2022 FALL OS
Project 2 Help Document

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NOTE

- 과제 **#2**

  기한: 11/05 midnight

  방법: 팀별 repository에 proj2 branch 생성 / 발표자료는 대표 한 명이 etl 제출

- 과제 **#3**

  기한: 11/26 midnight

  방법: 팀별 repository에 proj3 branch 생성 / 발표자료는 대표 한 명이 etl 제출

What you did in project 0

1. Build your kernel
2. Make image files
3. emulate Tizen with QEMU

What you did in project 1

1. Implement a ptree system call as a kernel module
2. run the evaluation on QEMU

Project 2 Overview

- Design and implement WRR (Weighted Round-Robin) scheduler
  - Define and implement a new scheduler
    - Implement load balancing mechanism
  - Examine the scheduler performance with trial
  - Improve the scheduler
    - Open question

WRR Scheduler

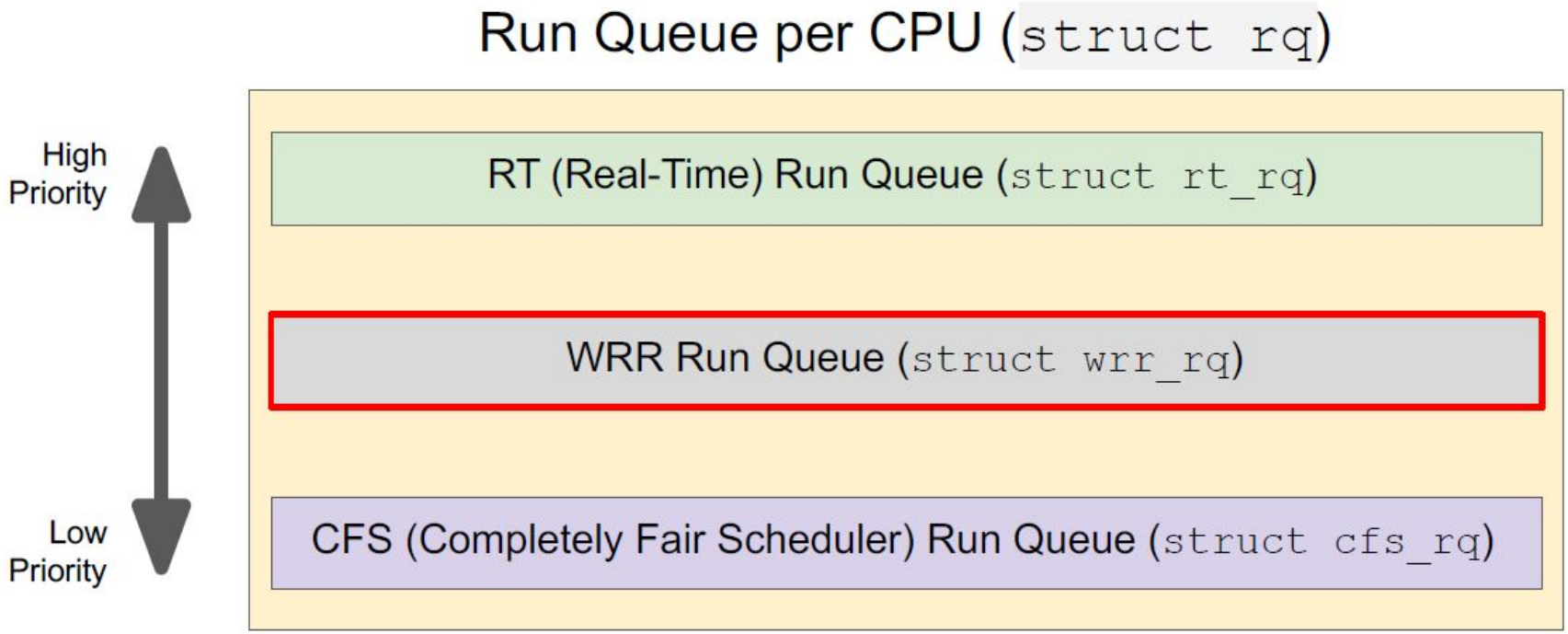
Linux Scheduler Basics

- Multi-level scheduling
  - Real-time tasks has priority over other tasks
- Real-time tasks: FCFS, RR, DL, …
- Other tasks: CFS
- Each CPU maintains separate run queues for tasks
  - To prevent contention while accessing run queue

WRR Scheduler

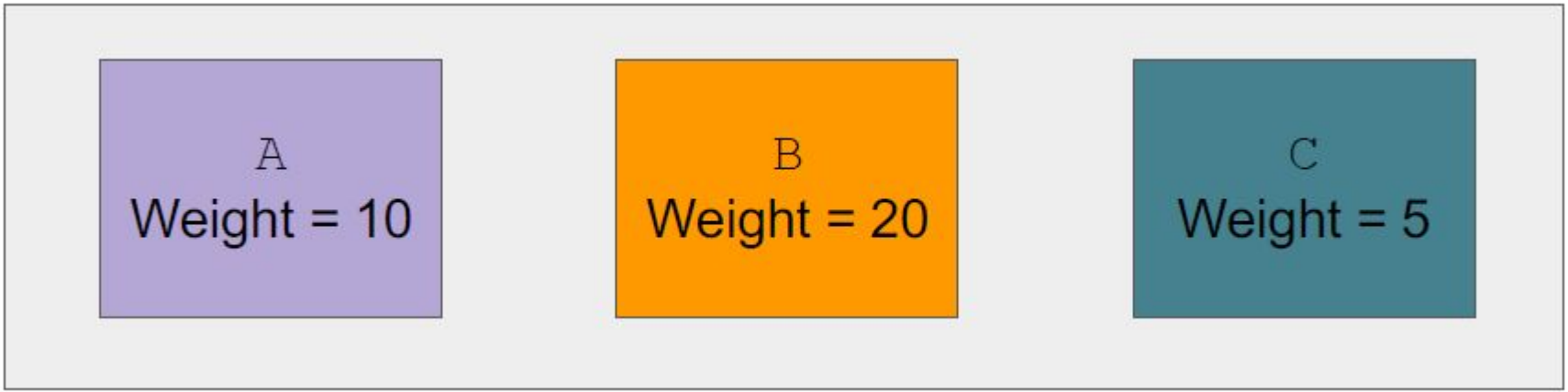
- Weighted Round-Robin Scheduler
- Tasks are executed in a round-robin fashion, but get different time slices according to their weights
  - Default weight is 10
  - Time slice = Weight * 10ms
- Priority: RT > WRR > CFS
- Load balancing

Multi-level Run Queue with WRR



WRR Scheduling EXAMPLE

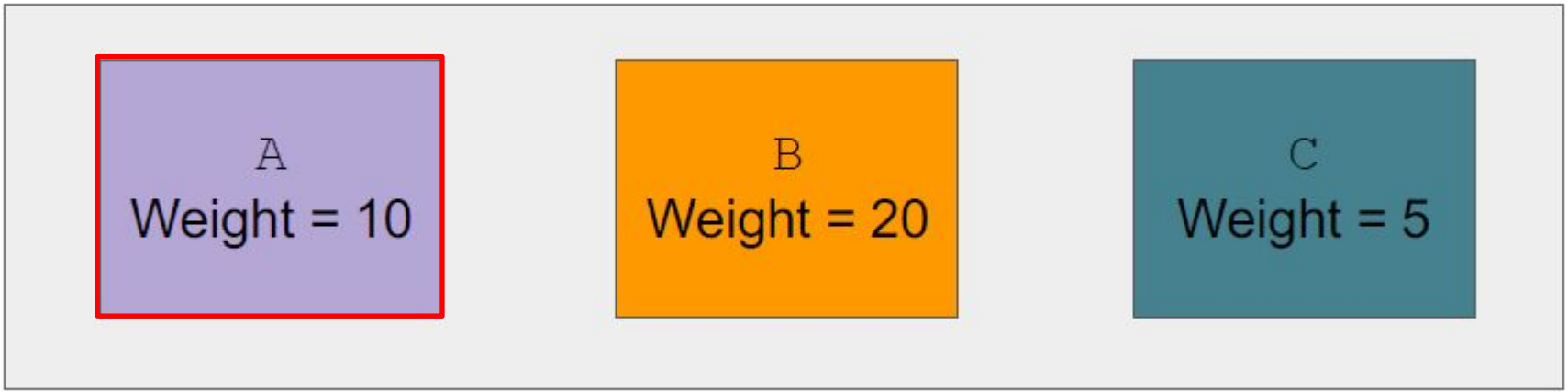
- Three tasks currently in WRR queue



WRR Scheduling EXAMPLE

T= 0ms

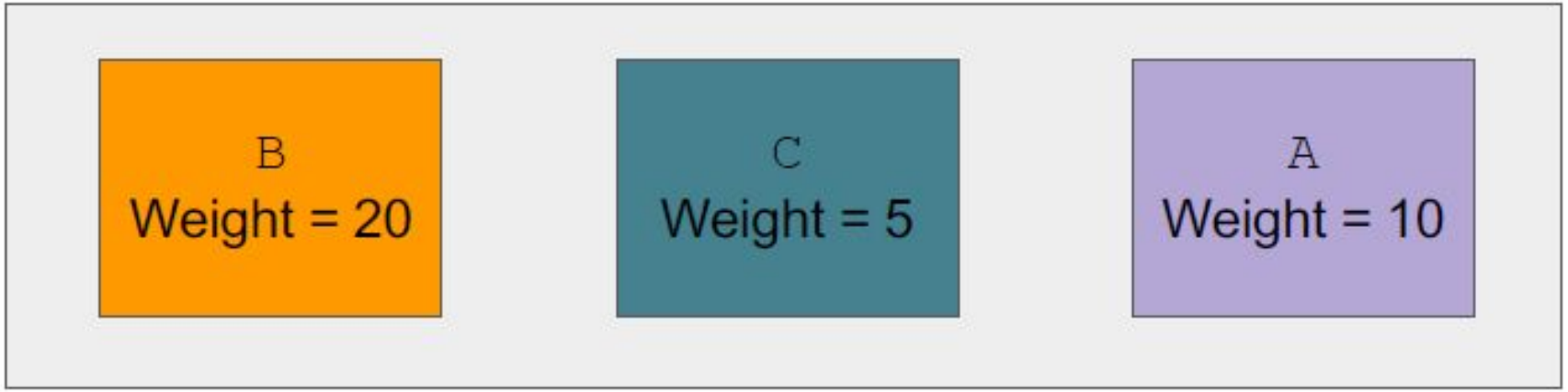
A starts running first



WRR Scheduling EXAMPLE

T = 100ms (Δt = 100ms)

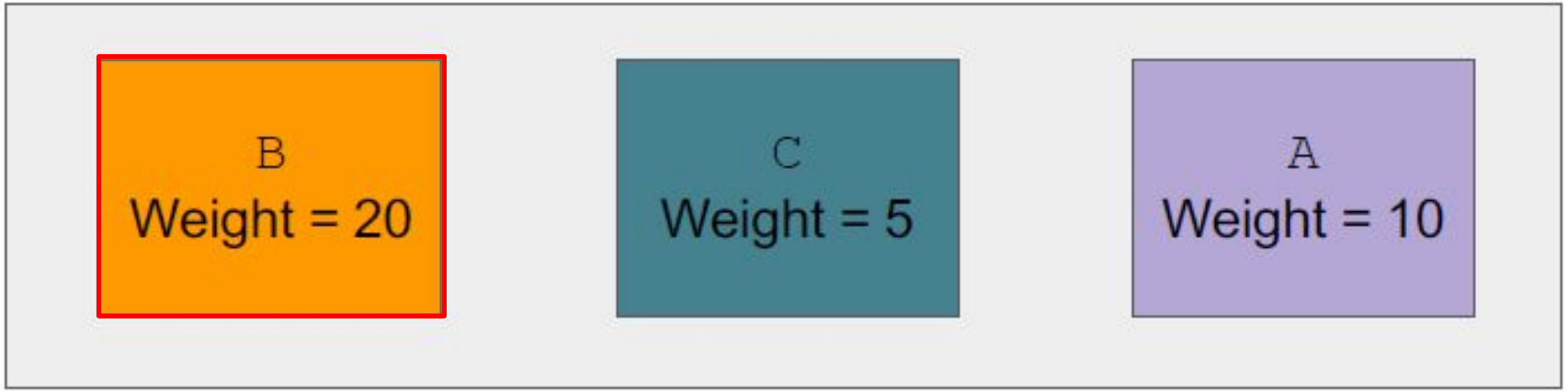
A stops and is moved to the tail of the run queue because the task is not finished



WRR Scheduling EXAMPLE

T = 100ms

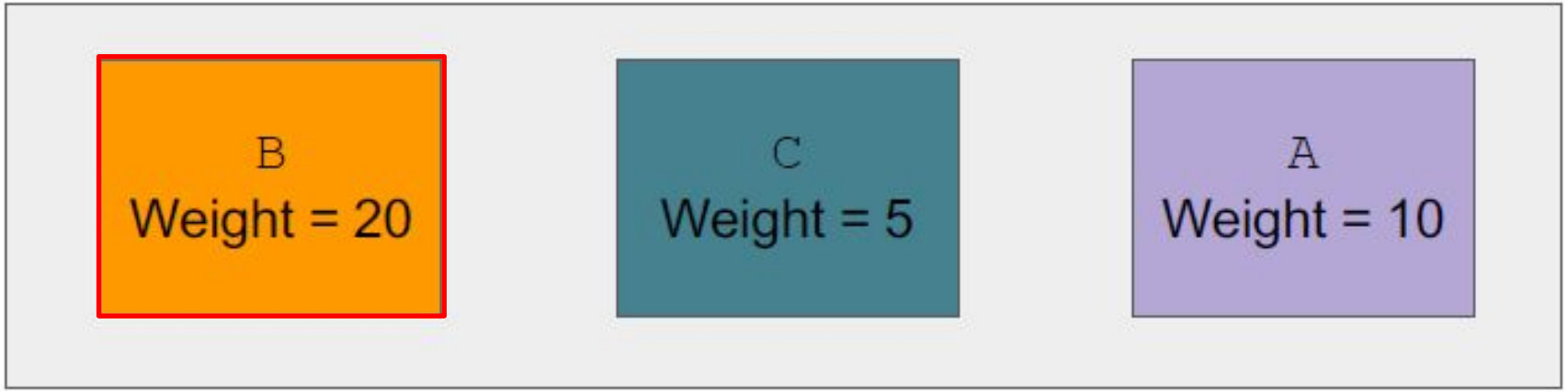
… and the next task (B) starts running



WRR Scheduling EXAMPLE

T = 200ms (Δt = 100ms)

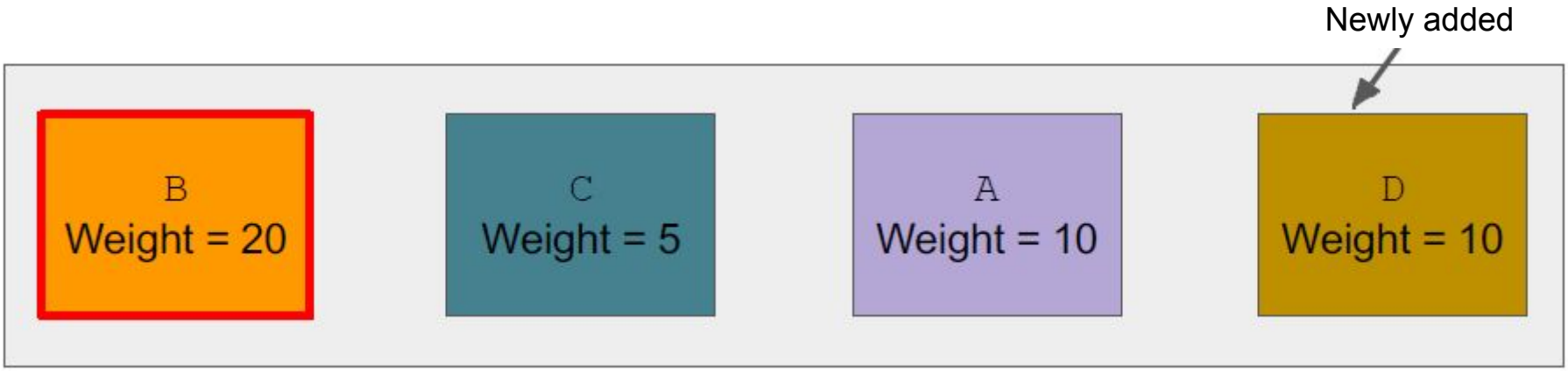
B is still running, because its time slice is 200ms



WRR Scheduling EXAMPLE

T = 250ms (Δt = 50ms)

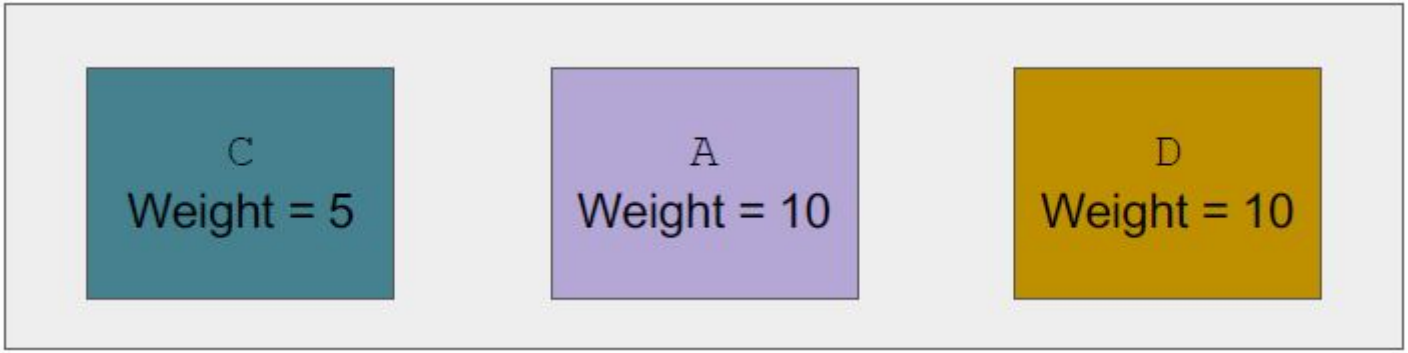
D comes in, and is added to the tail of the run queue



WRR Scheduling EXAMPLE

T = 280ms (Δt = 30ms)

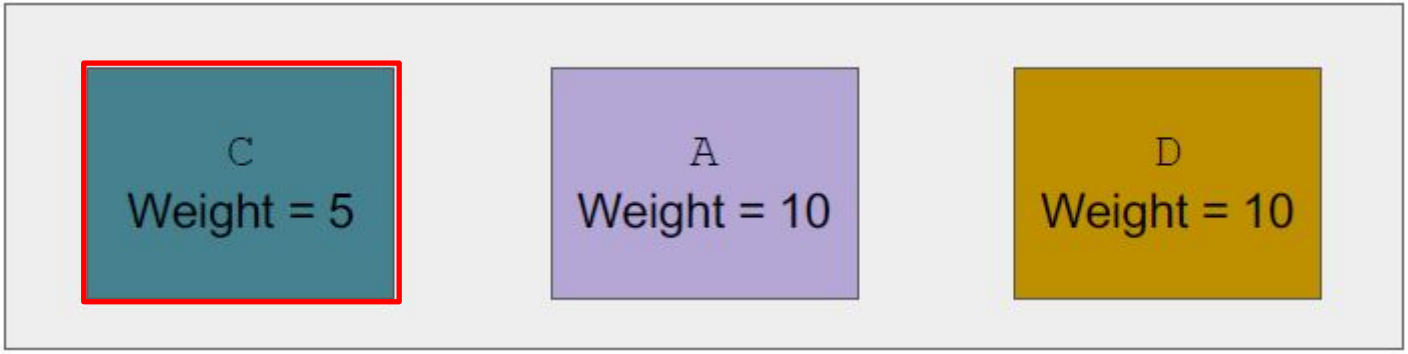
B finished its work and is terminated; now removed from the run queue…



WRR Scheduling EXAMPLE

T = 280ms

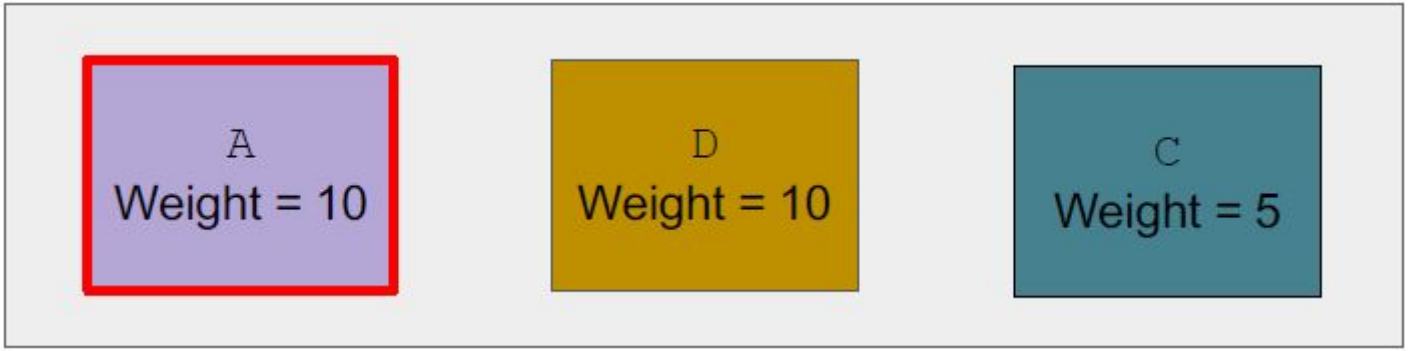
… and c starts running



WRR Scheduling EXAMPLE

T = 330ms (Δt = 50ms)

C is stopped and is moved to the tail. A starts running again



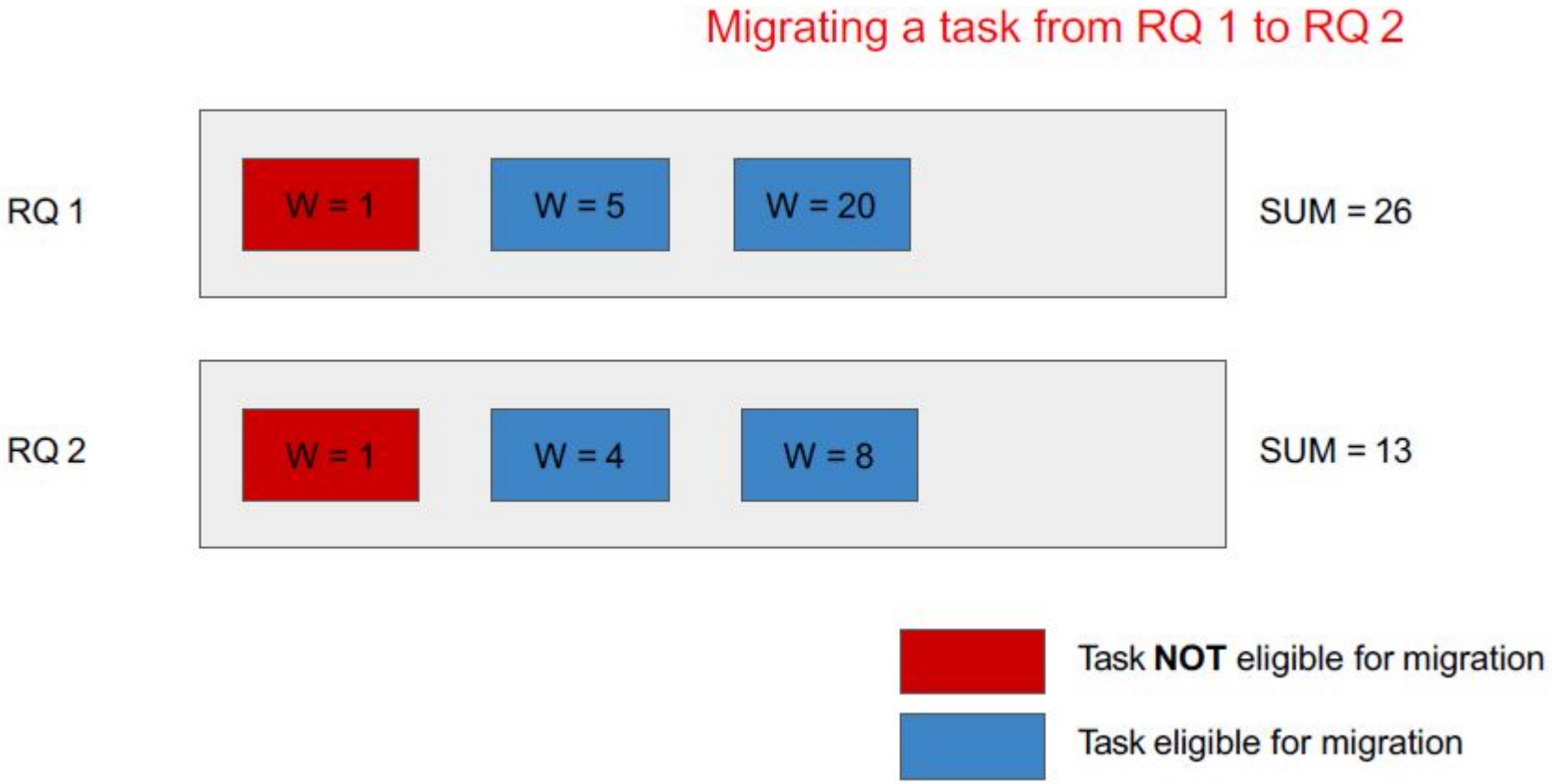
Load Balancing

- Balance load among the run queue of each CPU
- Make sure that it only works when more than one CPU is active
  - CPU hotplug
  - `for_each_online_cpu(cpu)`
- **Leave one run queue empty!**
- Should be attempted every 2000ms

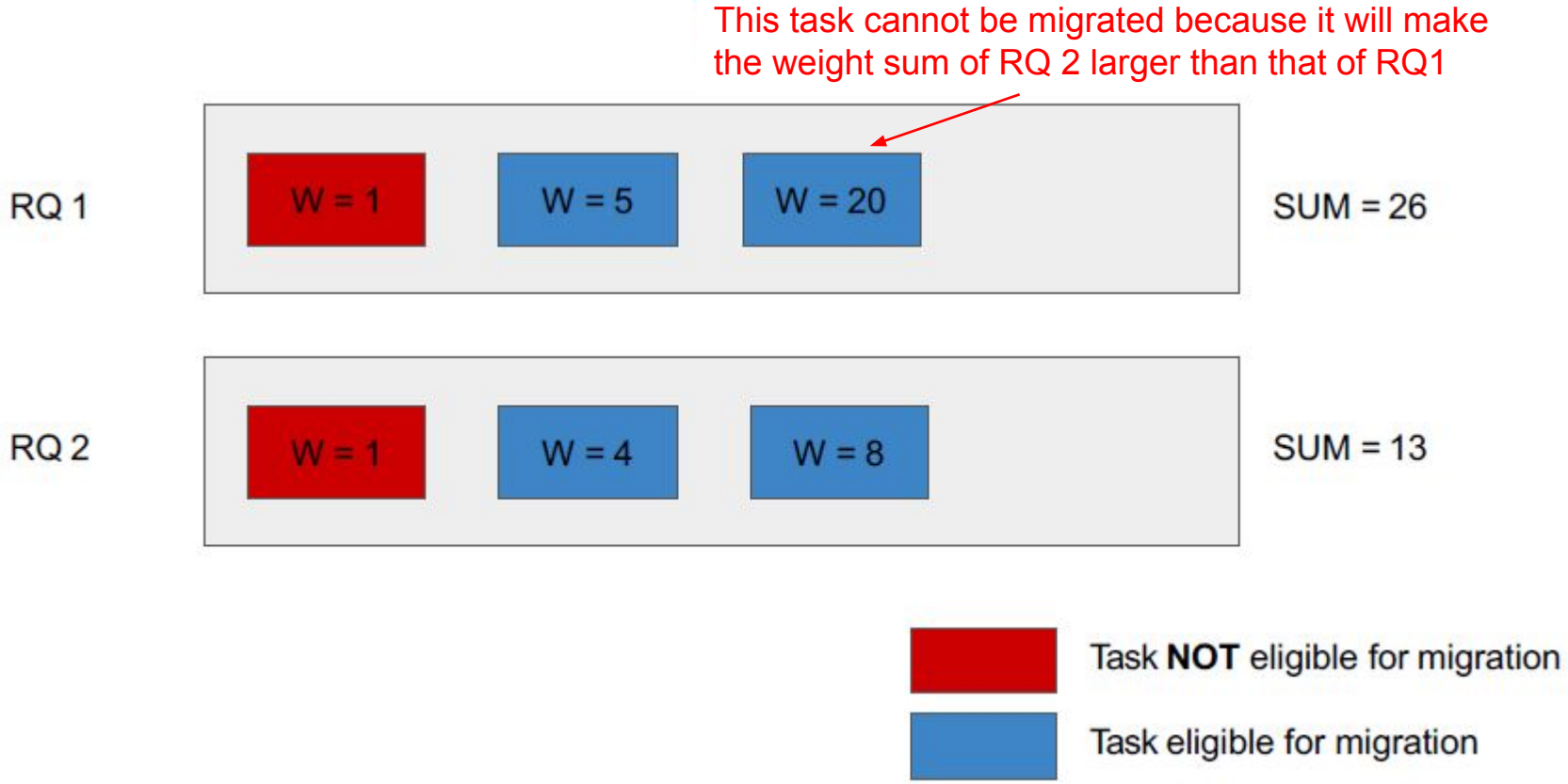
LOAD Balancing Algorithm

- Pick two run queues with the minimum weight sum and the maximum weight sum
  - Call them `RQ_MIN` and `RQ_MAX` respectively
- Pick a task with the largest weight among tasks that satisfy the following conditions:
  - The picked task should be able to be migrated to `RQ_MIN`
  - Migration should not cause weight of `RQ_MIN` to become **bigger than or equal** to `RQ_MAX`
  - Tasks currently running are not eligible for migration
- Migrate if an eligible task exists
  - There may be no eligible task

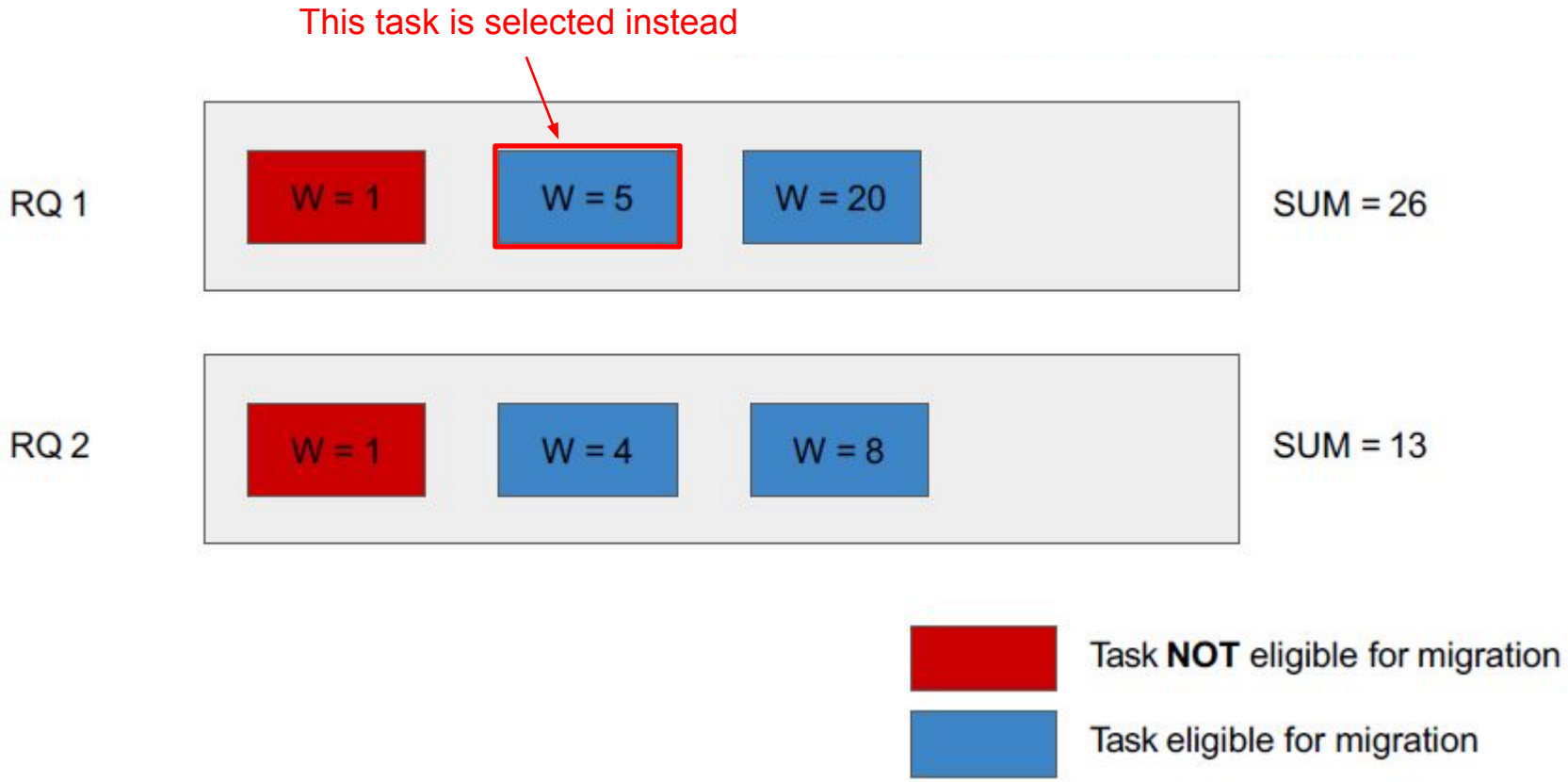
Load Balancing Example



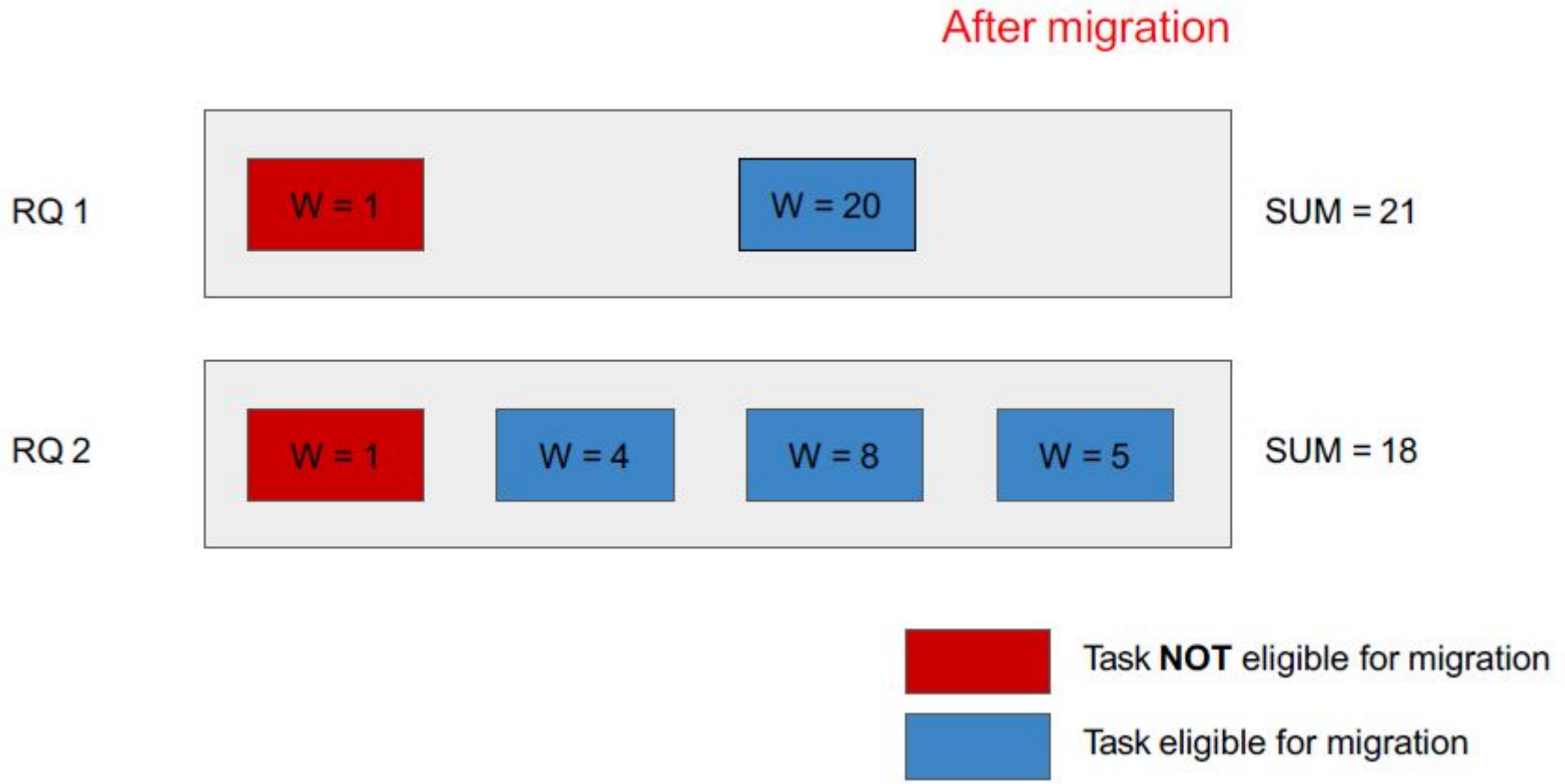
Load Balancing Example



Load Balancing Example

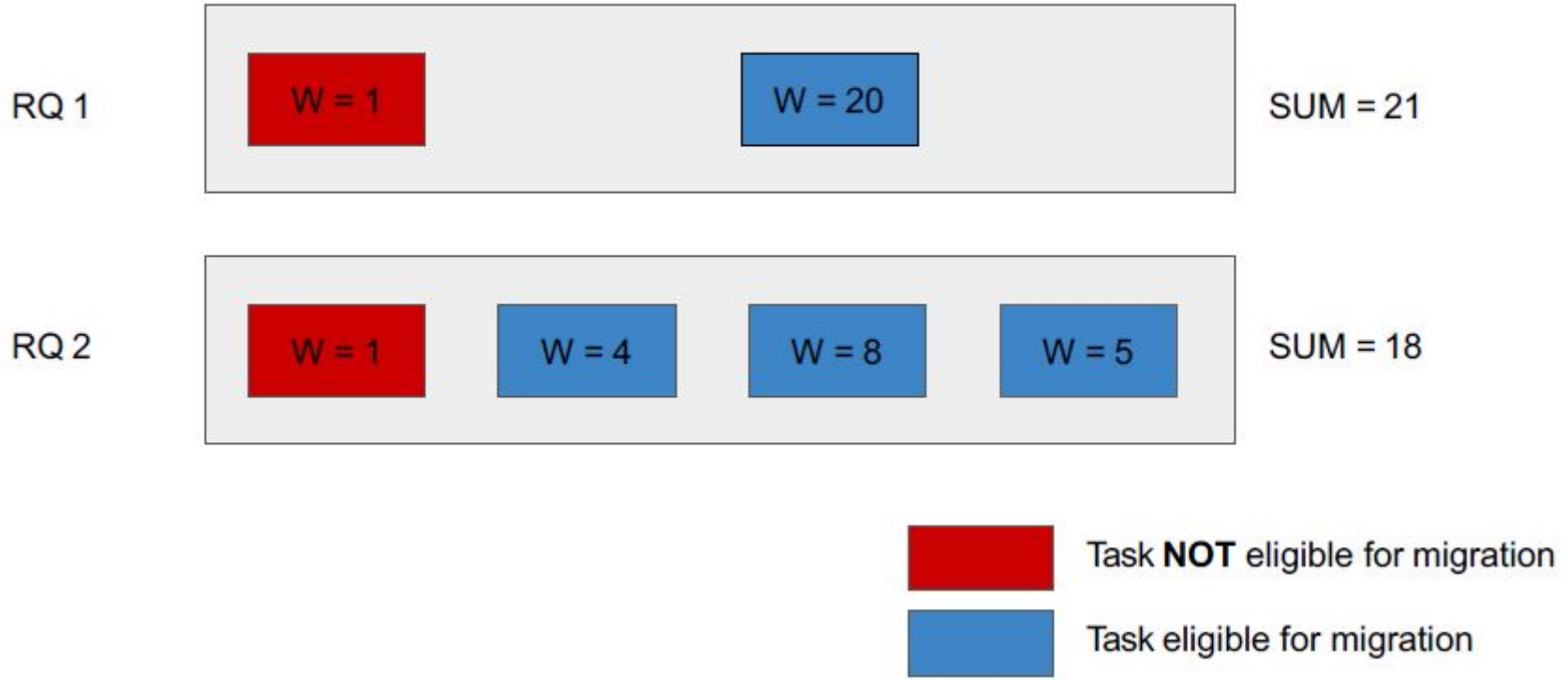


Load Balancing Example

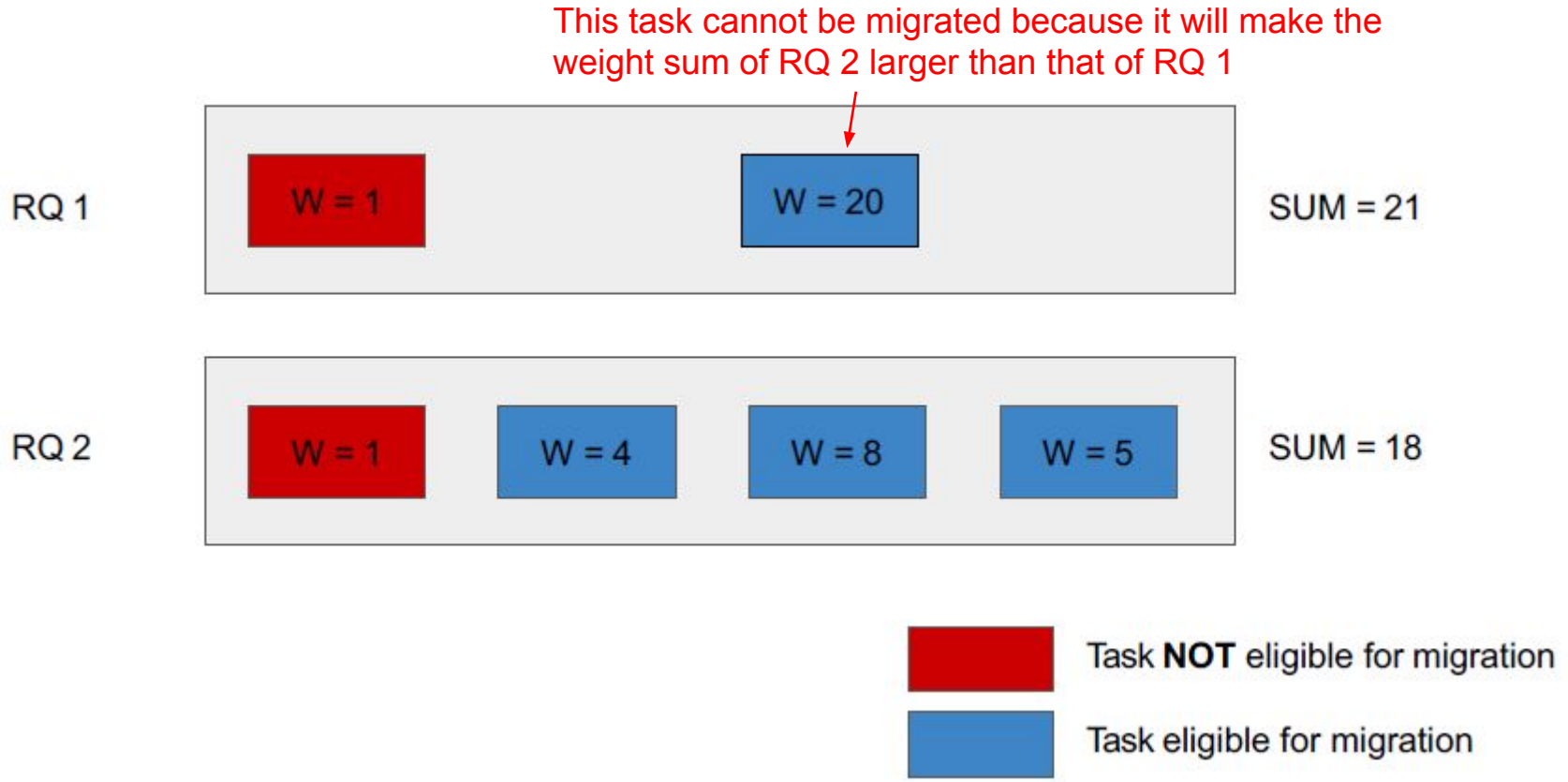


Load Balancing Example

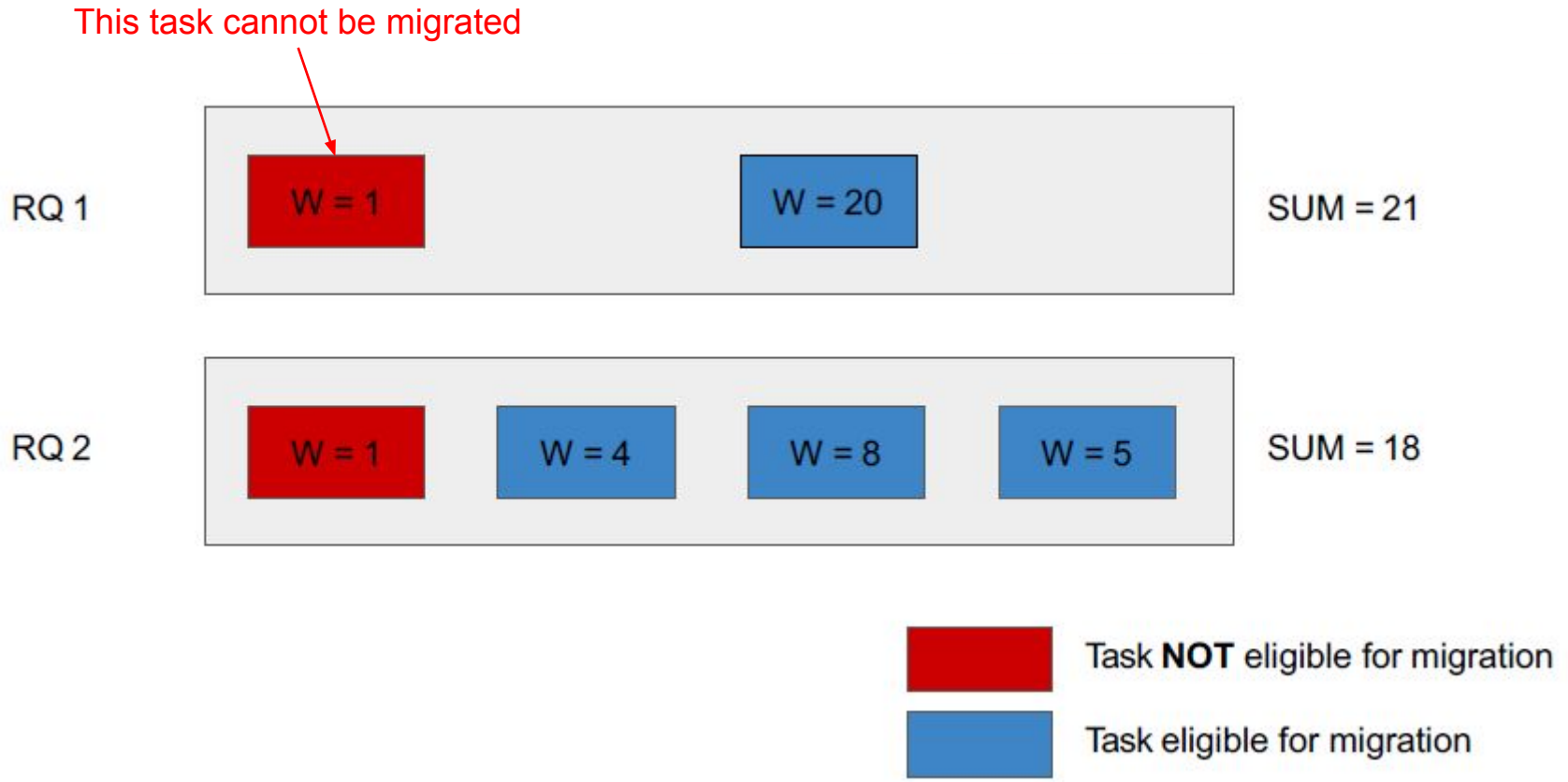
Migrating a task from RQ 1 to RQ 2 again



Load Balancing Example

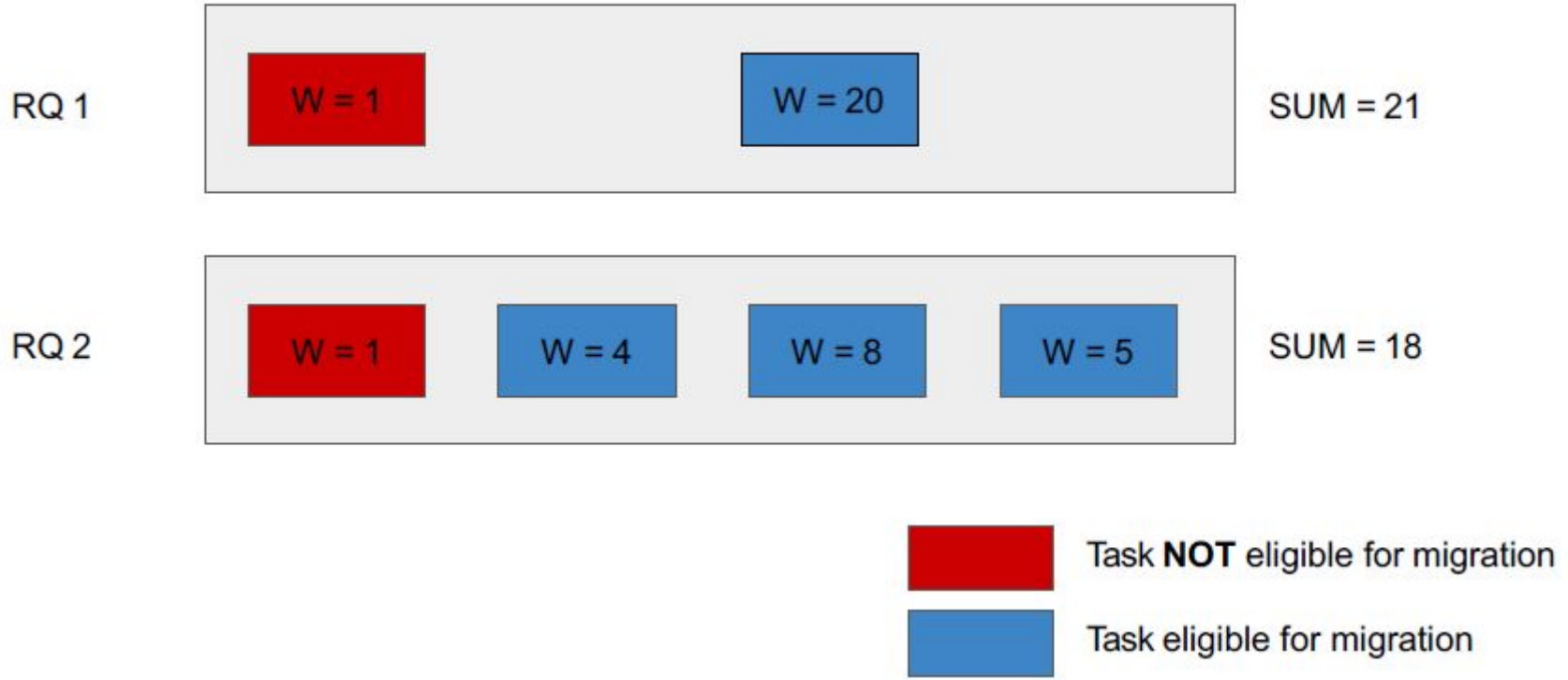


Load Balancing Example

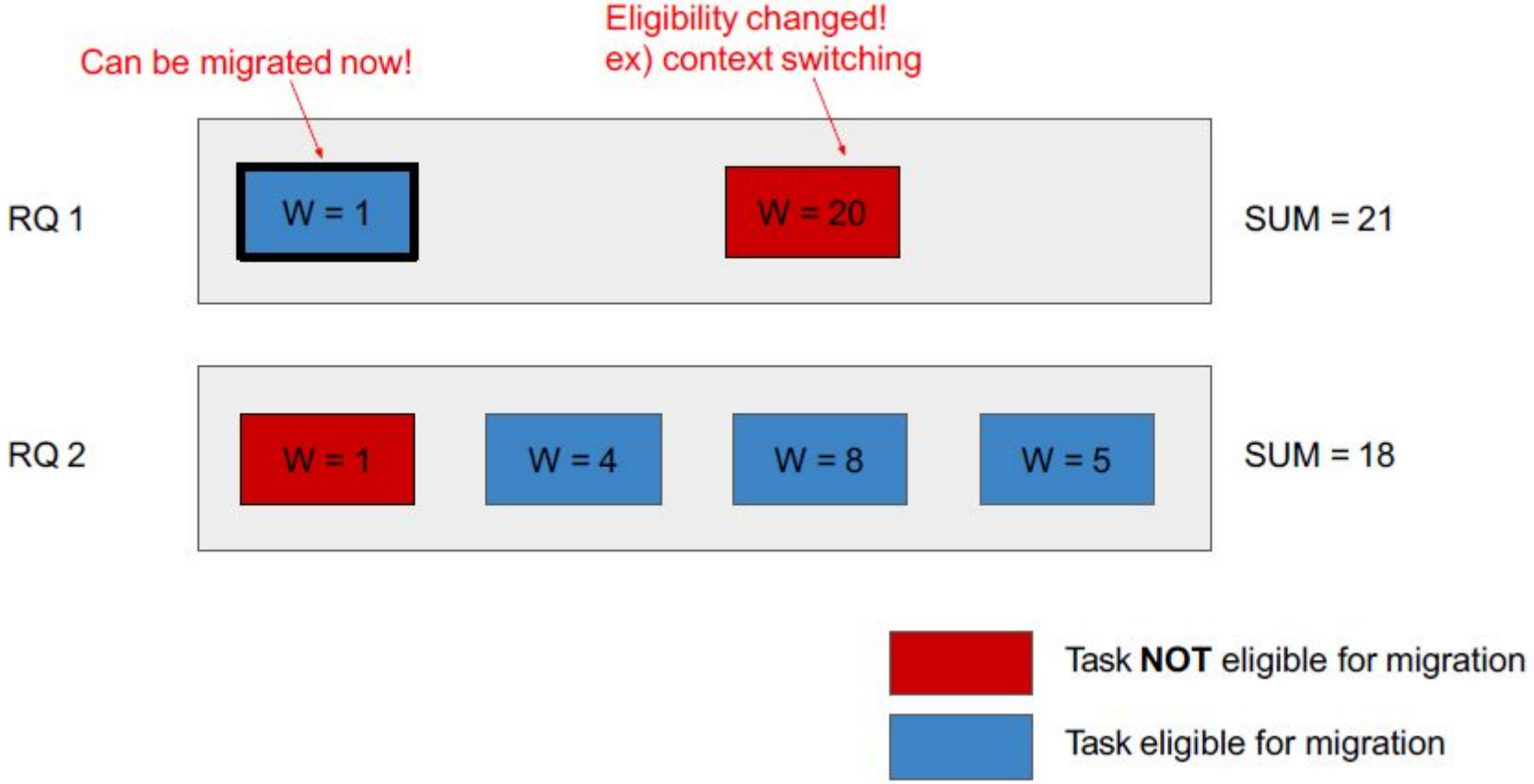


Load Balancing Example

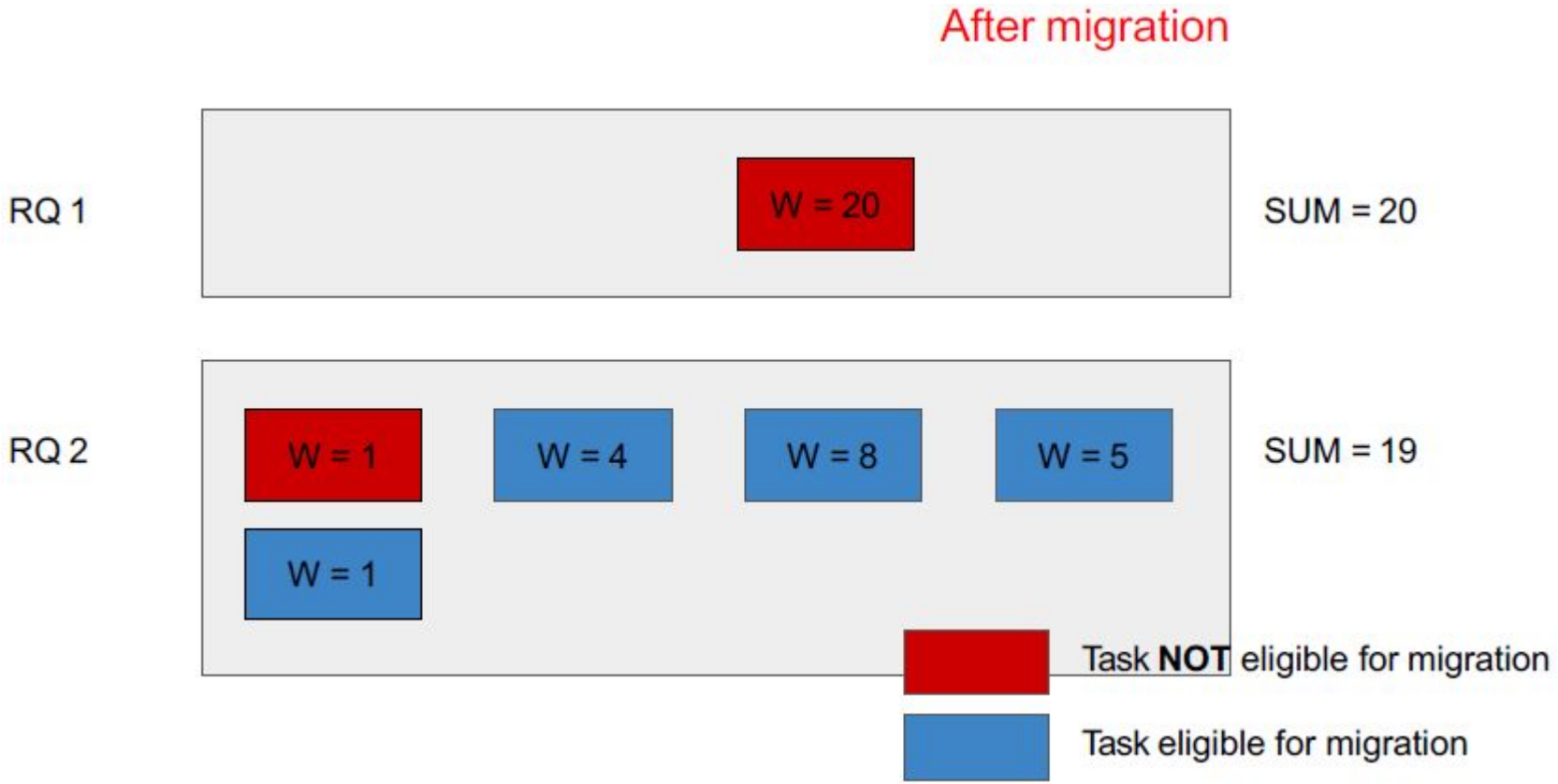
Load Balancing **Failed**



Load Balancing Example



Load Balancing Example



Scheduler Implementation

Preliminaries

Modify `arch/arm64/configs/tizen_bcmrpi3_defconfig`

- `CONFIG_SCHED_DEBUG=Y`
  - You need this option to debug your scheduler
  - Possible performance degradation
- (Optional) Enable `CONFIG_SCHEDSTATS` for more detailed debugging

Things to Keep in Mind...

- Memory protection
  - Corruption in kernel memory space can make the whole machine crash!

- No floating point or MMX operation
  - Dealing with real numbers can be challenging and painful!
- You unfortunately have to do it for some projects :(

- Rigid stack limit
  - Use extra caution when allocating local arrays or having recursive calls
  - `kmalloc` instead for huge arrays

- Your kernel code will run in a multi-core environment
  - Use proper synchronization mechanisms to avoid race conditions
  - Beware of deadlocks

Implementation Overview (1)

Define necessary constants and data structures

- `include/linux/sched.h`
- `include/uapi/linux/sched.h`
- ...

- Register a new scheduler class for WRR and implement necessary functions in `kernel/sched/wrr.c`
- Modify `kernel/sched/debug.c` to print additional necessary information about your scheduler
  - Optionally `kernel/sched/stats.c` too

Implementation Overview (2)

- Modify `kernel/sched/core.c` to support WRR
  - Trigger load balancing function, …
  - You might need to register some function signatures in `kernel/sched/sched.h`
- Implement necessary system calls
  - `sched_setweight, sched_getweight`
- Check that your scheduler is working with sched_setscheduler
  - One CPU run queue empty
  - Load balancing

Constants & Data Structures

- Define `SCHED_WRR` as **7**
  - `include/uapi/linux/sched.h`
- Define fields for WRR scheduler in `struct task_struct`
  - See how other schedulers like RT, CFS, … are implemented
  - `list_head` for WRR run queue
  - Weight, time slice, …
- Define a run queue for tasks under WRR scheduler
  - `struct rq` also needs information about WRR run queue
    - `struct rq` - CPU run queue
  - What kind of information should be stored here?
  - Should this have a locking mechanism?

Registering Scheduler

- Declare and define `wrr_sched_class` in `kernel/sched/sched.h` and in `kernel/sched/wrr.c`
  - Take a look at `kernel/sched/fair.c` & `kernel/sched/rt.c`
  - The next scheduler class (priority-wise) should be `fair_sched_class`
  - Similarly, the next scheduler class of `rt_sched_class` should be `wrr_sched_class`
- Implement necessary functions for `wrr_sched_class`
  - `enqueue_task, dequeue_task, …`
  - You don't need to implement all the functions
- Define other necessary functions for load balancing or debugging

Modifying `kernel/sched/core.c`

- Problem: it assumes that there are only classes predefined in the kernel, such as `rt_sched_class, fair_sched_class, …`
- We need to make sure that they are aware of `wrr_sched_class` too!
  - Initialize WRR run queue
  - Make `SCHED_WRR` policy valid
  - Manage forked tasks
    - The child should follow the same scheduler policy of its parent
  - …

Debugging

- Reminder: You should turn on `CONFIG_SCHED_DEBUG`
- You might want to modify `kernel/sched/debug.c` to check whether your WRR scheduler works properly or not
- Scheduling information is written to `/proc/sched_debug`

System Calls

- You all know how to implement system calls!
- Authentication is important in `sched_setweight`
  - Increasing weight: administrator only
  - Decreasing weight: process owner & administrator only
  - Check uid and euid
- Nothing hard here :)

Load Balancing (1)

- How do I check the remaining time slice or figure out when to trigger load balancing?
- `scheduler_tick`
  - `kernel/sched/core.c`
  - Called every tick
- Tick frequency: HZ
  - A macro which represents the number of ticks in a second

Load Balancing (2)

- How do I check the remaining time slice or figure out when to trigger load balancing? (cont'd)
- `scheduler_tick`
- Tick frequency: HZ
- `jiffies`
  - A global variable containing the number of ticks after systemboot
  - unsigned long - beware of overflow!
  - There are macros for comparing time
    - `time_after, time_before, time_after_eq, time_before_eq`
  - More things: http://www.makelinux.net/ldd3/chp-7.shtml

Load Balancing (3)

- How do I determine if a task can be migrated?
- Tasks that are currently running cannot be migrated
- Some tasks may have some restrictions on cores they can run on
  - How can we know it? / Why do they have restrictions?
  - Refer to existing load balancing code to find the answer

Load Balancing (4)

- How do I prevent race condition while load balancing?
- `scheduler_tick` is called for every available CPU!
  - You need to make sure that only one thread is working on load balancing at any time!
- One seemingly simple & plausible solution
  - Make only a certain CPU can do load balancing
  - But, because `CONFIG_HOTPLUG_CPU` is on by default, the designated CPU could be turned off anytime…
  - What happens if the designated CPU is turned off? How can we prevent it?
- Think carefully about synchronization issues and CPU hotplug!

Experiment

- Main question: how the weight affects the performance
- Measure the time for `trial division` to finish for varying:
  - weights
  - number of processes
  - …
- You should make sure that all cores (except the one that should be left empty) are active when you start your experiment!
  - Initially, it is very likely that only one core is active
  - You can make a number of processes run for some time to make all cores active

More details

- CFS is highly optimized, while your scheduler is not: slow!
  - When the shell is not responding, just wait for a while
  - Do not create way too many processes at once (ex: 100 `forks`)
  - Always leave one core empty (no WRR tasks running)
- `rcu_read_lock` when iterating over CPU cores
- This is the hardest project so far, and the only project that you may not be able to finish on time, so start early!

About Submission (IMPORTANT!)

- Make sure your branch name is ***proj2***
- Don't be late! marks will be deducted

  We allow 3 days late submission! TA will not grade any submissions after that!

- You should start from master branch of kernel (like Project 0)

- Slides and Demo

  Submit to etl before deadline.

  we allow 3 day late submission, after that submission on etl will not be possible

  - zip dir title: [OS-ProjX] TeamX submission

  inside the directory there should be 4 files:

  - The slides to your presentation: TeamX-slides.ppt(.pdf)
  - Your Demo Video: TeamX-demo.mp4(.avi….)
  - Recorded presentation(sound only): TeamX-presentation.mp3(.wav….)
  - Git diff file that contains all of your modification from master branch: TeamX.diff
    - It should be applied on the top of master branch (e.g. git apply TeamX.diff)