The Linux Completely Fair Scheduler (CFS)

CMPU 334 – Operating Systems

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The Linux Completely Fair Scheduler (CFS)

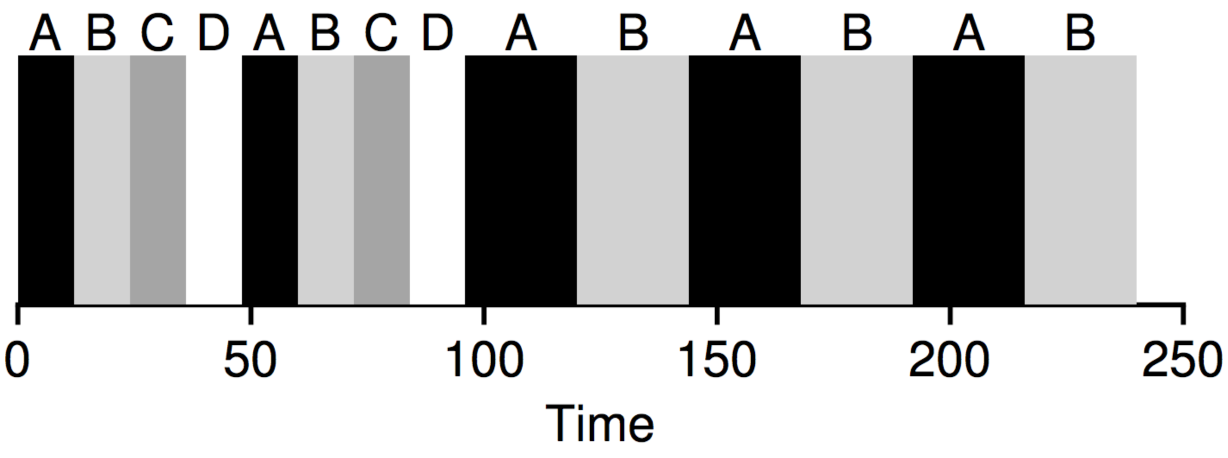
- Implements fair-share scheduling
  - Guarantees that each job obtains *a certain percentage* of CPU time
- Efficient and scalable
  - Quickly make a scheduling decision
- Scheduling performance is important
  - Scheduling uses about 5% of datacenter CPU time at Google

CFS Operation Basics

- Fairly divides a CPU evenly among all competing (runnable) processes
  - Doesn't use a fixed time slice
- Uses the **virtual runtime** (`vruntime`) of a process
  - Accumulates as the process runs
  - To schedule a process, pick the one with the lowest `vruntime`
- When to schedule?
  - Frequent switches increase fairness but has a higher overhead
  - Fewer switches give better performance at the cost of fairness
- Controlled by **`sched_latency`** parameter
  - Maximum time a process can run before considering a switch (e.g., 20 ms)
  - This is divided by the number of runnable processes to get a process time slice
  - CFS will be completely fair over this time period

CFS Example

- `sched_latencey` = 48 ms
- Four processes that are runnable to start
  - Per process time slice of 12 ms (48/4)
  - `vruntime` is starts at 0 for these jobs
- Pick job with the lowest `vruntime` (A, B, C, or D in this case)
- Run job A until it has used 12 ms of `vruntime`
  - Then make a scheduling decision
  - Run the job with the lowest vruntime
    - (B, C, or D)
- C and D complete after 96 ms
  - Time slice is adjusted to 24 ms (48/2)



Too many processes runnable?

- Per process time slice is the `sched_latency` / runnable processes
  - A lot of runnable processes could lead to small time slices
    - Lots of context switches and more overhead
- CFS `min_granularity` parameter
  - Minimum time slice of a process (e.g., 6 ms)
  - CFS will never set the time slice of a process to less than this value
  - In this case, CFS may not be perfectly fair over the target scheduling latency
    - E.g., `sched_latencey` = 48 ms with 10 runnable processes
    - time slice 4.8 --> 6 ms
    - all jobs won't run during the 48 ms
- Timer interrupts
  - Time slices are variable, how to set the timer?
  - Timer goes off frequently (e.g., 1 ms)
  - Gives the CFS scheduler a chance to see if the current job has reached the end of its run

Niceness Levels

- Gives the user control over process priority
  - Give some processes a higher (or lower) share of the CPU
- A **nice** level of a process
  - A measure of how nice (to other processes) your job is
  - 19 (lowest priority)
  - -20 (highest priority)
- Nice levels are mapped to a weight used to compute an effective time slice for a process

Niceness Weightings

```
static const int prio_to_weight[40] = {
 /* -20 */     88761,     71755,     56483,     46273,     36291,
 /* -15 */     29154,     23254,     18705,     14949,     11916,
 /* -10 */      9548,      7620,      6100,      4904,      3906,
 /*  -5 */      3121,      2501,      1991,      1586,      1277,
 /*   0 */      1024,       820,       655,       526,       423,
 /*   5 */       335,       272,       215,       172,       137,
 /*  10 */       110,        87,        70,        56,        45,
 /*  15 */        36,        29,        23,        18,        15,
};
```

$$\texttt{time\_slice}_k = \frac{\texttt{weight}_k}{\sum_{n=0}^{n-1} \texttt{weight}_i} \cdot \texttt{sched\_latency}$$

Niceness Weighting Example

- Two processes, A and B
  - A's niceness level is -5 (boost in priority)
  - B's niceness level is 0 (default)
- Calculate the time slice for A and B
  - Weight A: 3121, weight B: 1024, total weight: 4145
  - Time slice A: 3121 / 4145 = 0.753 * sched_latency
  - Time slice B: 1024 / 4145 = 0.247 * sched_latency
- Assuming a 48 ms sched_latency:
  - Process A gets about 75% of the sched_latency (36 ms)
  - B gets about 25% of the sched_latency (12 ms)
- Weight table is constructed to preserve CPU proportionally ratios when the difference in nice values is constant
  - E.g., if process A had a nice value of 5 and B had a nice value of 10, they would be scheduled the same way as above

Calculating vruntime

- Higher priority processes get a longer time slice
- But we pick the process with the lowest `vruntime` to run next
  - To handle priority properly, `vruntime` must scale inversely with priority
- For our example:
  - A's `vruntime` will accumulate at about a 1/3 the rate of B's

$$\texttt{vruntime}_i = \texttt{vruntime}_i + \frac{\texttt{weight}_0}{\texttt{weight}_i} \cdot \texttt{runtime}_i$$

CFS efficiency

- How quickly can the scheduler find the next job to run
  - Lists don’t scale if you have 1000s of processes to search through ever millisecond
- CFS keeps processes in a **red-black tree**
  - A type of balanced tree
  - Does a little extra work to maintain low depths
  - $O(\log n)$ for operations (search, insert, delete)
- CFS only keeps running and runnable processes in this structure
  - If a process is waiting on I/O, it is removed from the tree and kept track elsewhere
  - What to do when process wakes up?
    - `vruntime` will be behind the others and could monopolize the CPU
    - CFS sets the vruntime for the job to the minimum value found in the tree
    - Jobs that sleep for short periods often do not ever get their fair share of the CPU

Linux CFS Summary

- Linux Completely Fair Scheduler (CFS)
  - Most widely used fair-share scheduler in existence
  - A bit like a weighted round-robin with dynamic time slices
  - Built to scale and perform well under load