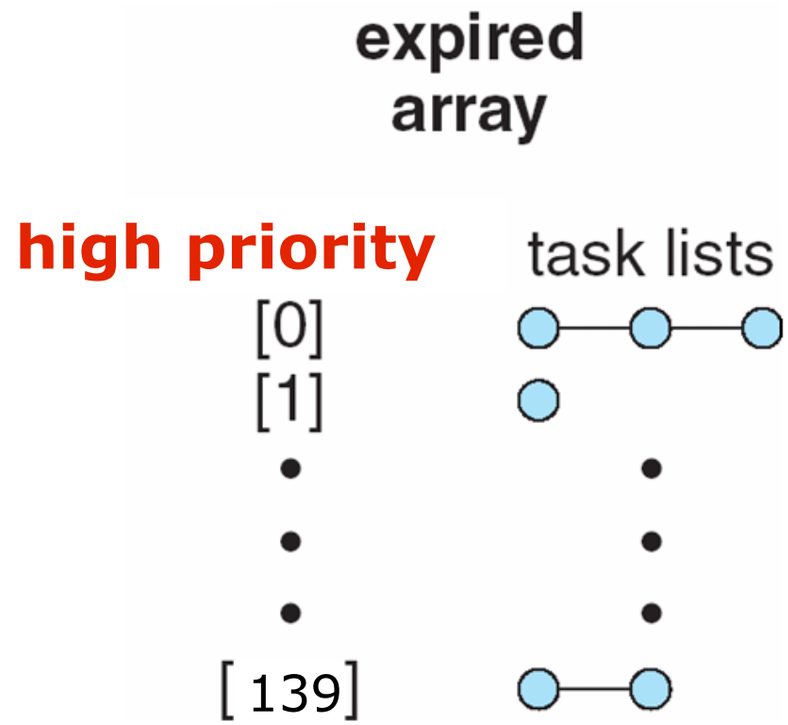
Source: http://www.ibm.com/developerworks/linux/library/l-scheduler

O(1) runqueue data structure

In order to support SMP, each processor maintains its runqueue and schedules itself independently. Each runqueue contains two priority arrays: active and expired.



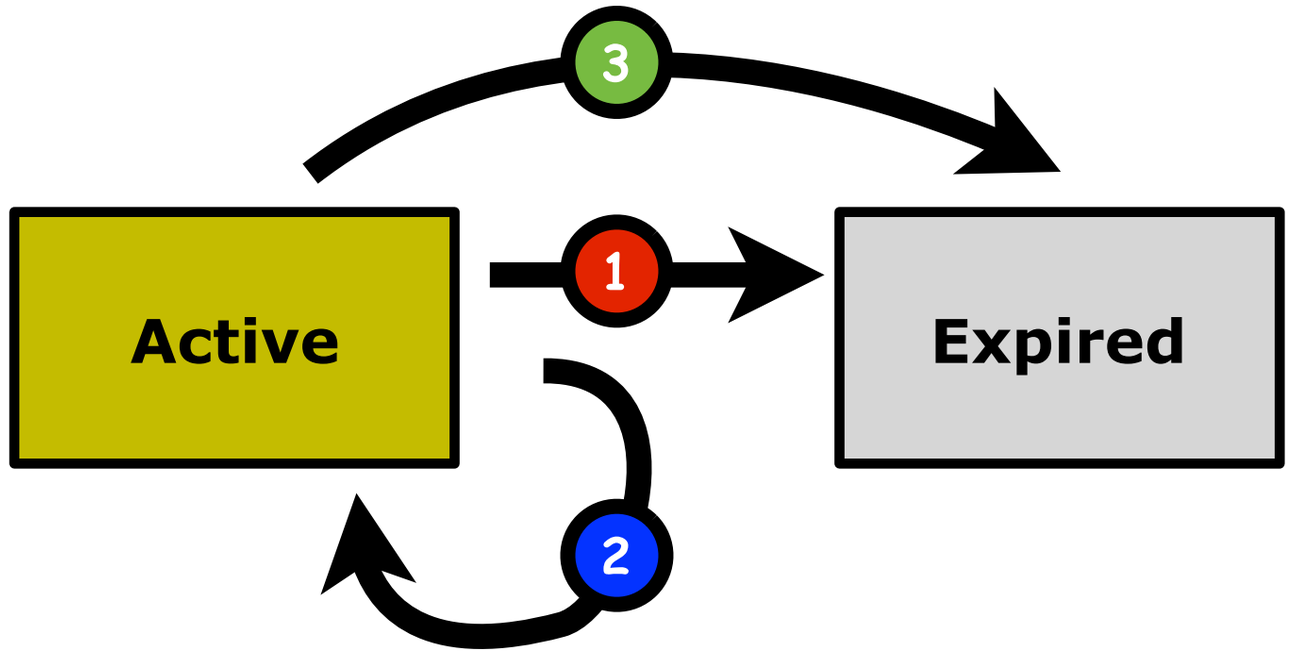
These runnable processes have not yet exhausted their time quantum and are thus allowed to run.



These runnable processes have exhausted their time quantum and are thus forbidden to run until all active processes expire.

Both arrays are indexed according to priority value (0 - 139).

When the set of active processes becomes empty, the expired set becomes the new active set and vice versa.



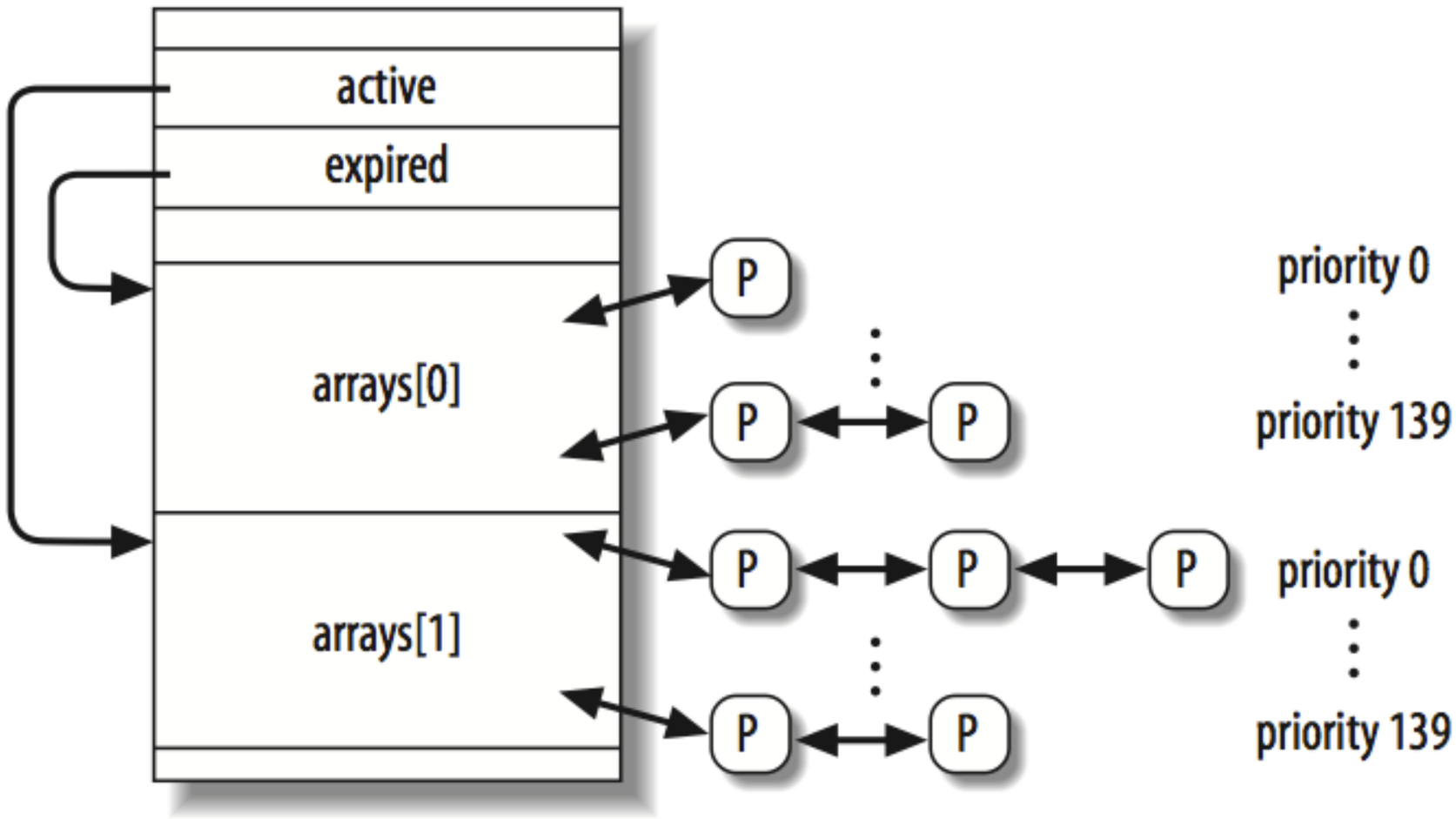
Heuristic	Scheduler action
1 The scheduler tries to boost the performance of interactive processes.	An active batch process that finishes its time quantum always becomes expired.
2 An active interactive process that finishes its time quantum usually remains active.	The scheduler refills its time quantum and leaves it in the set of active processes.
3 If the eldest expired process has already waited for a long time, or if an expired process has higher static priority (lower nice value) than the interactive process.	The scheduler moves an interactive process that finished its time quantum into the set of expired processes

As a consequence, the set of active processes will eventually become empty and the expired processes will have a chance to run.

Source: Understanding the Linux kernel, 3rd edition.

Swapping active and expired

Periodically, the role of the active and expired data changes: the active processes suddenly become the expired processes, and the expired processes become the active ones.



Swaping the active and expired process sets is simple, only swap the pointers active and expired.

Image: Understanding the Linux kernel, 3rd edition, page 268.

Choose a task to run as fast at possible

The job of the scheduler is simple, choose the task on the highest priority list to execute.

To make it fast to find the next process to execute, a **bitmap** is used to keep track of the existence or not of tasks for all priority lists.

	Task bitmap																									
	32 bit word						32 bit word					32 bit word					32 bit word					32 bit word					
Priority	Highest priority																						Lowest priority			
	0	1	2	3	...	31	32	33	34	...	63	64	65	66	...	95	96	97	98	...	127	128	129	130	...	139	
Bit value	1	1	0	0	...	0	0	1	1	...	1	0	0	0	...	1	0	1	0	...	0	0	1	0	...	1	

If there are tasks in a task list with priority X, bit number X is set to 1 in the task bit map, otherwise the bit is set to 0.

On most architectures, a **find-first-bit-set instruction** is used to find the highest priority bit set in one of five 32-bit words (for the 140 priorities).

O(1)

The time it takes to find a task to execute depends not on the number of active tasks but instead on the number of priorities.

This makes the 2.6 scheduler an **O(1)** process because **the time to schedule is both fixed and deterministic regardless of the number of active tasks.**

Completely Fair O(log n) Scheduler

Default scheduler since kernel 2.6.23 (2007-10-09)

Completely Fair Scheduler (CFS)

The Completely Fair Scheduler (CFS) is the name of a process scheduler which was merged into the 2.6.23 release of the Linux kernel and is the default scheduler.

Instead of the run queues used in the O(1) scheduler, a single **red-black tree** is used to track all processes which are in a runnable state.

The process which pops up at the leftmost node of the tree is the one which is most entitled to run at any given time.

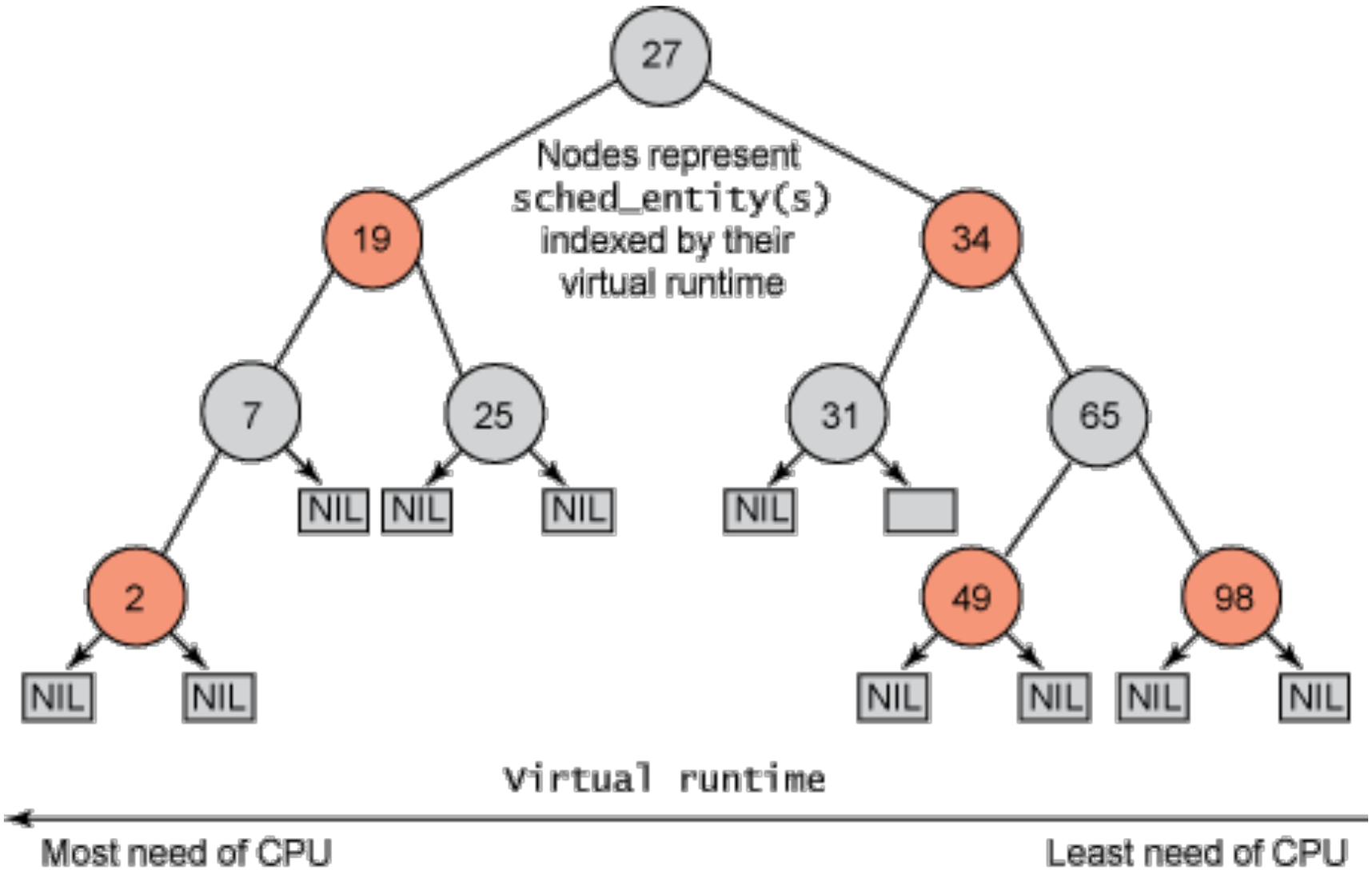
Source: http://lwn.net/Articles/230574/ Accessed 2014-02-01

Because of this simple design, CFS no longer uses active and expired arrays and dispensed with sophisticated heuristics to mark tasks as interactive versus non-interactive.

Self-balancing time-ordered red-black-tree (1)

CFS maintains a time-ordered red-black tree using virtual runtime as keys.

Each runnable task chases the other to maintain a balance of virtual execution time across the set of runnable tasks in the tree.



Source: http://www.ibm.com/developerworks/library/l-completely-fair-scheduler/ Accessed 2014-02-01

Self-balancing red-black-tree

A red-black tree is a tree with a couple of interesting and useful properties.

First, it's **self-balancing**, which means that no path in the tree will ever be more than twice as long as any other.

Second, operations on the tree occur in **O(log n)** time (where n is the number of nodes in the tree).

This means that you can insert or delete a task quickly and efficiently.

Source: http://www.ibm.com/developerworks/library/l-completely-fair-scheduler/ Accessed 2014-02-01

Virtual runtime

To balance the black-red-tree, CFS maintains the amount of time provided to a given task in what's called the virtual runtime.

The smaller a task's virtual runtime,

meaning the smaller amount of time a task has been permitted access to the processor

, the higher its need for the processor.

Source: http://www.ibm.com/developerworks/library/l-completely-fair-scheduler/ Accessed 2014-02-01

Sleeper fairness

Like the old O(1) scheduler, CFS uses a concept called **sleeper fairness**, which considers sleeping or waiting tasks equivalent to those on the runqueue.

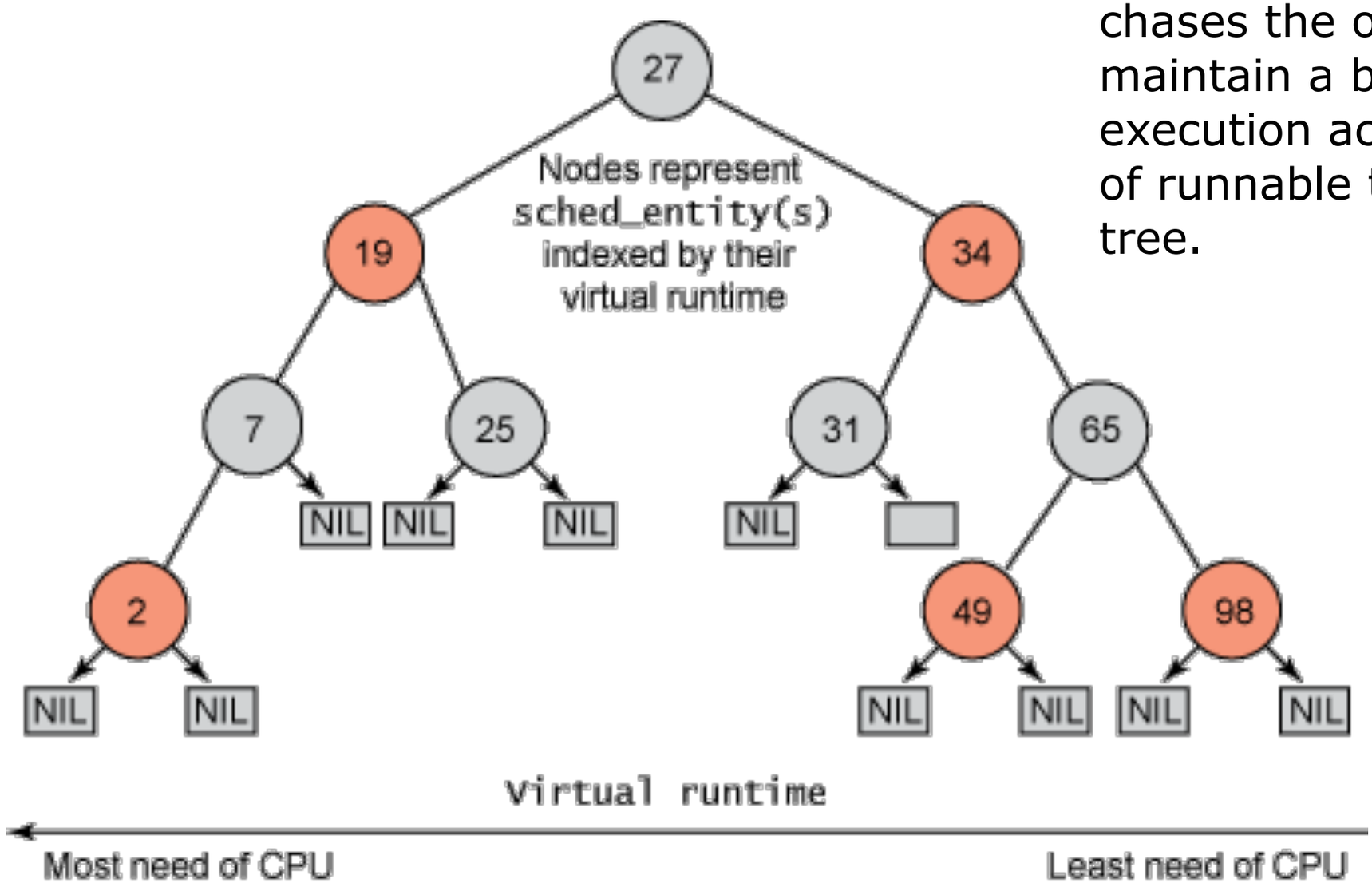
- ★ Interactive tasks which spend most of their time waiting for user input or other events get a comparable share of CPU time when they need it.

- ★ If a task spends a lot of its time sleeping, then its virtual runtime value is low and it automatically gets a priority boost when it finally needs it. Hence such tasks do not get less processor time than the tasks that are constantly running.

Source: http://en.wikipedia.org/wiki/Completely_Fair_Scheduler Accessed 2014-02-01

Self-balancing time-ordered red-black-tree (2)

Tasks on the left side of the tree are given time to execute, and the **tasks** in the tree **migrate from the right to the left** to maintain **fairness**.



Each runnable task chases the other taks to maintain a balance of execution across the set of runnable tasks in the tree.

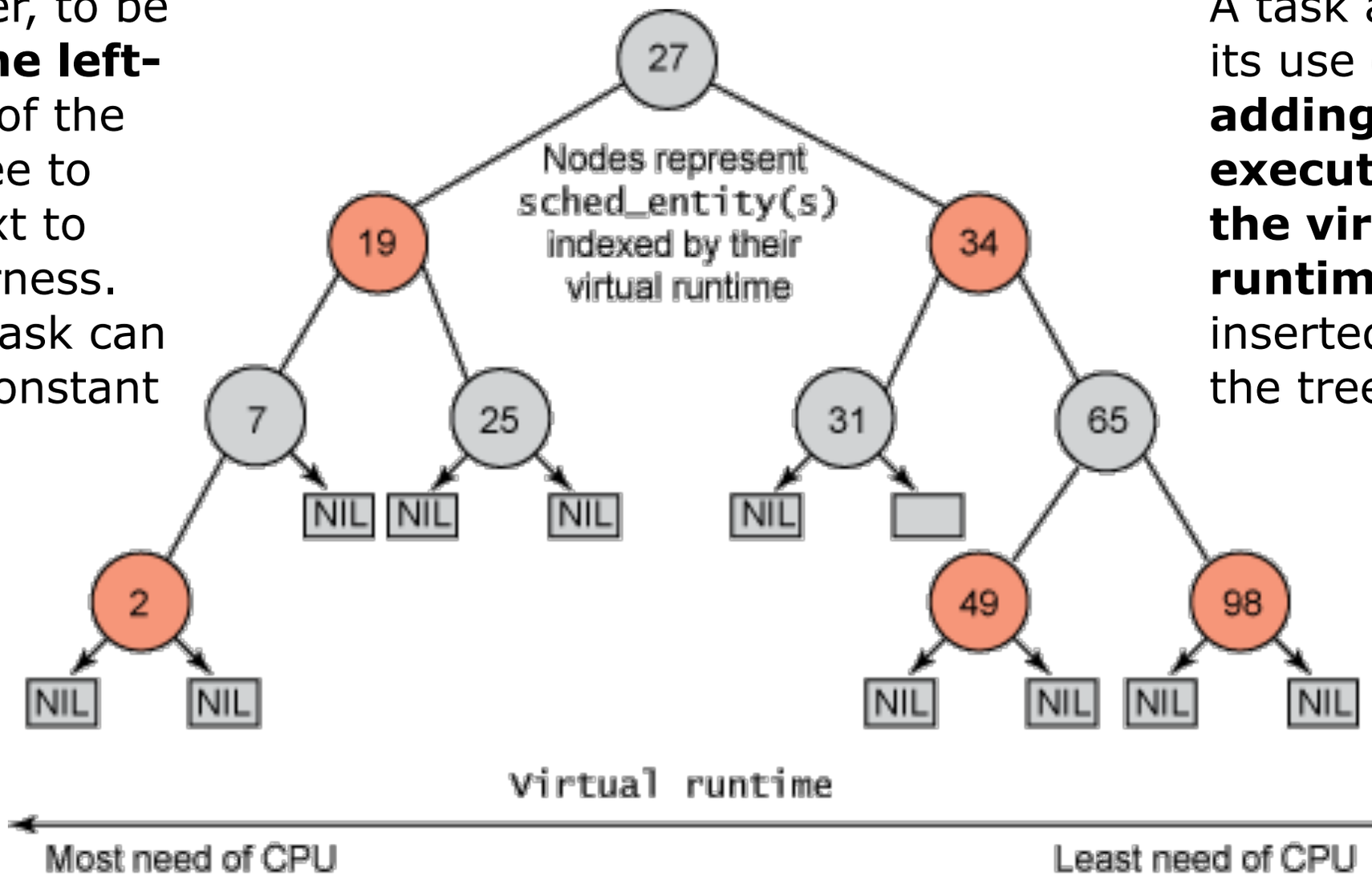
Source: http://www.ibm.com/developerworks/library/l-completely-fair-scheduler/ Accessed 2014-02-01

Self-balancing time-ordered red-black-tree (3)

Choosing a task can be done in constant time O(1) but inserting a task back into the tree if runnable is O(log n).

O(1)

The scheduler, to be fair, **picks the left-most node** of the red-black tree to schedule next to maintain fairness. Choosing a task can be done in constant time.



O(log n)

A task accounts for its use of the CPU by **adding** its **execution time to the virtual runtime** and is then inserted back into the tree if runnable.

Source: http://www.ibm.com/developerworks/library/l-completely-fair-scheduler/ Accessed 2014-02-01