Assignment 4 Tutorial
Linux Scheduler

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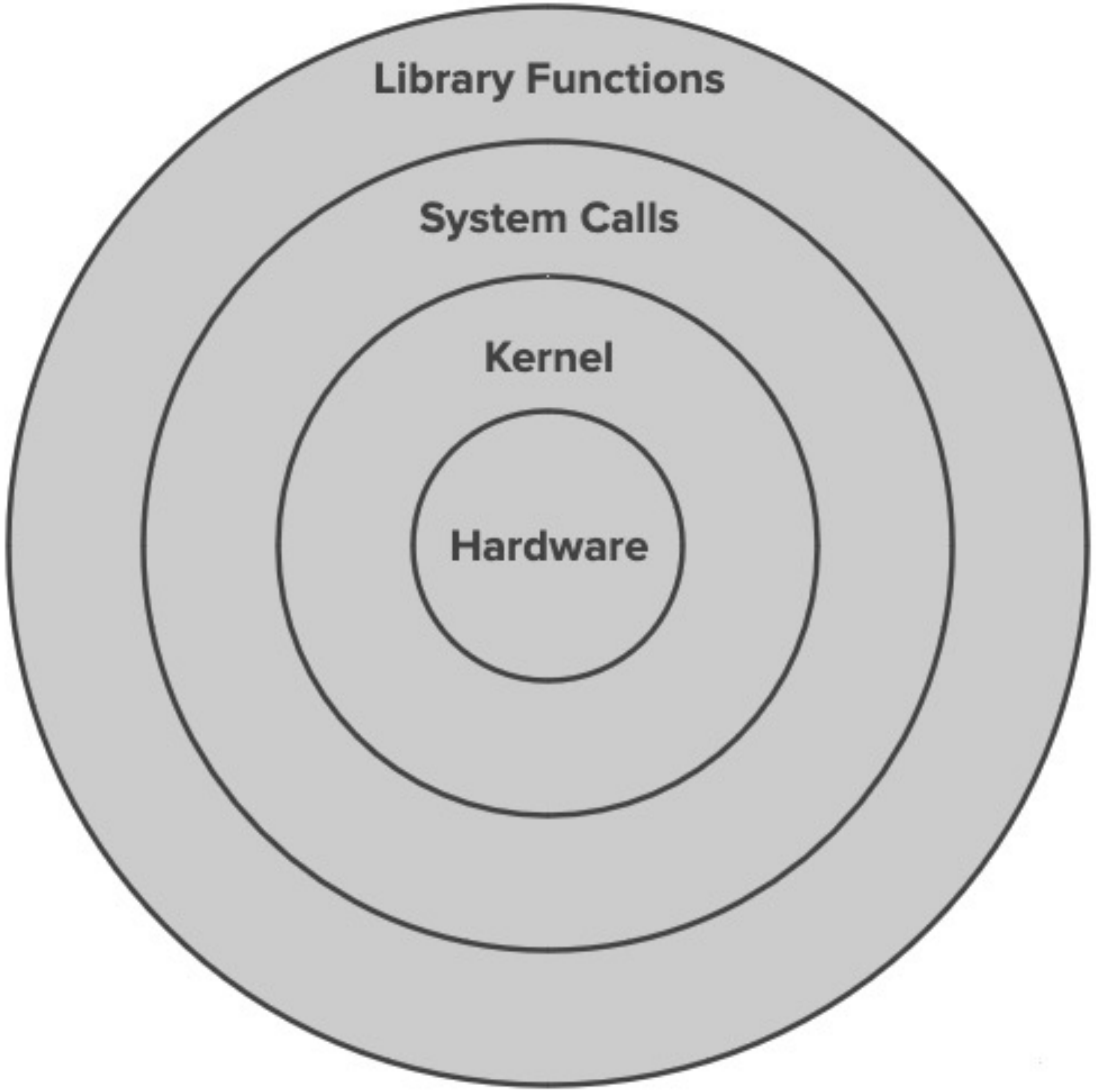
HY345: Operating Systems

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

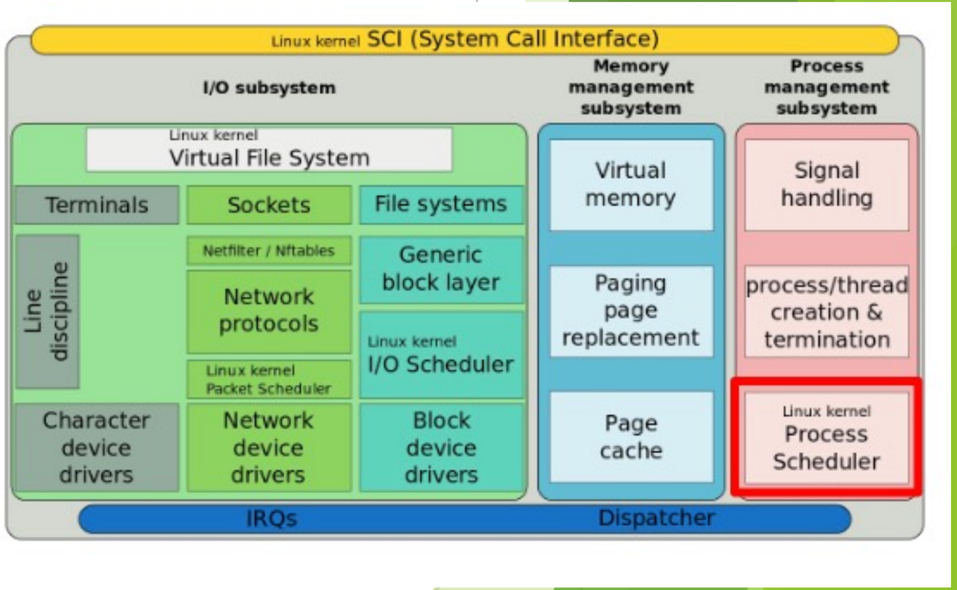


Process Management

- **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**

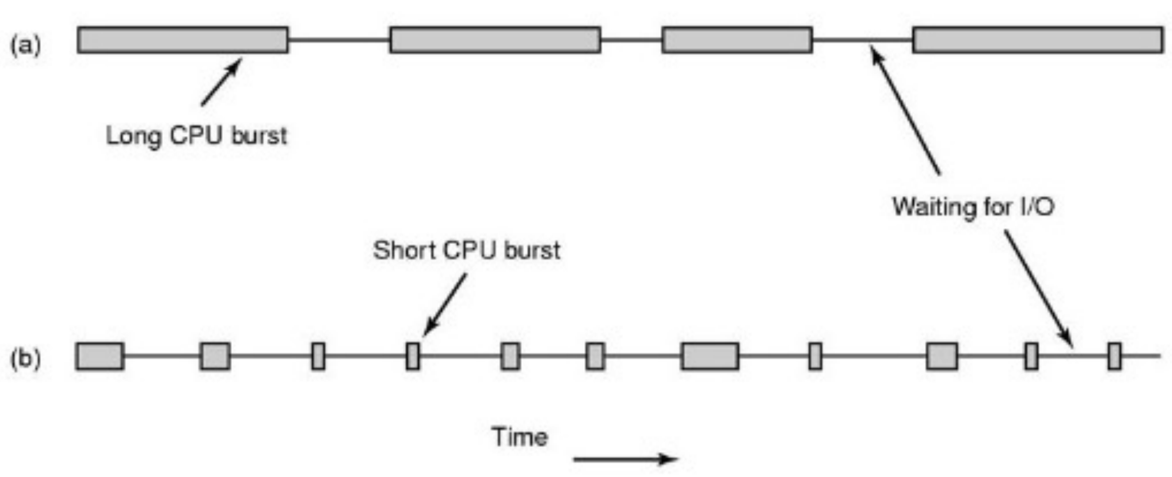
Scheduler

- Coordinates how tasks share the available processors
- Prevents task starvation and preserves fairness
- Take into account system tasks



Task Types

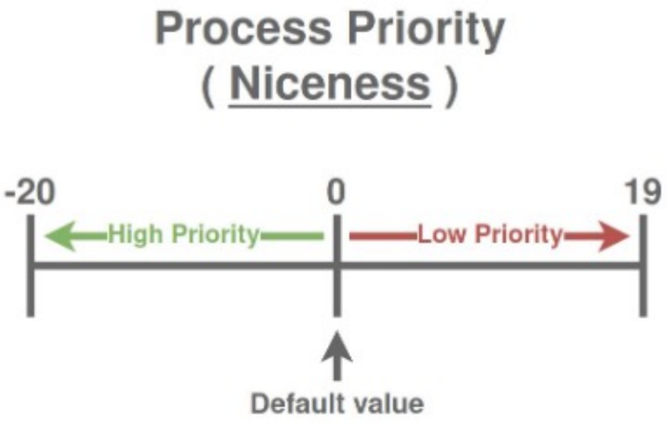
- Balance between two types of processes
  - Batch processes
  - I/O Bound tasks
- Preemption: temporarily evict a running task
- Quantum: Variable but keep it as long as possible



Internals

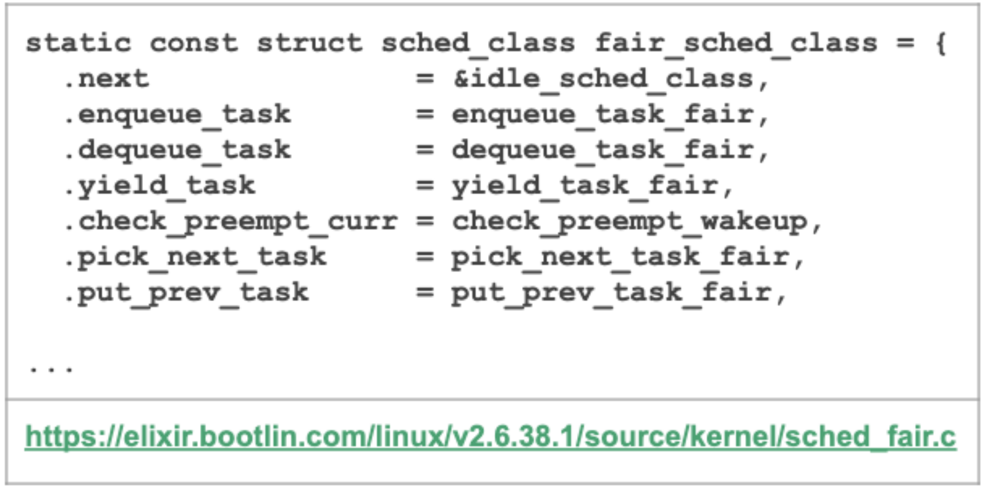
Priority

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



Process Descriptor and scheduler design

- Scheduler needs information for each process
  - task_struct holds multiple information about each process
- Scheduler supports a modular design to easily support different scheduling policies
  - Each task belongs to a scheduling class
  - The scheduling class defines the scheduling policy
  - Some scheduling policies:
    - SCHED_NORMAL – Default linux task policy (CFS, fair)
    - SCHED_FIFO- Special time critical tasks (real-time)
    - SCHED_PR – Round-robin scheduling (real-time)



```
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

The schedule function: schedule(void)

- Main scheduler function is schedule(void) – kernel/sched.c
  - It replaces the currently executing process with another
- Called from different places
  - Periodic scheduler
  - Current task enters sleep state
  - Sleeping task wakes up

```
/*
 * schedule() is the main scheduler function.
 */
asmlinkage void __sched schedule(void)
{
        struct task_struct *prev, *next;
        unsigned long *switch_count;
        struct rq *rq;
        int cpu;

need_resched:
        preempt_disable();
        cpu = smp_processor_id();
        rq = cpu_rq(cpu);
        rcu_note_context_switch(cpu);
        prev = rq->curr;

        release_kernel_lock(prev);
need_resched_nonpreemptible:

        schedule_debug(prev);

        if (sched_feat(HRTICK))
                hrtick_clear(rq);

        raw_spin_lock_irq(&rq->lock);

        switch_count = &prev->nivcsw;
        if (prev->state && !(preempt_count() & PREEMPT_ACTIVE)) {
                if (unlikely(signal_pending_state(prev->state, prev))) {
                        prev->state = TASK_RUNNING;
                } else {
                        /*
                         * If a worker is going to sleep, notify and
                         * ask workqueue whether it wants to wake up a
                         * task to maintain concurrency.  If so, wake
                         * up the task.
                         */
                        if (prev->flags & PF_WQ_WORKER) {
                                struct task_struct *to_wakeup;

                                to_wakeup = wq_worker_sleeping(prev, cpu);
                                if (to_wakeup)
                                        try_to_wake_up_local(to_wakeup);
                        }
```

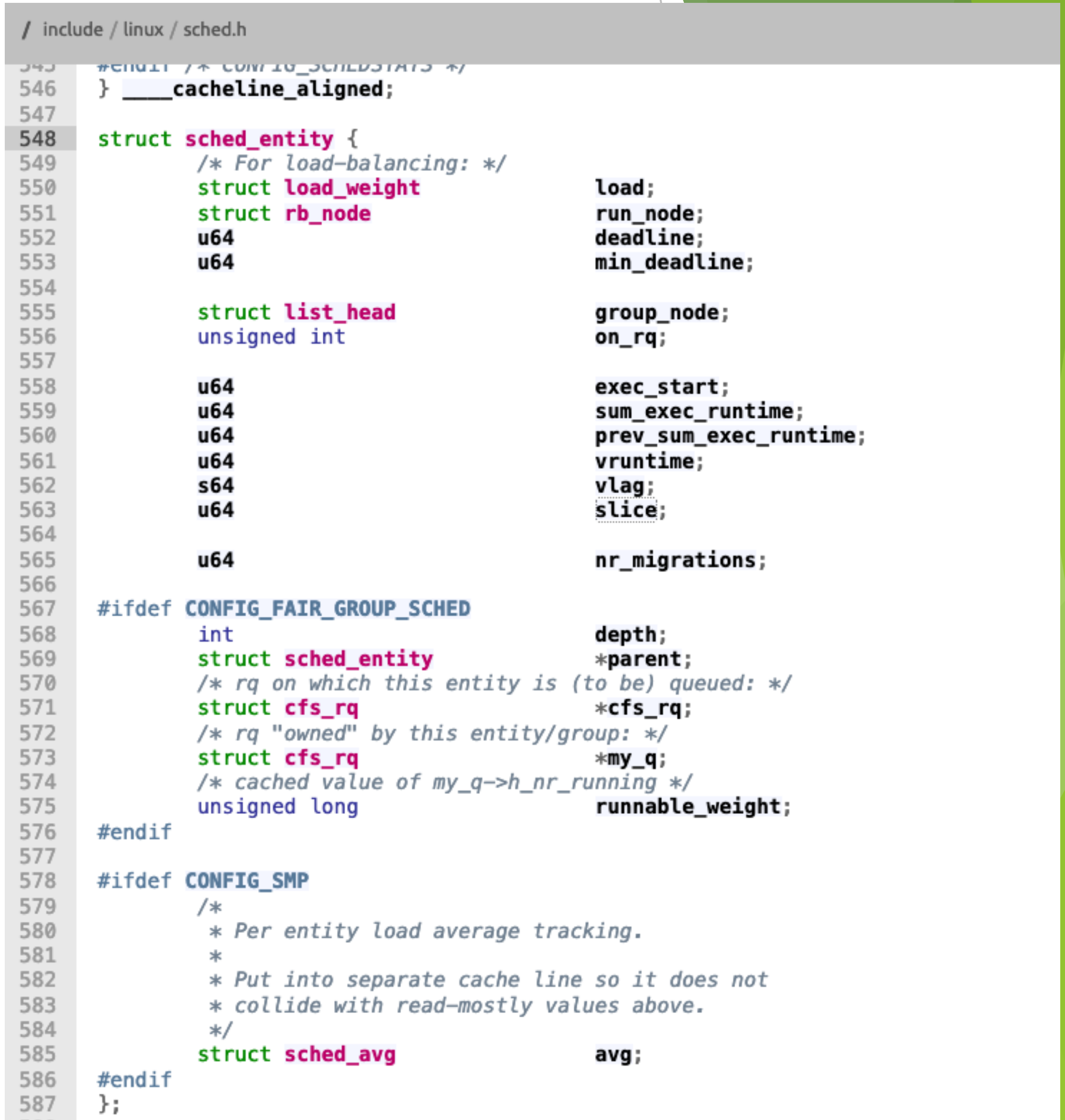
Run queue

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

```
/*
 * This is the main, per-CPU runqueue data structure.
 *
 * Locking rule: those places that want to lock multiple runqueues
 * (such as the load balancing or the thread migration code), lock
 * acquire operations must be ordered by ascending &runqueue.
 */
struct rq {
        /* runqueue lock: */
        raw_spinlock_t lock;

        /*
         * nr_running and cpu_load should be in the same cacheline because
         * remote CPUs use both these fields when doing load calculation.
         */
        unsigned long nr_running;
        #define CPU_LOAD_IDX_MAX 5
        unsigned long cpu_load[CPU_LOAD_IDX_MAX];
        unsigned long last_load_update_tick;
#ifdef CONFIG_NO_HZ
        u64 nohz_stamp;
        unsigned char nohz_balance_kick;
#endif
        unsigned int skip_clock_update;

        /* capture load from *all* tasks on this cpu: */
        struct load_weight load;
        unsigned long nr_load_updates;
        u64 nr_switches;

        struct cfs_rq cfs;
        struct rt_rq rt;

#ifdef CONFIG_FAIR_GROUP_SCHED
        /* list of leaf cfs_rq on this cpu: */
        struct list_head leaf_cfs_rq_list;
#endif
#ifdef CONFIG_RT_GROUP_SCHED
        struct list_head leaf_rt_rq_list;
#endif
```

Sched_entity

- Every task_struct has a sched_entity
  - It’s a schedulable object
- Contains timing information used for load balancing and scheduling.


/ include / linux / sched.h

```
#endif /* CONFIG_SCHEDSTATS */
} ____cacheline_aligned;

struct sched_entity {
        /* For load-balancing: */
        struct load_weight              load;
        struct rb_node                  run_node;
        u64                             deadline;
        u64                             min_deadline;

        struct list_head                group_node;
        unsigned int                    on_rq;

        u64                             exec_start;
        u64                             sum_exec_runtime;
        u64                             prev_sum_exec_runtime;
        u64                             vruntime;
        s64                             vlag;
        u64                             slice;

        u64                             nr_migrations;

#ifdef CONFIG_FAIR_GROUP_SCHED
        int                             depth;
        struct sched_entity             *parent;
        /* rq on which this entity is (to be) queued: */
        struct cfs_rq                   *cfs_rq;
        /* rq "owned" by this entity/group: */
        struct cfs_rq                   *my_q;
        /* cached value of my_q->h_nr_running */
        unsigned long                   runnable_weight;
#endif

#ifdef CONFIG_SMP
        /*
         * Per entity load average tracking.
         *
         * Put into separate cache line so it does not
         * collide with read-mostly values above.
         */
        struct sched_avg                avg;
#endif
};
```

Linux Kernel source files

- Browse easily through the Linux Kernel source files using this link
  - https://elixir.bootlin.com/linux/v2.6.38.1/source
- Actual context switch code, runqueue struct definition, etc.
  - kernel/sched.c https://elixir.bootlin.com/linux/v2.6.38.1/source/kernel/sched.c
- Implementation of Completely Fair Scheduling (CFS)
  - kernel/sched_fair.c https://elixir.bootlin.com/linux/v2.6.38.1/source/kernel/sched_fair.c
- Implementation of Real-Time Scheduling (RT)
  - kernel/sched_rt.c https://elixir.bootlin.com/linux/v2.6.38.1/source/kernel/sched_rt.c
- Tasks are abstracted as struct sched_entity and struct sched_rt_entity (for rt class); Also, check struct sched_class
  - include/linux/sched.h https://elixir.bootlin.com/linux/v2.6.38.1/source/include/linux/sched.h

History

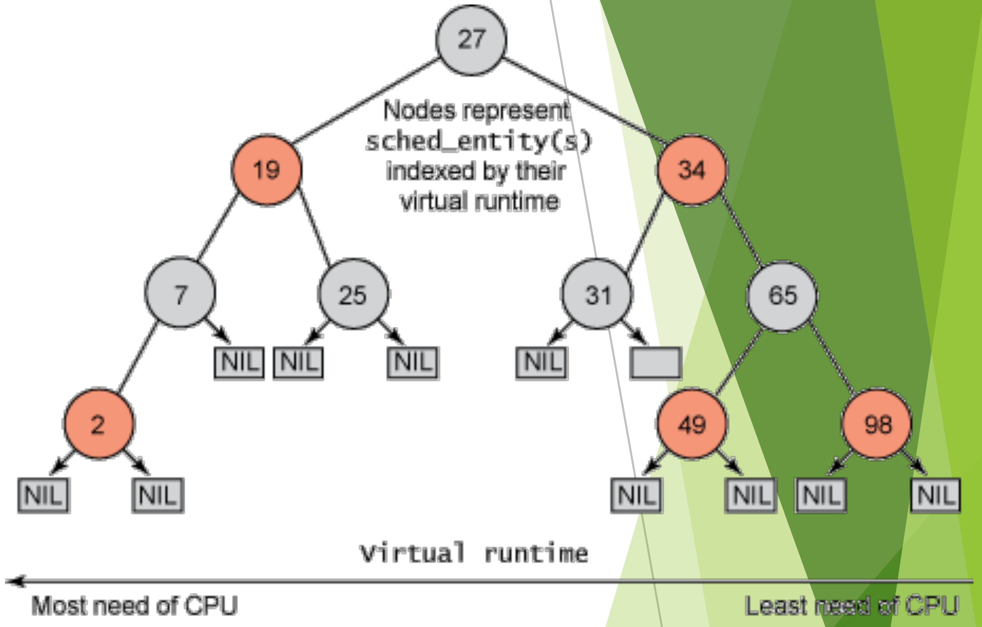
- Genesis
  - Circular queue
  - Round-robin policy
- Linux v2.4 - O(n) scheduler
  - Each task runs a quantum of time in each epoch
  - Epoch advances after all runnable tasks have their quantum
  - At the beginning of each epoch, all tasks get a new quantum
- Linux v2.6 - O(1) Scheduler
  - Division between real-time and normal tasks
  - One list per priority
- Linux v2.6.23 – CFS
  - Introduced in 2007, Improved in 2016

Completely Fair Scheduling

- 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 Scheduling

- Time-ordered red-black tree
  - Runnable tasks are sorted by vruntime
- When a task is executed its vruntime increases
  - Moves to the right of the tree
- Scheduler always selects leftmost leaf
  - Task with the smallest vruntime
- The leftmost node is cached (O(1) access)
- Reinsertion of a preempted task takes O(logn)



Assignment 4 – Group Fairness Scheduling algorithm

- **Implement the Group Fairness scheduling algorithm, which assigns equal portion of the CPU to groups and equal equal portion to the processes inside a group**

- **Process runtime: T(process_params, number_of_groups) = 100/number_of_groups/number_of_processes_in_group(process_params.group_name)**

- **Use your code from Assignment 3**

- **Use the guidelines from Assignment 3 to compile and run the Linux kernel**

Assignment 4 – Group Fairness Scheduling algorithm

- Each process is assigned to a group during creation
- Each groups get an equal share of the CPU
  - For N groups: 100/N
- Each process inside a group gets an equal percentage of the group's share
  - For M processes inside the group: 100/N/M
- Process runtime: T(process_params, number_of_groups) = 100/number_of_groups/number_of_processes_in_group(process_params.group_name)

Assignment 4 – Group Fairness Scheduling algorithm

- Process A1 starts and it’s assigned to group A:
  - Process A1 gets 100% of the CPU since A is the only group and process A1 is the only process in this group (100/1/1)
- Process A2 starts and it’s assigned to group A:
  - Process A2 gets 50% of the CPU since A is the only group and process A2 is the only process in this group (100/1/2). The portion of A1 also need to be recalculated
- Process B1 starts and it’s assigned to group B:
  - Process B1 gets 50% of the CPU since now there are 2 groups (A,B) and on B there is only one process B1 (100/2/1)
  - Process A1 and A2 need to recalculate their CPU portions since now there are 2 groups (100/2/2) and they need to update their portion to 25%
- Process A3 start and it’s assigned to group A:
  - Process A3 gets 16.6% of the CPU since there are 2 groups and 3 processes to group A (100/2/3)
  - Processes A1 and A2 need to recalculate their portions
  - Process B1 portion doesn’t change since it’s in a different group

Assignment 4 – Helpful tips

- When a new process is starting or the scheduler selects the next process
- Scan all the processes in the run queue list
- Count the number of different groups and number of processes in the groups
- Update the portions of CPU time per slice for each process
- Processes can be added or removed, so remember to check

Assignment 4 – Demo

- Create simple demo processes
  - Each process sets its parameters
- Each processes should spin for some time
  - Infinite loop, not sleep
- The scheduler should print:
  - The PID of the task it selected
  - Its parameters
  - Its portion of the CPU

Assignment 4 – More Notes

- Browse kernel code with: https://elixir.bootlin.com/linux/v2.6.38.1/source
- Another way to map source code is by using ctag:
  - http://www.tutorialspoint.com/unix_commands/ctags.htm
- Understand how the scheduler works
  - For example, you can start with printing inside the schedule() function
- Follow the function call path from schedule in order to find out how the next task is picked
- Use the printk() function often, its syntax is close to printf and it’s an easy way to observe the kernel’s behaviour from the user level (with dmesg)
- Reuse existing code snippets within the kernel source code (e.g., to traverse data structures or access members in struct nodes)
- Compile after small changes in the source code (good for easy debugging)
- Submit ANYTHING you can that helps you show your effort!

Assignment 4 – Turnin

1. bZImage
2. Modified or created source files
3. Test programs and headers in Guest OS
4. README - Document your effort, and it can go a long way!