Assignment 4 Tutorial

Linux Scheduler

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Outline

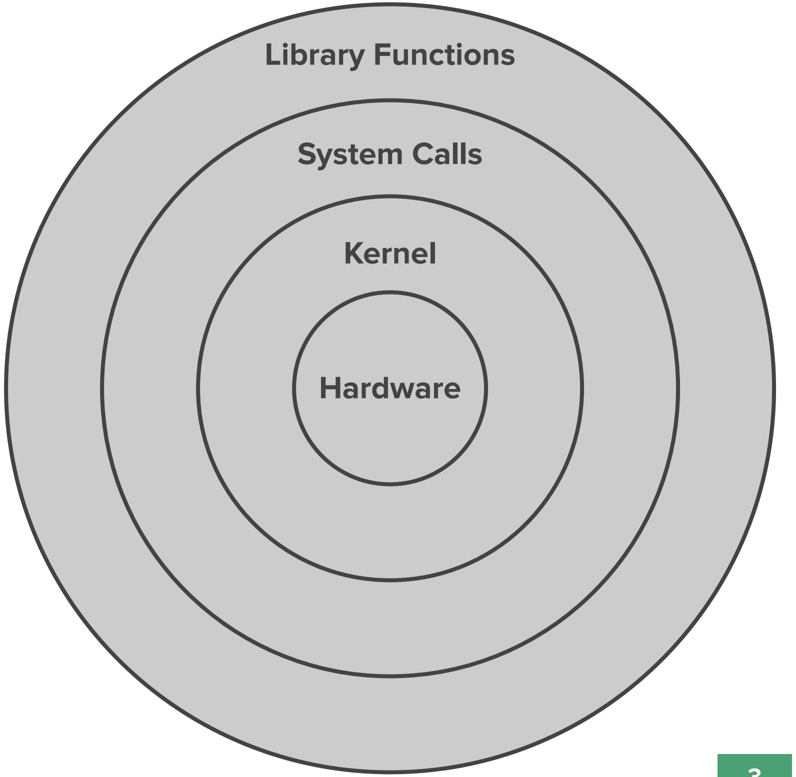
- Linux Scheduler
- Scheduler internals
- History
- Assignment 4

Linux Kernel

- **Heart of the Operating System**

- **Interface between resources and user processes**

- **What the Kernel does**
  - Memory Management
  - **Process Management**
  - Device Drivers
  - System Calls

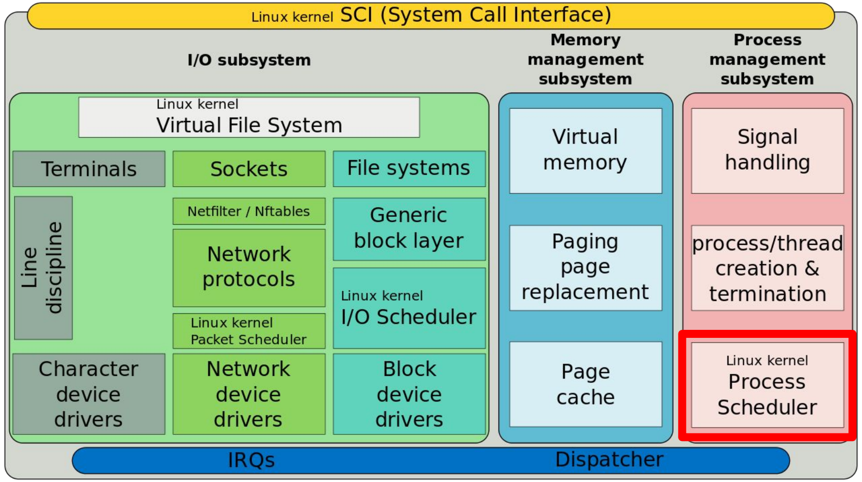


Process Management

- **Multitasking operating systems**
  - Tasks must run in parallel
- **Usually tasks are more than the CPU cores**
- **Need to make it possible to execute tasks at the “same” time**

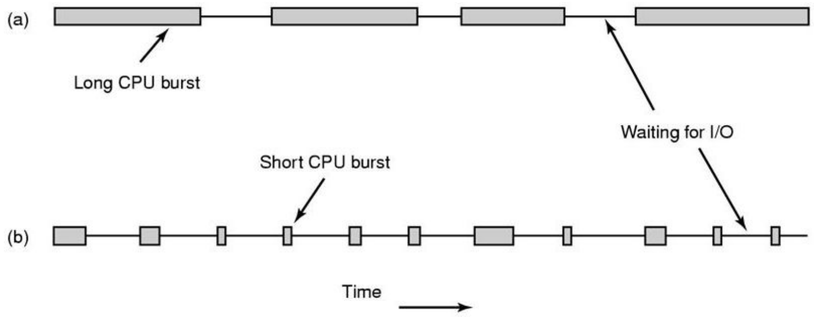
Scheduler

- Coordinates how tasks **share** the available processor(s)
- Prevents task starvation and preserves **fairness**
- Take into account **system** tasks



Task Types

- **Balance between two types of processes:**
  a. Batch processes
  b. I/O Bound tasks



- **Preemption: temporarily evict a running task**

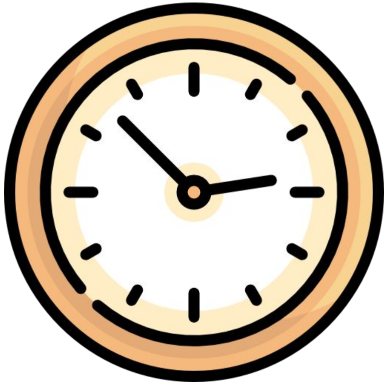
- **Quantum: Variable but keep it as long as possible**

Real-time processes

- **Need guarantee about their execution in time boundaries**

- **Soft real-time processes**
  - A task might run a bit late

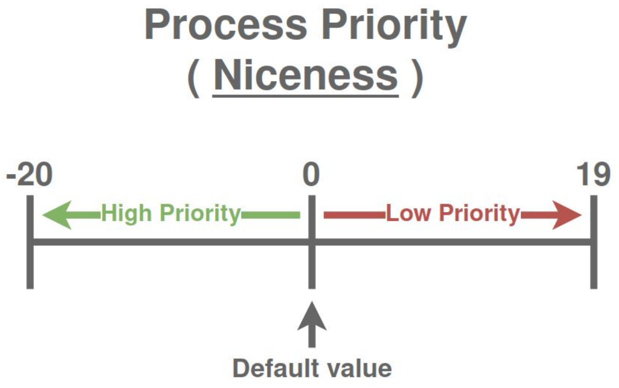
- **Hard real-time processes**
  - Strict time limits
  - Not supported by default Linux

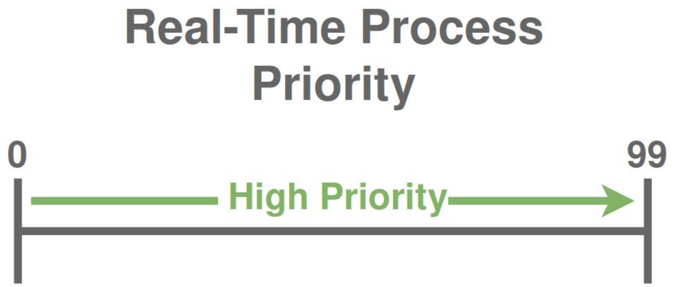


Scheduler Internals

Priority

- Linux provides Priority-based scheduling
- A "number" determines how important a task is

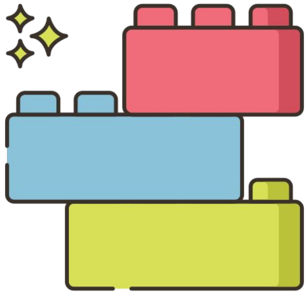




Process Descriptor

- **Scheduler needs information for each process**

- **Useful fields in task_struct:**
  - prio: Process priority
  - sched_class: Scheduling class
  - policy: Scheduling policy



Scheduler Design

- **Extensible** hierarchy of scheduler modules
- Each module encapsulates a **scheduling policy**
- Real-time classes:
  - SCHED_FIFO
  - SCHED_RR

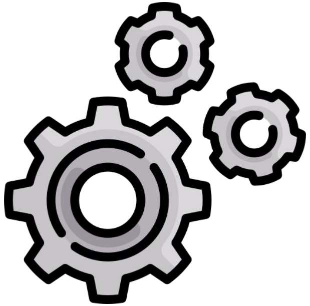
```
static const struct sched_class fair_sched_class = {
  .next               = &idle_sched_class,
  .enqueue_task       = enqueue_task_fair,
  .dequeue_task       = dequeue_task_fair,
  .yield_task         = yield_task_fair,
  .check_preempt_curr = check_preempt_wakeup,
  .pick_next_task     = pick_next_task_fair,
  .put_prev_task      = put_prev_task_fair,

...
```

https://elixir.bootlin.com/linux/v2.6.38.1/source/kernel/sched_fair.c

`schedule(void)`

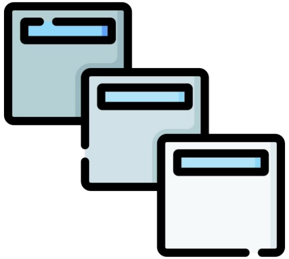
- **Main scheduler function is `schedule( )`**
  - Replace currently executing process with another

- **Called from different places**
  - Periodic scheduler
  - Current task enters sleep state
  - Sleeping task wakes up



Run queue

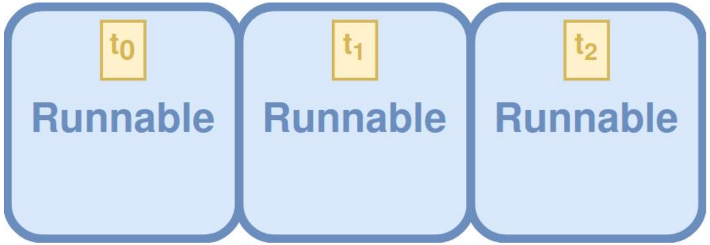
- Data structure that manages active processes
- Holds tasks in the "runnable" state



History

History

- **Genesis**
  - Circular queue
  - Round-robin policy



- **Linux v2.4 - O(n) scheduler**
  - Each task runs a quantum of time in each epoch
  - Epoch advances after all runnable tasks have their quantum
  - At the beginning of each epoch, all tasks get a new quantum

History

- **Linux v2.6 - O(1) Scheduler**
  - Division between real-time and normal tasks
  - One list per priority

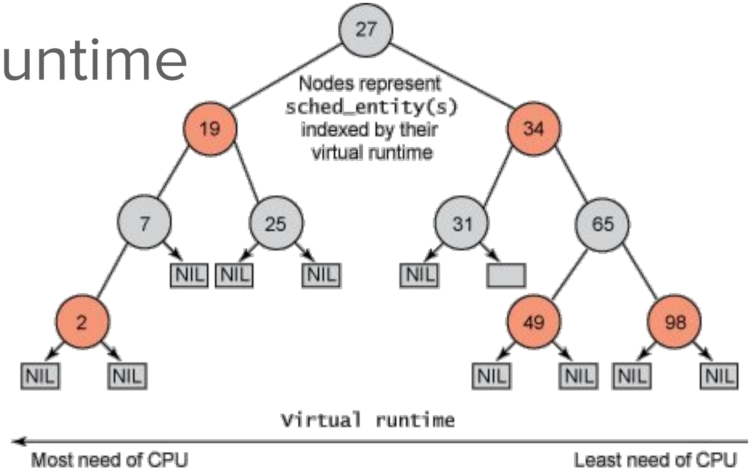
- **Linux v2.6.23 - CFS**
  - Introduced in 2007, Improved in 2016

Completely Fair Scheduler

- **Models an "ideal, precise multitasking CPU"**
- **Ideal scheduling: *n* tasks share 100/*n* percentage of CPU effort each**
- **Fairness:**
  - Tasks get their share of the CPU relative to others
  - A task should run for a period proportional to its priority

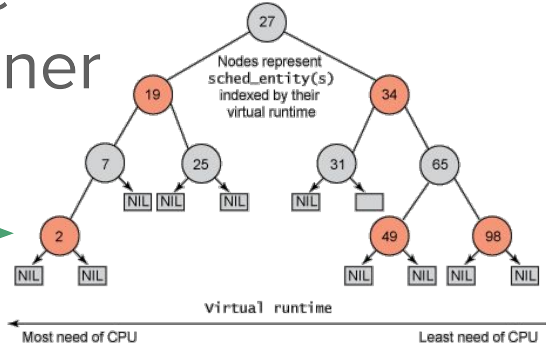
Completely Fair Scheduler

- **Time-ordered red-black tree**
  - Runnable tasks are sorted by vruntime
- **When a task is executing its vruntime increases**
  - Moves to the right of the tree
- **Scheduler always selects leftmost leaf**
  - Task with smallest vruntime



Completely Fair Scheduler - Improvements

- **Virtual clock ticks slowly for important tasks**
  - Move slower to the right of the tree
  - Chance to be scheduled again sooner
- **Leftmost node is cached**
  - O(1) access
- **Reinsertion of preempted tasks takes `O(logn)`**



Assignment 4

Assignment 4 - Highest Value First

- **Each process is defined by:**
  - Deadlines (**2** values)
  - (Estimated) Computation Time

- ***"The process that will return the highest value should go first"***

↳ ???

Value Definition

First Deadline

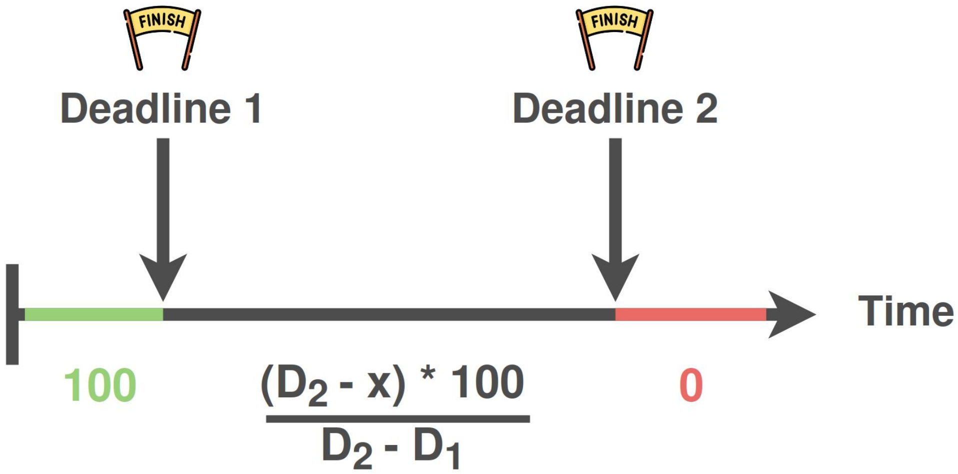
Completion Time

$$Value(x) = \begin{cases} 100, & x < D_1 \\ \frac{(D_2 - x) * 100}{D_2 - D_1}, & D_1 < x < D_2 \\ 0, & x > D_2 \end{cases}$$

Second Deadline

“The process that gives the highest value goes first”

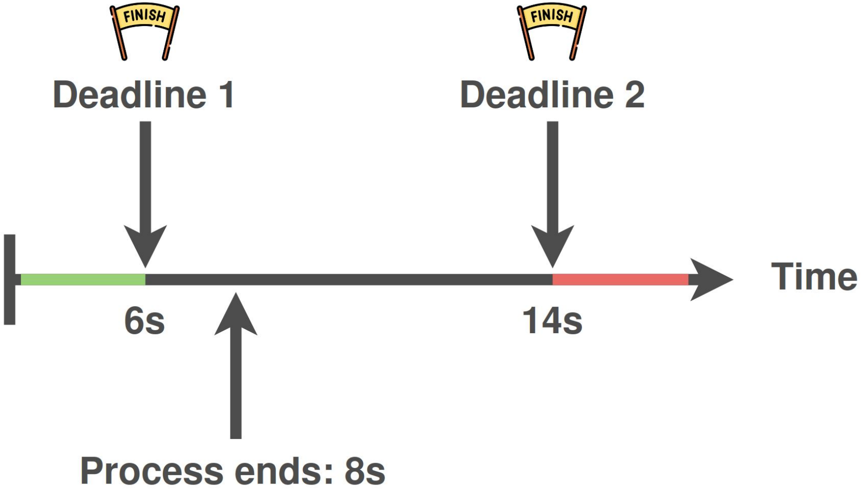
Value Definition



- We don't consider when the process started, we only care about when it will end.
- The further you move away from D_1, the lower the value

Example 1

- **Deadlines**
  - D1 at 6s
  - D2 at 14s
- **Process ends at 8s**
- $Value = \frac{(D_2 - x) * 100}{D_2 - D1}$



Example 1

- **Deadlines**
  - D1 at 6s
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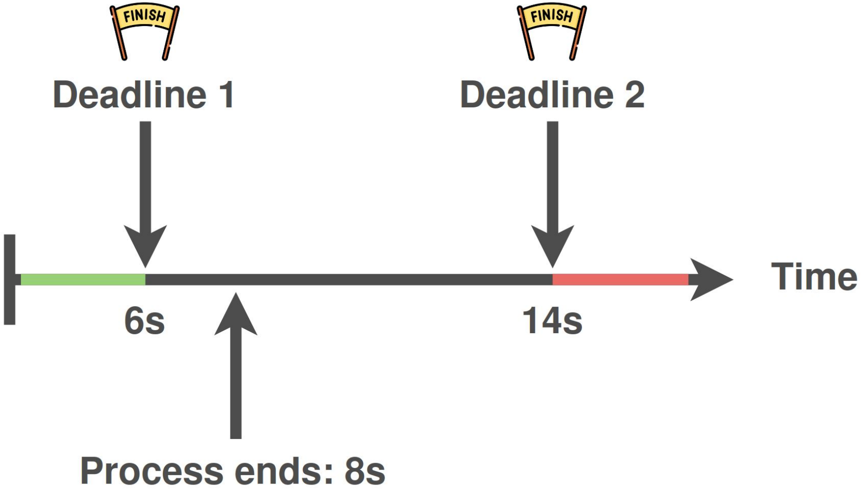
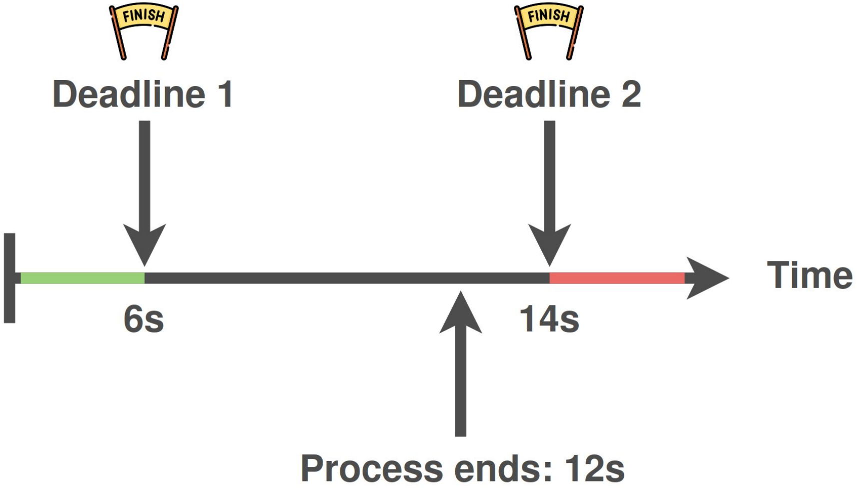


- **Process ends at 8s**

- $Value = \frac{(D_2 - x) * 100}{D_2 - D1} = \frac{(14 - 8) * 100}{14 - 6} = \frac{600}{8} = 75$

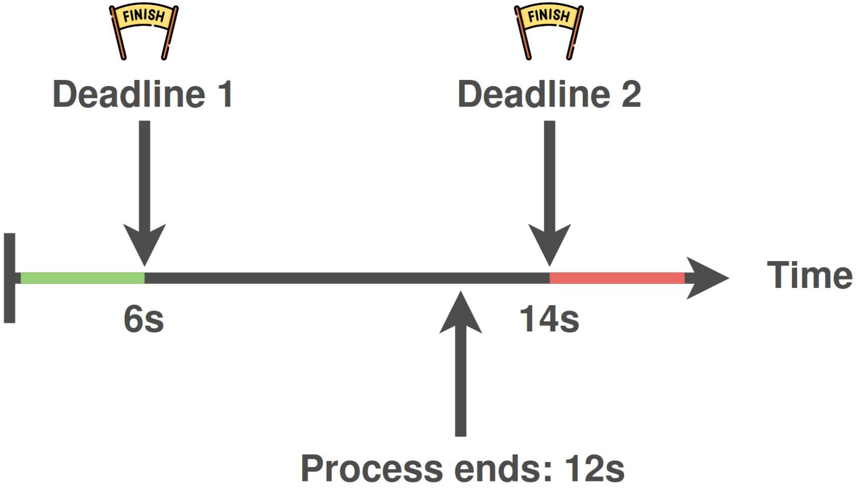
Example 2

- **Deadlines**
  - D1 at 6s
  - D2 at 14s
- **Process ends at 12s**
- $$Value = \frac{(D_2 - x) * 100}{D_2 - D1}$$



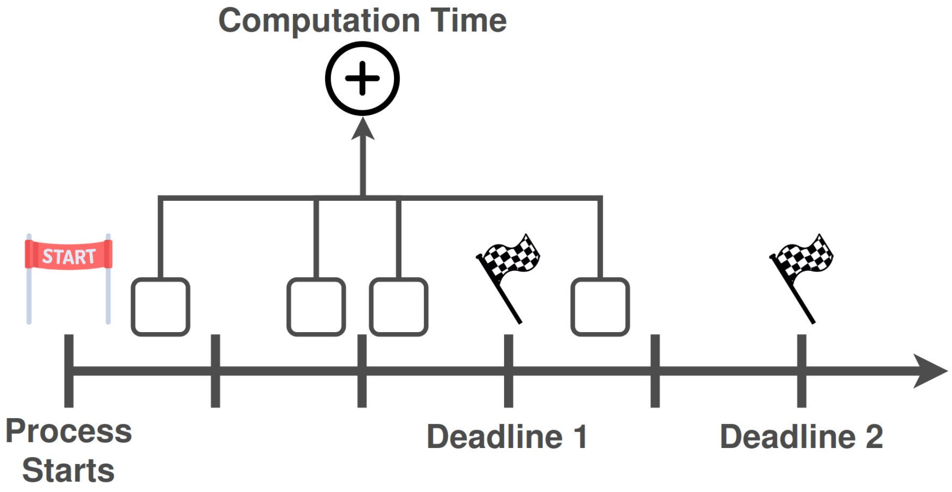
Example 2

- **Deadlines**
  - D1 at 6s
  - D2 at 14s
- **Process ends at 12s**
- $Value = \frac{(D_2 - x) * 100}{D_2 - D1} = \frac{(14 - 12) * 100}{14 - 6} = \frac{200}{8} = 25$



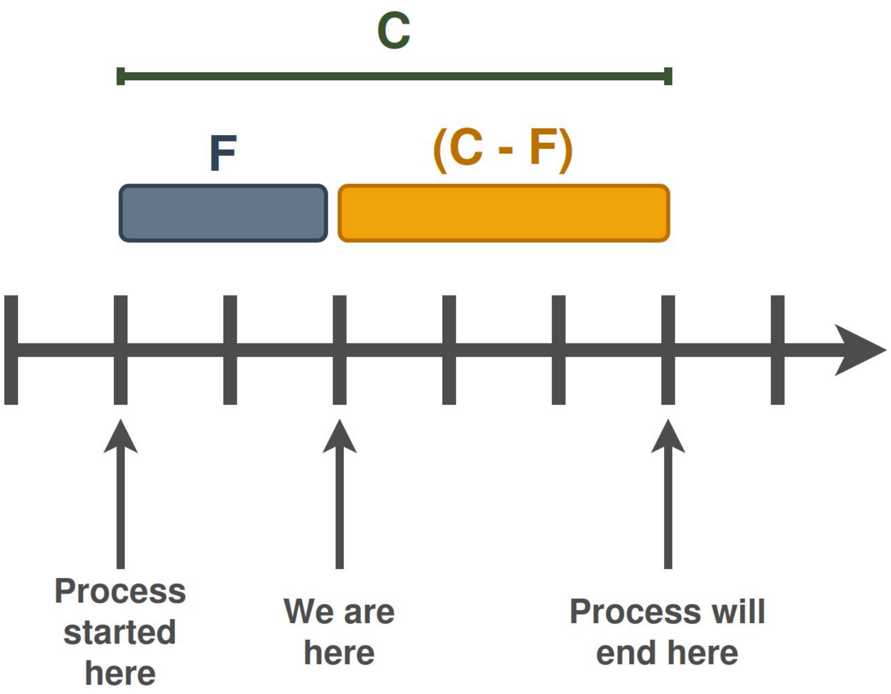
Computation Time

- **How do we know when a process will end?**
  - The process defines its computation time



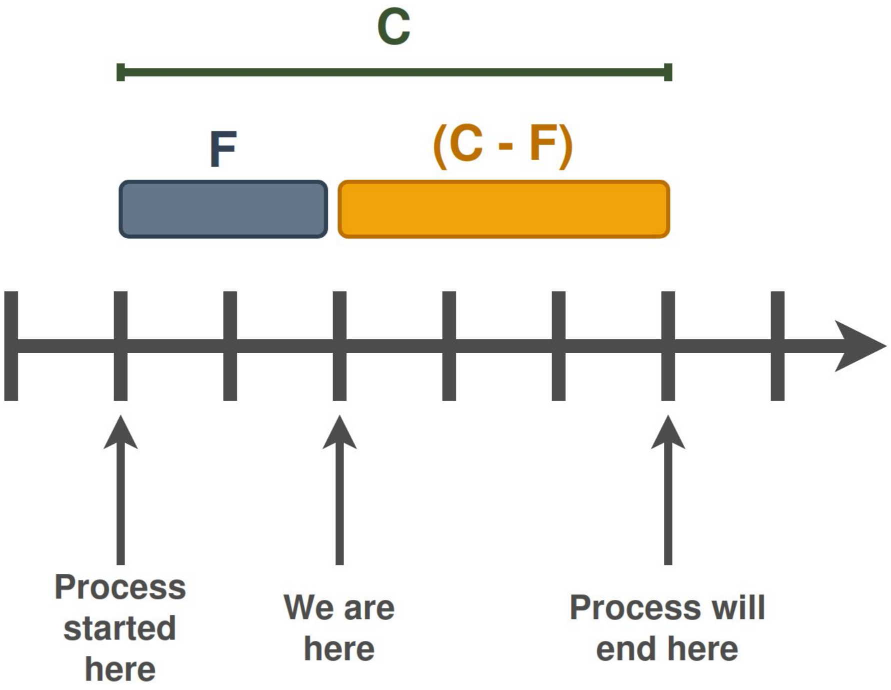
Computation Time

- Process has already run for F ms
- Its computation time is C ms
- Its remaining computation time is (C - F) ms
- Process will end in (C-F) ms from now

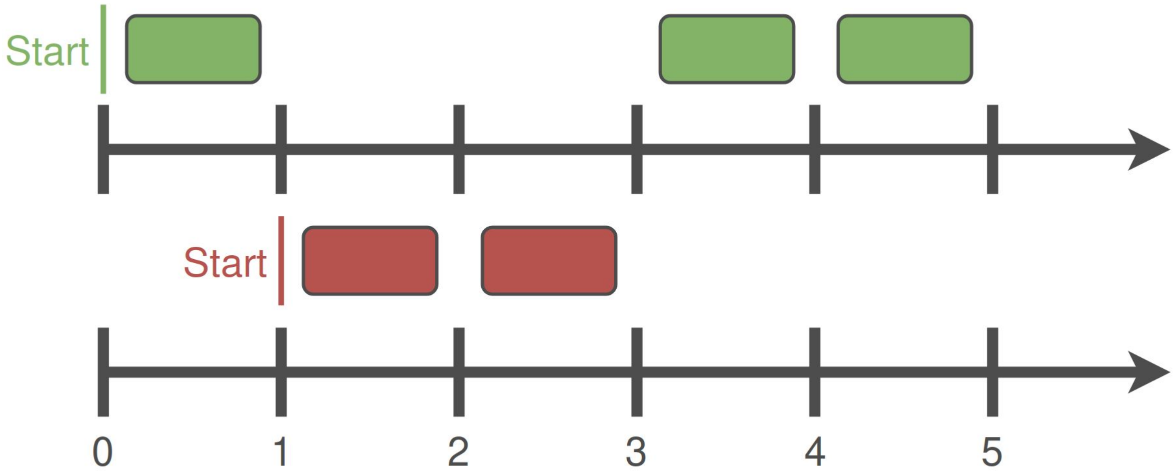


Computation Time

- We already know C because the process has defined it (with system call)
- We need to somehow remember F
- At any time we need to know for how much time the process has already run



Preemption



P1:
Deadline 1: 4s, Deadline 2: 10s, Computation Time: 6s

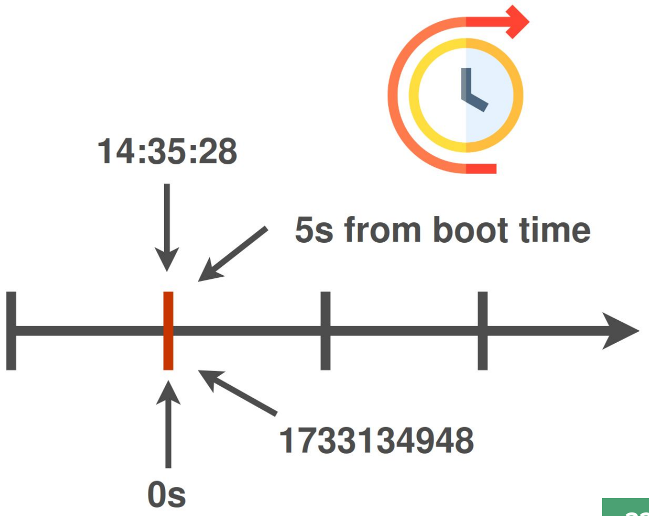
P2:
Deadline 1: 8s, Deadline 2: 11s, Computation Time: 2s

Time	P1	P2
0	$\frac{(10-6)*100}{10-4} = 66$	-
1	$\frac{(10-6)*100}{10-4} = 66$	100
2	$\frac{(10-7)*100}{10-4} = 50$	100
3	$\frac{(10-8)*100}{10-4} = 33$	-
4	$\frac{(10-8)*100}{10-4} = 33$	-
…	…	…

Time

- **How do we measure time?**
  - Do we use absolute values (like in examples)?
  - Do we use wall clock time?
  - Do we use a reference point?

- **Free to choose whatever suits your implementation**



Implementation

- **Use your code from assignment 3**
  - System calls set deadlines
- **Linux kernel compilation process**
  - Instructions in assignment 3
- **Might need to make changes to `task_struct`**

Testing

- **Create simple demo processes**
  - Each initially sets its parameters
- **Each process should spin forever**
  - Infinite loop, not sleep
  - Scheduler will kill process once computation time has been fulfilled
- **Scheduler should print:**
  - PID of the task it selected
  - Its parameters
- **Don’t forget existing processes**
  - Don’t want to schedule only ours


```
[HVF Scheduler][Timestamp: 0] Selected process 1 [D1: 4s, D2: 10s, C: 6] with value  66
[HVF Scheduler][Timestamp: 1] Selected process 2 [D1: 8s, D2: 11s, C: 2] with value 100
[HVF Scheduler][Timestamp: 2] Selected process 2 [D1: 8s, D2: 11s, C: 2] with value 100
[HVF Scheduler][Timestamp: 3] Selected process 1 [D1: 4s, D2: 10s, C: 6] with value  33
[HVF Scheduler][Timestamp: 4] Selected process 1 [D1: 4s, D2: 10s, C: 6] with value  33
```

You can grep this

Notes

Files

- **Actual context switch**
  - kernel/sched.c
- **Completely Fair Scheduler**
  - kernel/sched_fair.c
- **Scheduling structs**
  - include/linux/sched.h
- **Process descriptor**
  - include/linux/sched.h
- **Real-time scheduling**
  - kernel/sched_rt.c

sched.c

```c
asmlinkage void __sched schedule(void) {

struct task_struct *prev, *next;
 ...
struct rq * rq;
 ...
preempt_disable();
 ...
prev = rq->curr;
 ...
pur_prev_task(rq, prev);

next = pick_next_task(rq);

 ...
if (likely(prev != next)) {
 ...
    context_switch(rq, prev, next);
```

Previous and next tasks

The processors runqueue (1 in this assignment)

Disable preemption (avoid schedule inside schedule)

Previous is the current task runnin

Put prev task in the runqueue

The appropriate pick function is called depending on the scheduling class

Actual context switch

Notes

- **Use Bootlin to find functions, structs, etc...**
  - https://elixir.bootlin.com/linux/v2.6.38.1/source

- **You can also map source code using ctags**
  - http://www.tutorialspoint.com/unix_commands/ctags.htm

- **Understand how the scheduler works**
  - Use **printk** to observe kernel behavior
  - Follow the call to find out how the next tasked is picked

Notes

- **Reuse existing code snippets within the kernel**
  - E.g. traversing data structures
- **Compile often with small changes**
  - Massively helps debugging
- **Submit anything you can to show your effort!!!**
  - A **README** file goes a long way
  - Even if your implementation does not fully work

Turnin

What to submit:

1. bzImage
2. Modified or created source files
3. Test programs and headers in Guest OS
4. README

Credit

Icons from FlatIcon, made by Freepik

Thank You!

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Questions?