Project 3 Help Document

SNU Operating Systems
Nov 12, 2020
DCS Lab

Project 3 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

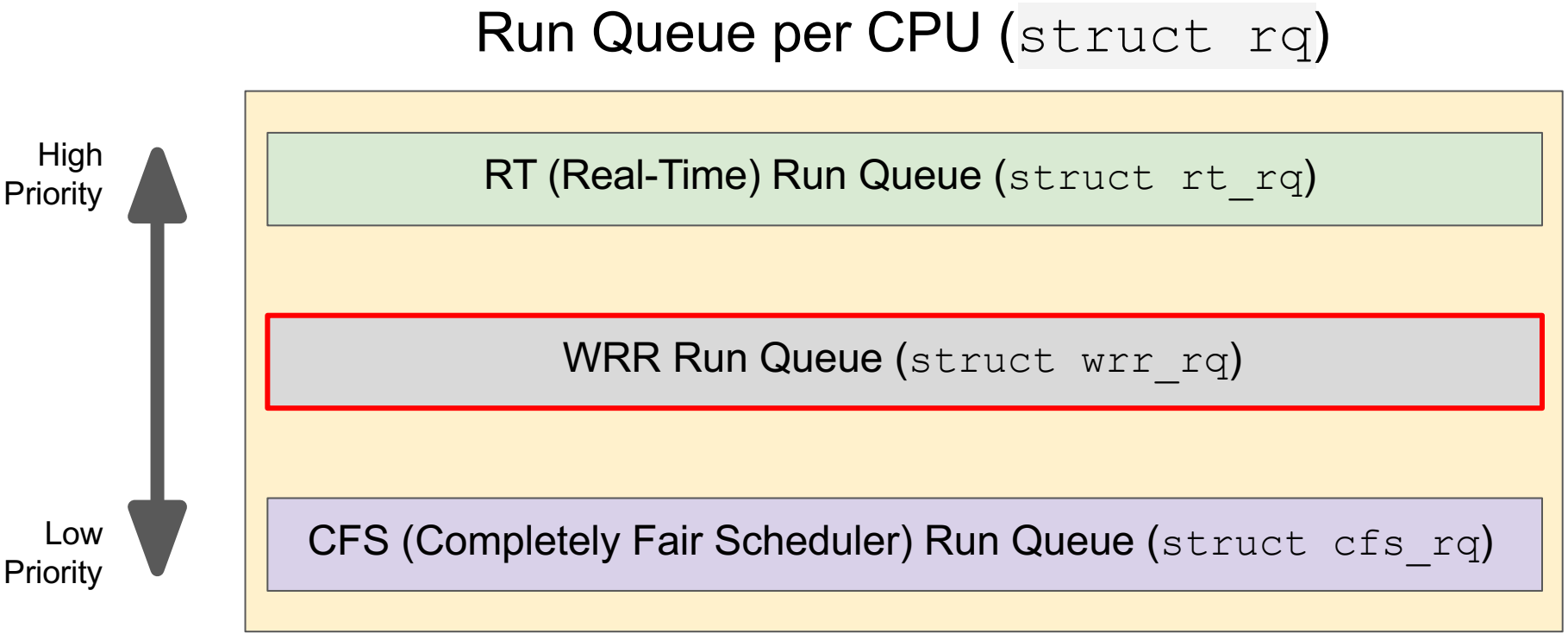
Linux Scheduler Basics

- 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

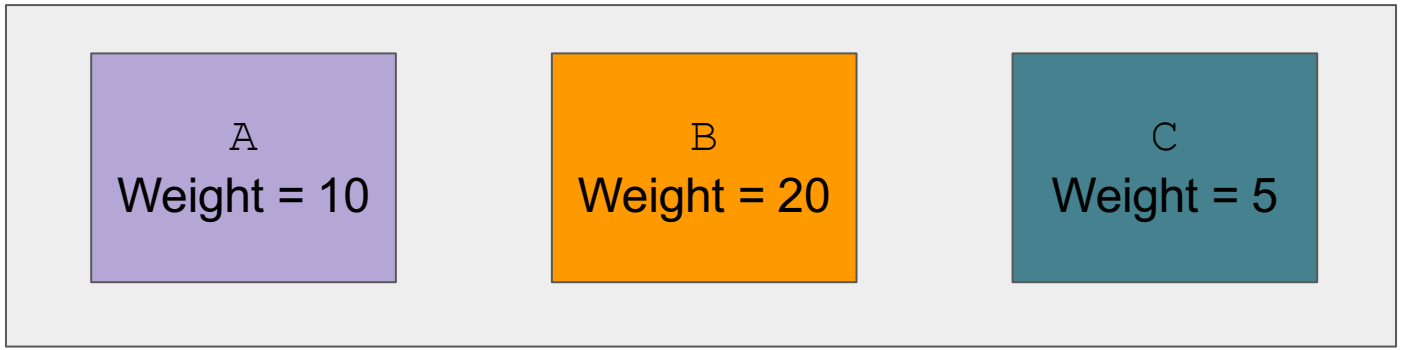
- Weighted Round-Robin Scheduler
- Tasks are executed in a round-robin fashion, but get different time slices according to their weights
  - Default weight is 10
  - Time slice = Weight * 10ms
- Priority: RT > WRR > CFS
- Load balancing

Multi-level Run Queue with WRR



WRR Scheduling Example

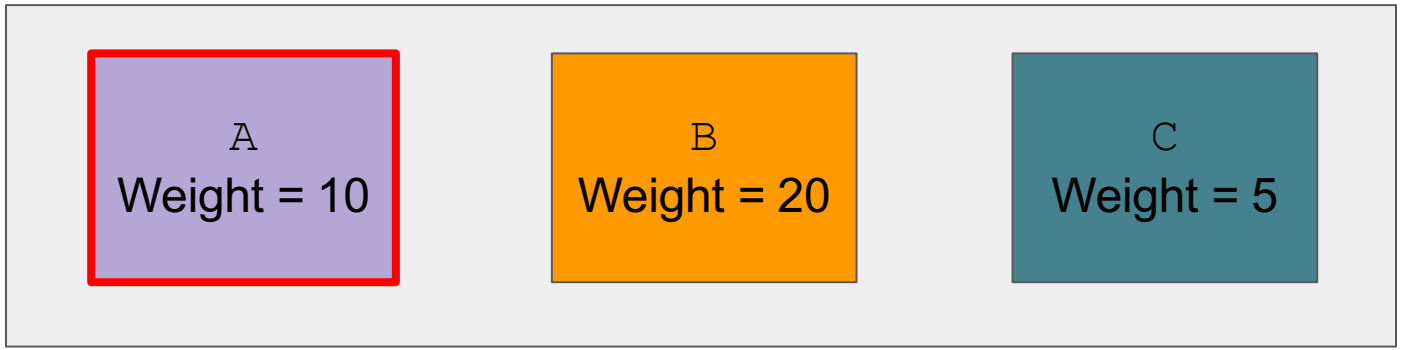
Three tasks currently in WRR run queue



WRR Scheduling Example

t = 0ms

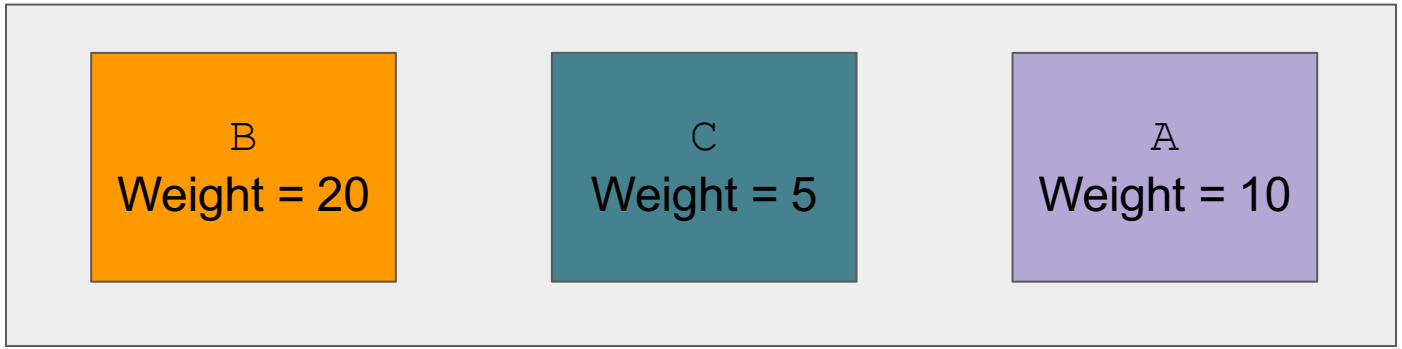
`A` starts running first



WRR Scheduling Example

t = 100ms (Δt = 100ms)

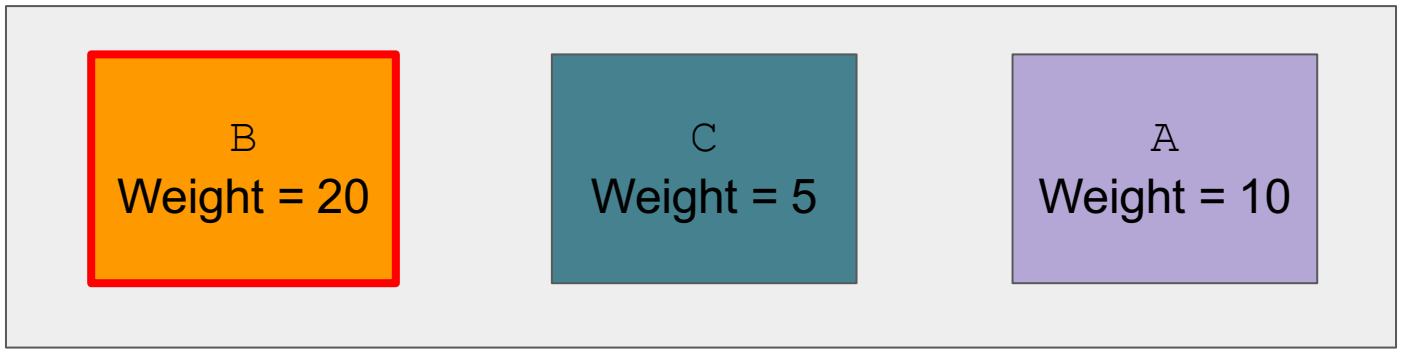
`A` stops, and is moved to the tail of the run queue because the task is not finished…



WRR Scheduling Example

t = 100ms

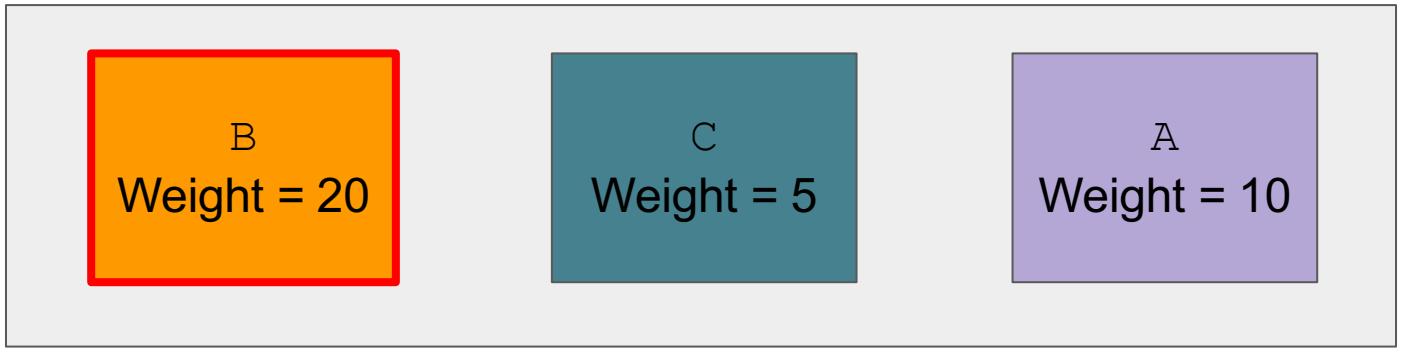
… and the next task (`B`) starts running



WRR Scheduling Example

t = 200ms (Δt = 100ms)

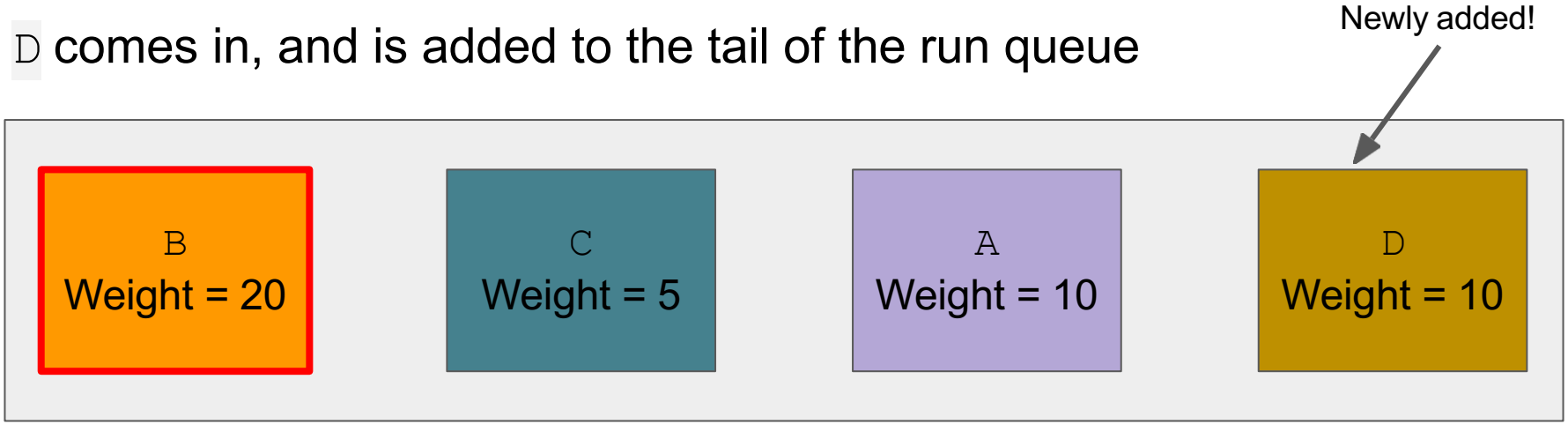
`B` is still running, because its time slice is 200ms



WRR Scheduling Example

t = 250ms (Δt = 50ms)

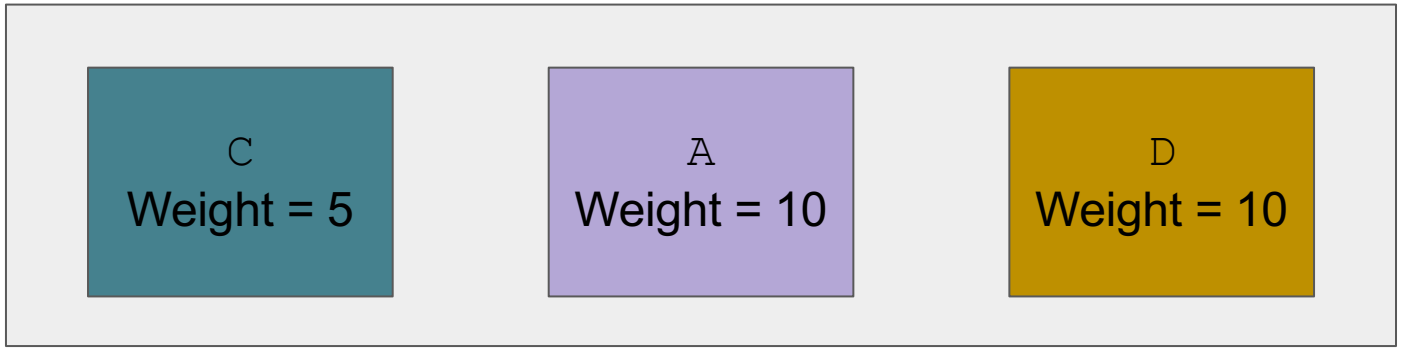
`D` comes in, and is added to the tail of the run queue



WRR Scheduling Example

t = 280ms (Δt = 30ms)

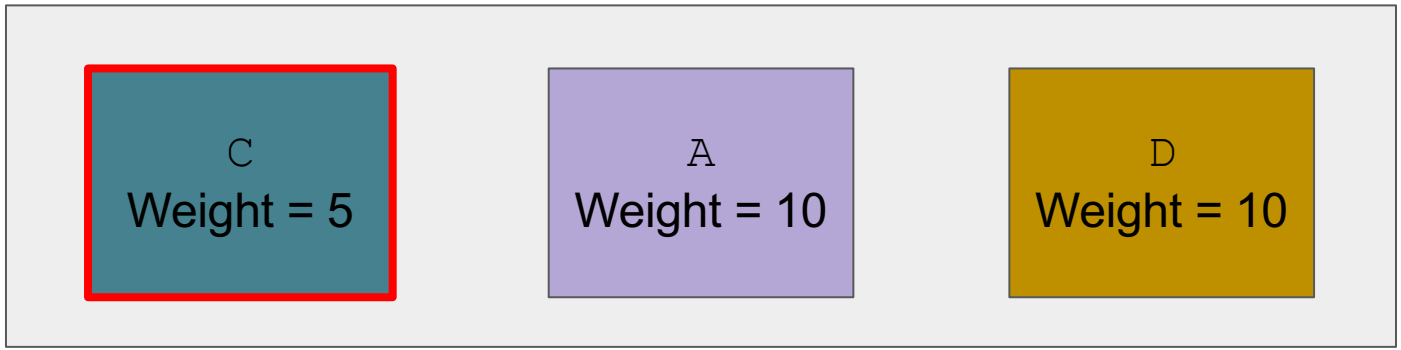
`B` has finished its work and is terminated; now removed from the run queue…



WRR Scheduling Example

t = 280ms

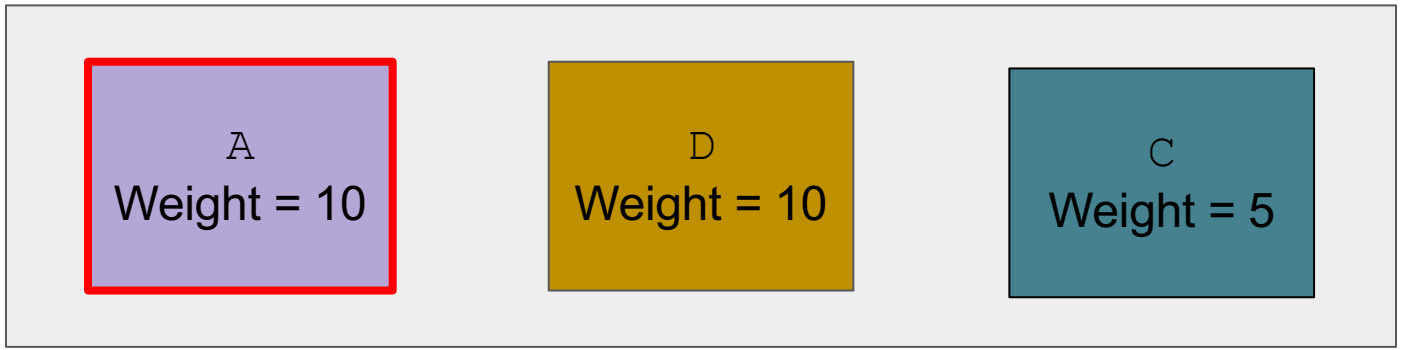
… and `C` starts running



WRR Scheduling Example

t = 330ms (Δt = 50ms)

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



Load Balancing

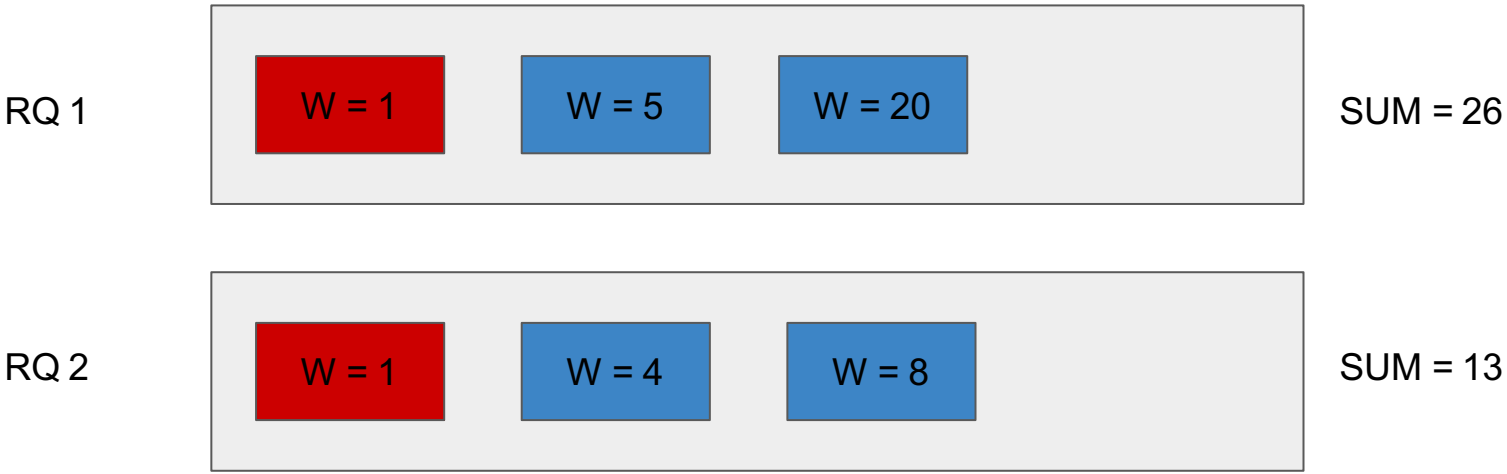
- Balance load among the run queue of each CPU
- Make sure that it only works when more than one CPU is active
  - CPU hotplug
  - `for_each_online_cpu(cpu)`
- **Leave one run queue empty!**
- Should be attempted every 2000ms

Load Balancing Algorithm

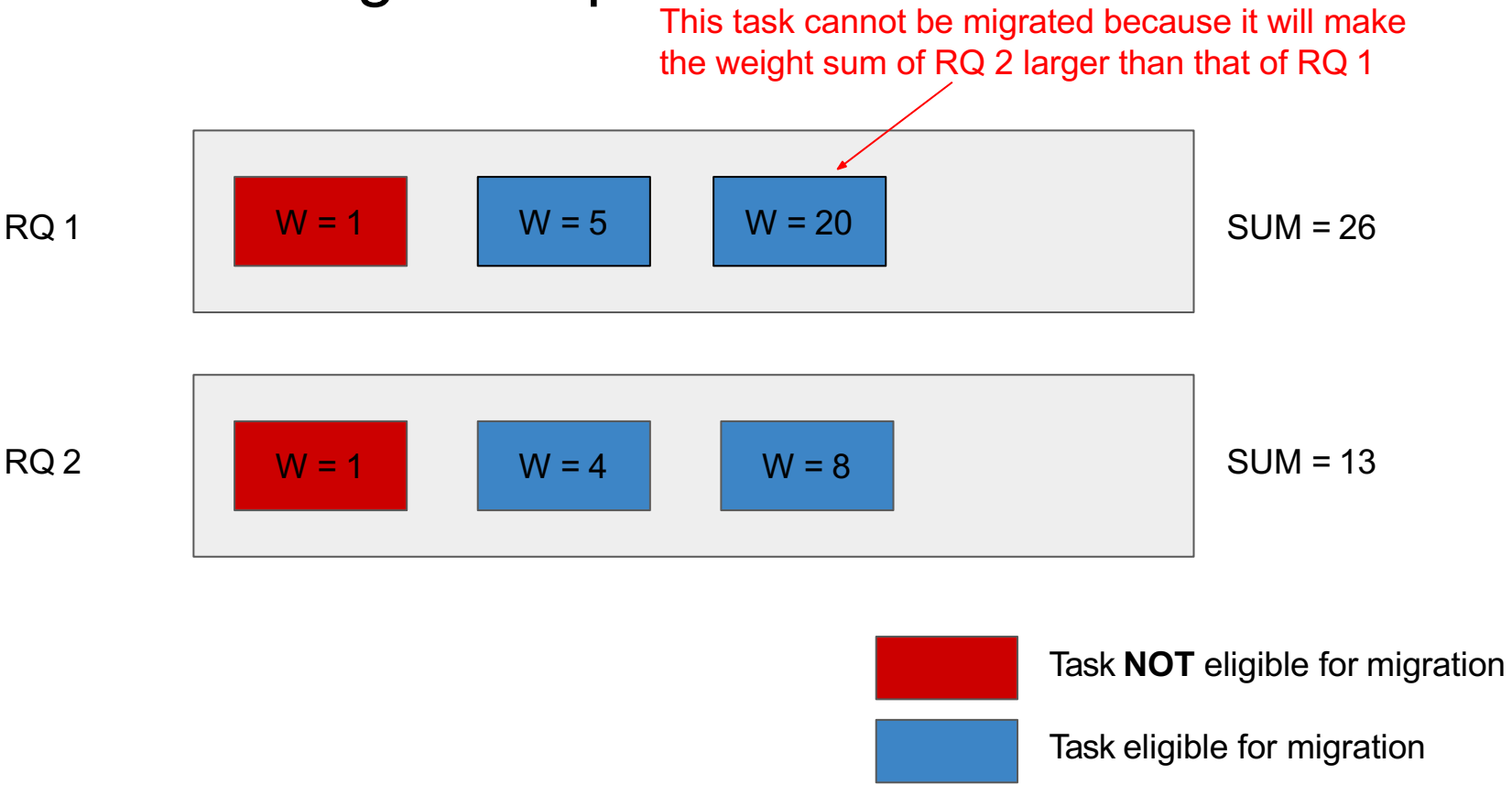
- Pick two run queues with the minimum weight sum and the maximum weight sum
  - Call them `RQ_MIN` and `RQ_MAX` respectively
- Pick a task with the largest weight among tasks that satisfy the following conditions:
  - The picked task should be able to be migrated to `RQ_MIN`
  - Migration should not 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

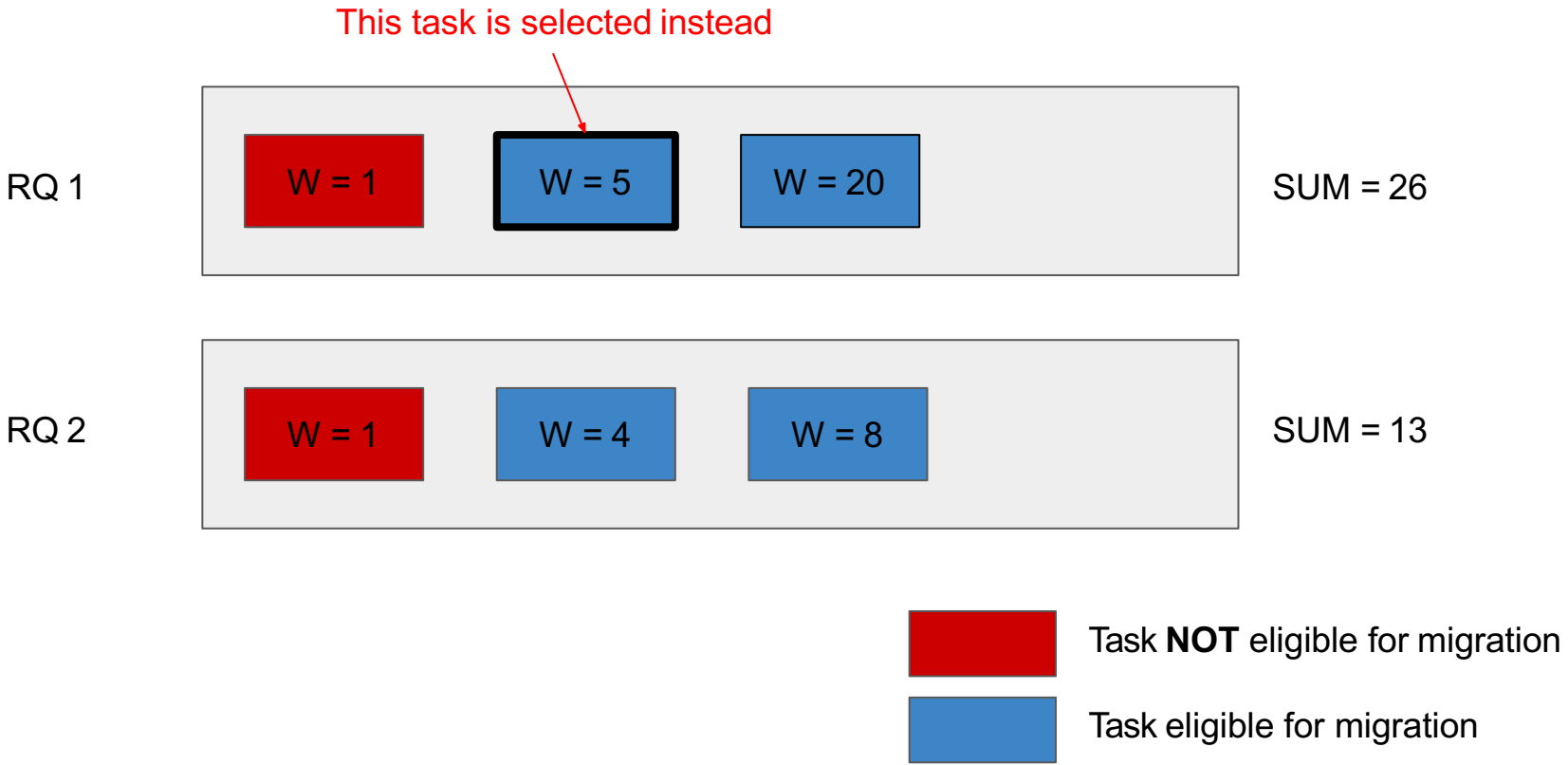
Migrating a task from RQ 1 to RQ 2



Load Balancing Example

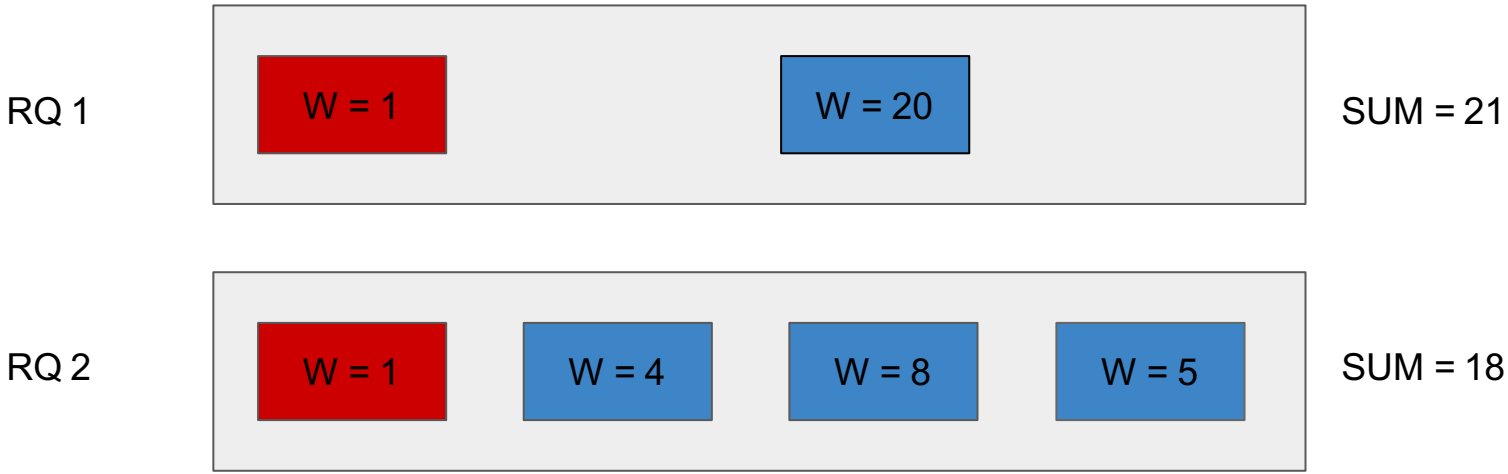


Load Balancing Example



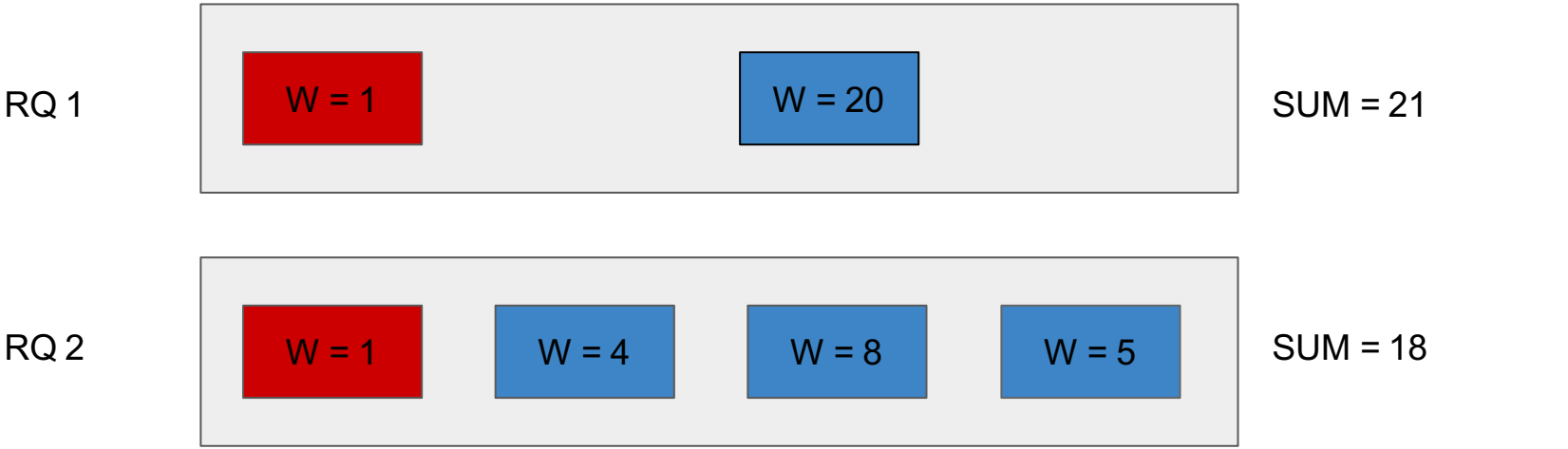
Load Balancing Example

After migration

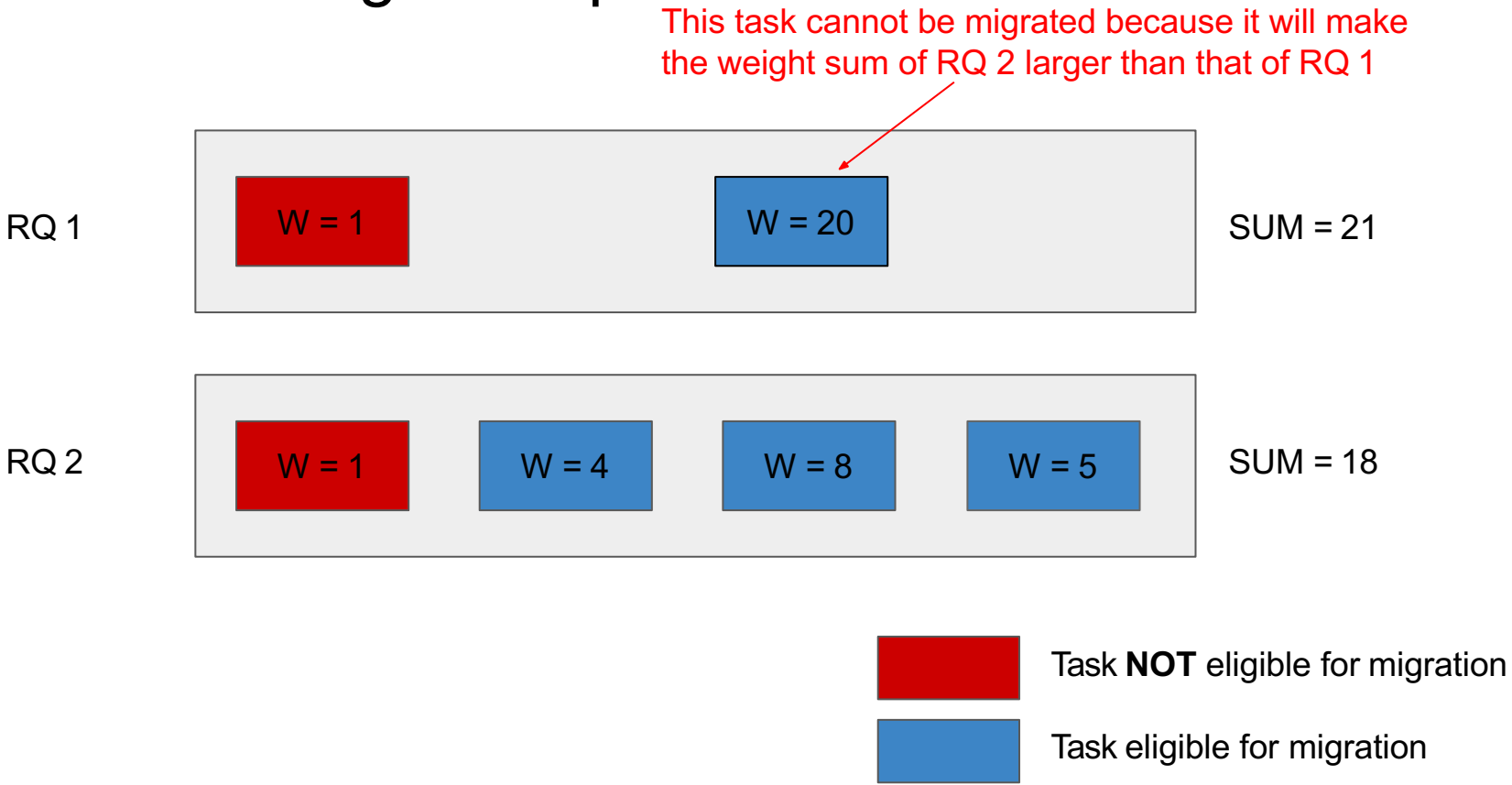


Load Balancing Example

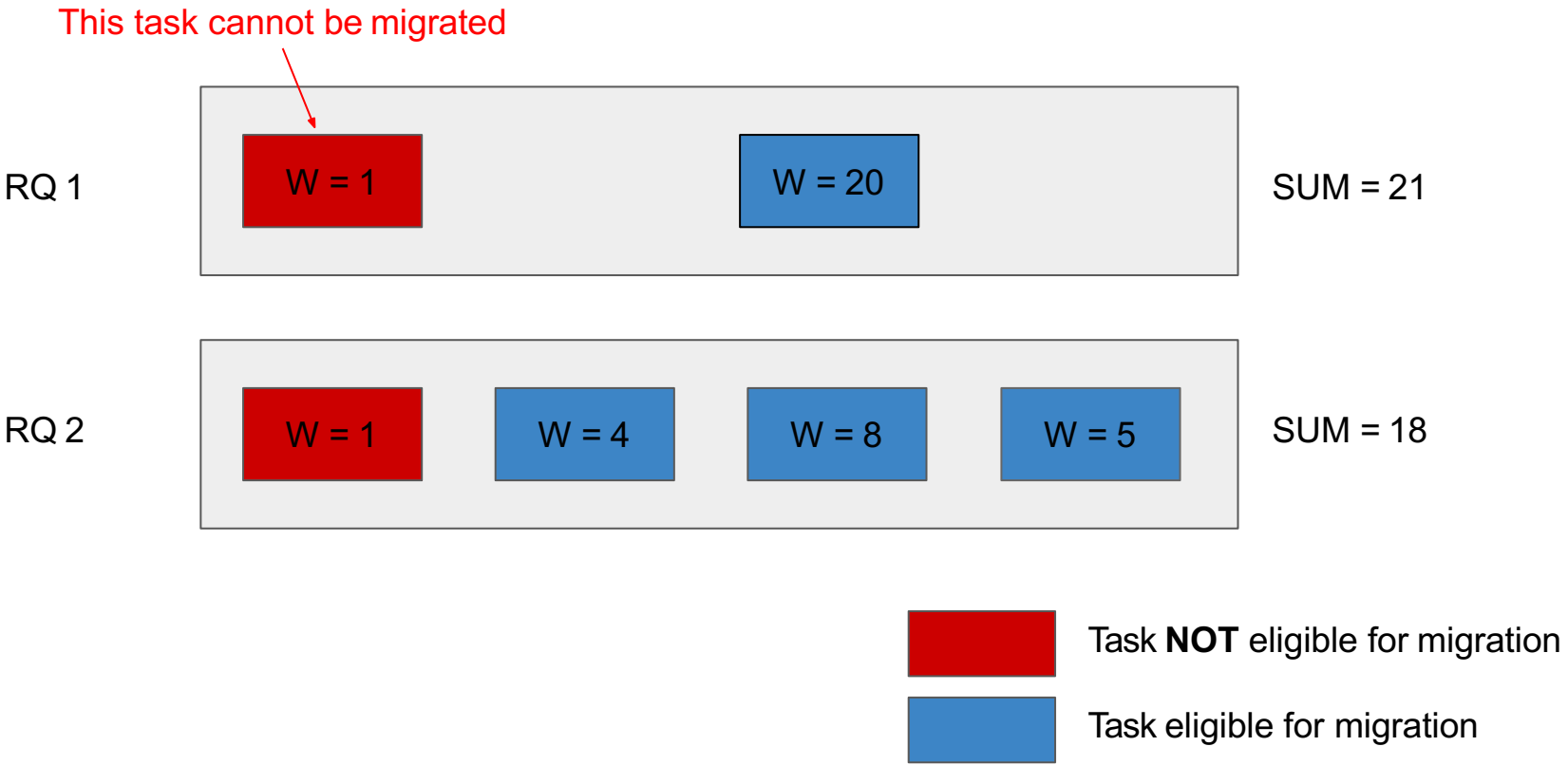
Migrating a task from RQ 1 to RQ 2 again



Load Balancing Example

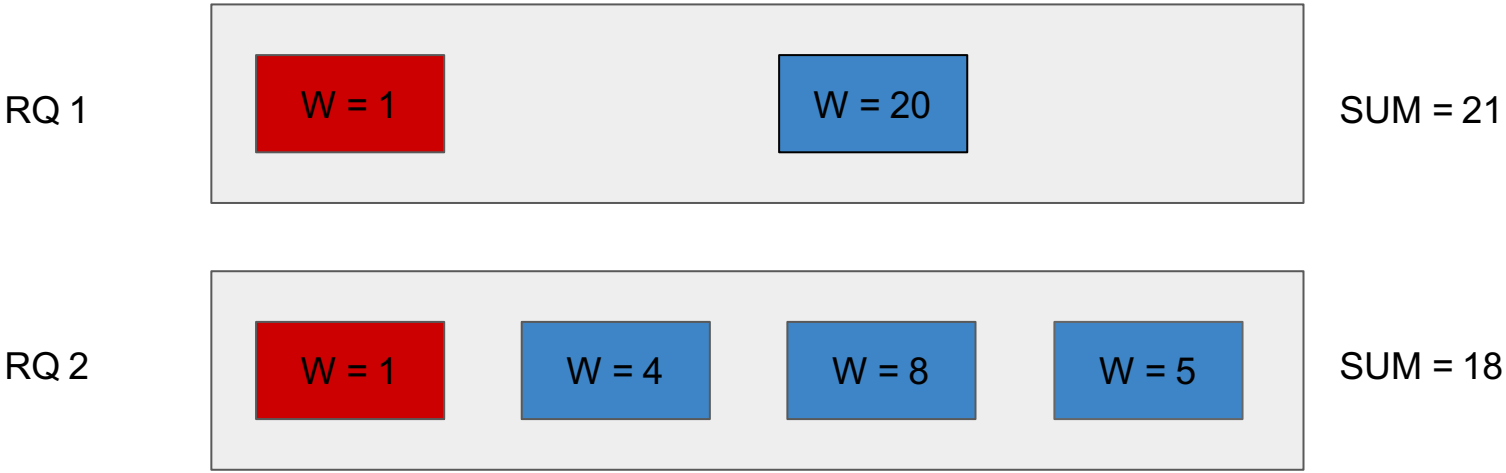


Load Balancing Example

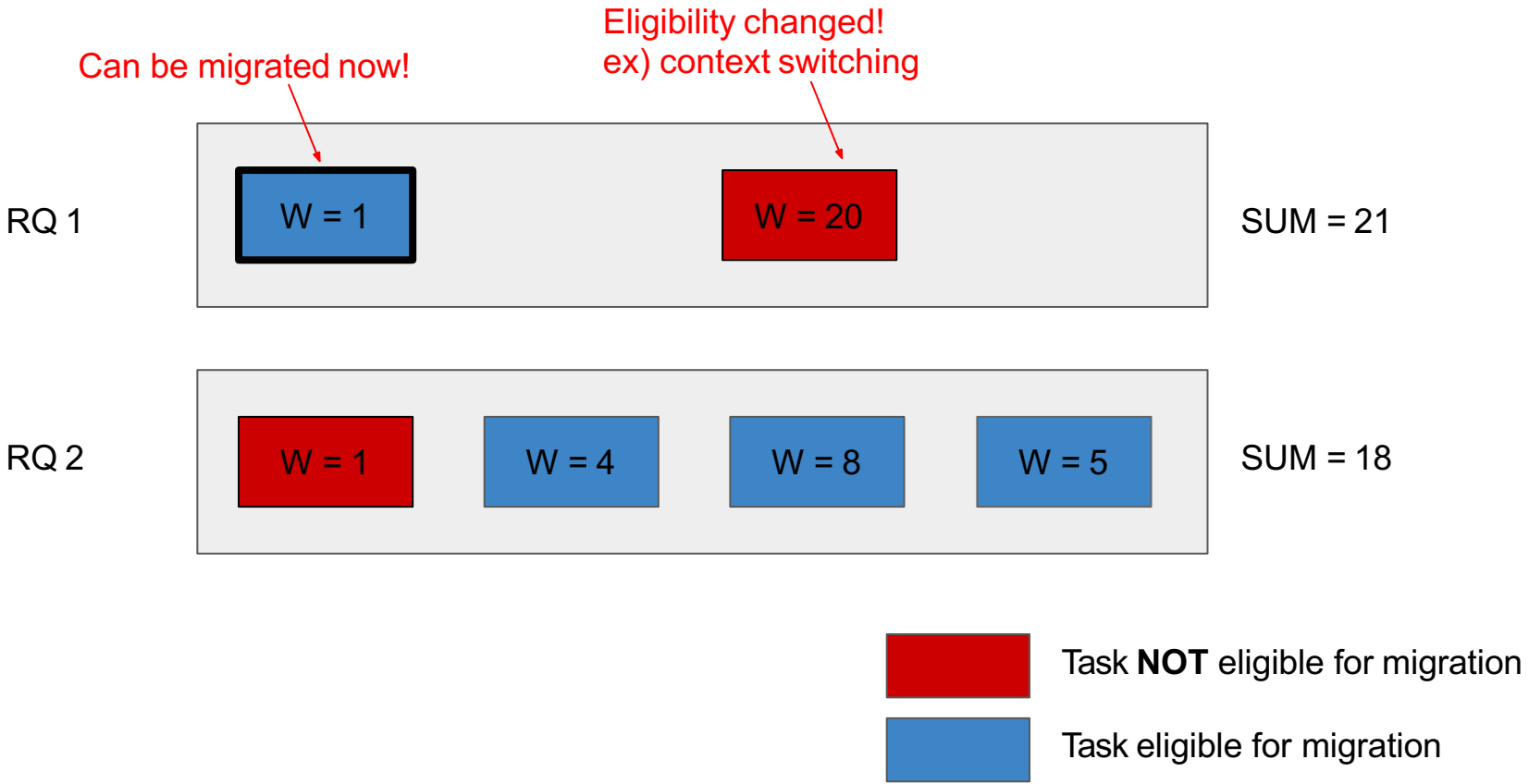


Load Balancing Example

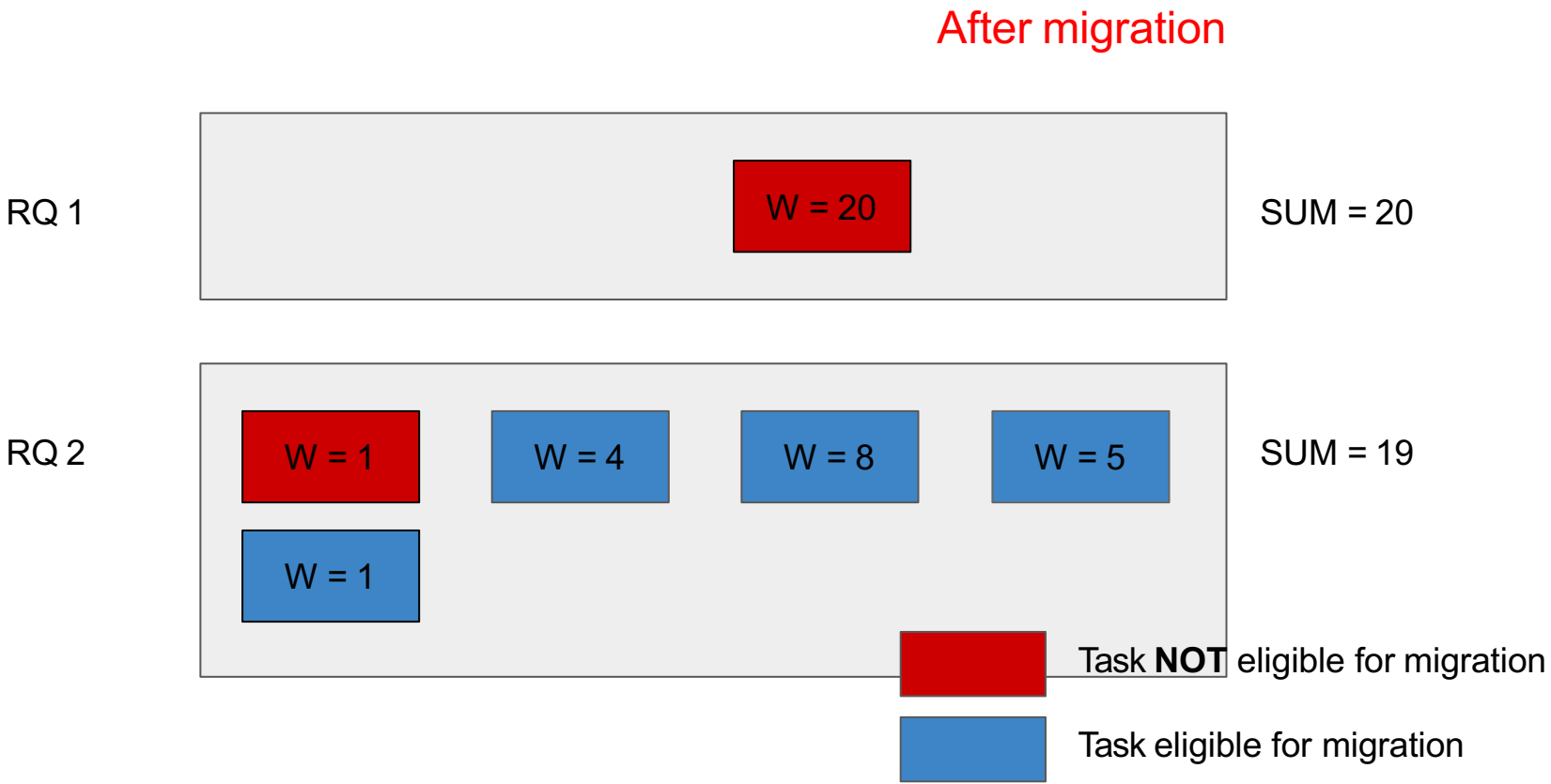
Load balancing **failed**



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

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 system boot
  - 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` 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 Things...

- 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 `fork`s)
  - 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!)

- **Due: 2020-12-01 Tuesday 17:00:00 KST**
- Make sure your branch name is *proj3*
- Don't be late!
  - We will not grade the commits after the deadline
- Slides and Demo
  - Send it to the TA (**os-tas@dcslab.snu.ac.kr**) before the deadline
  - Title: **[OS-ProjX] TeamX slides&demo submission**
  - File name: **TeamX-slides.pptx(.ppt, .pdf)**, **TeamX-demo.mp4(.avi, …)**
- Please submit only one video

Q & A