## Abstract

## Introduction

### Modifications to OS

### A diagram of a scheduler heap Description automatically generatedFixed priority Scheduler (Compulsory Task)

A screenshot of a diagram

Description automatically generated

#### Scheduler Data Structure

In adapting the initial round-robin structure to support fixed-priority scheduling, we replicate the round-robin for each priority level, akin to a bucket queue. Traditionally, a bucket queue includes a pointer to the highest-priority level with a task. However, this approach necessitates a linear search through the priority list when extracting the highest-priority task,

To enhance efficiency and eliminate the need for this search, we employ a binary min-heap. The min-heap tracks priority levels in the scheduler that contain tasks. Upon removing the highest-priority task, instead of searching the priority list, we identify the next highest priority level by extracting the root of the min-heap.

#### Fixed Priority Scheduling

Before initiating the operating system, the scheduler is preloaded with all tasks to be executed by the user, up to a maximum task limit defined within the scheduler head file. Tasks are initialised with a fixed priority that remains constant throughout runtime, except when influenced by mutex priority inheritance. The initial priority is constrained within the range defined by the number of priority levels specified in our scheduler header file.

Task priority is represented by an unsigned integer, with zero indicating the highest priority. Priorities decrease as the integer value increases, up to the defined limit of priority levels. This design allows assigning a priority of zero to system-critical tasks, ensuring they always hold the highest priority. Increasing the number of priority levels does not require adjusting the priority of these critical tasks since, at priority zero, they consistently remain at the highest priority, regardless of the total number of priority levels.

#### Context Switching

In the context switch process, several safety checks facilitate the smooth operation and transition between tasks. Firstly, any priority levels devoid of tasks are pruned from the scheduler heap. Subsequently, the highest priority level containing tasks is retrieved from the heap using a peek operation. The head of this priority level is saved for later execution. Before concluding the switch, the context switch increments the head, introducing round-robin behaviour within the priority level, if multiple tasks exist at the level.

#### Task Management

Various operations are employed to move tasks within the scheduler, including:

* **Task Waiting:** Removing a task from the scheduler and placing it in a waiting list.
* **Task Notification:** Removing a task from the waiting list and returning it to the scheduler.
* **Task Priority Modification:** Changing a tasks priority by extracting it from the scheduler, updating the priority, and returning the task to the scheduler at the new priority level.

#### Mutual Exclusivity

To safeguard against deadlocks and race conditions, alterations to the scheduler heap are restricted to the context switch interrupt. Similarly, modifications to individual tasks within priority levels, as detailed in the task management section above, are reserved for SVC interrupts. An exception is made for sleeping tasks, which are polled and returned to the scheduler during the context switch. This ensures the regular comparison of the current system tick counter against the wake time of sleepings tasks.

### Sleeping task module (Compulsory Task)

### Purpose

At times, there is a need to temporarily pause a task, such as when polling a memory section one per second. Although measuring an exact second internally is challenging without an external timer, a viable alternative is to make a task wait for a designated number of system ticks, referred to as ‘sleeping’ in this implementation.

### Sleeping Task Representation

Sleeping tasks are organised in a sleep list using the same binary min-heap structure as the scheduler. Unlike sorting by priority, tasks in this list are sorted based on their wake-up time. This arrangement ensures that the task with the earliest wake-up time is always at the root of the heap, streamlining the scheduler’s task of checking whether any tasks need to be awakened.

### Sleeping Mechanism

Before being placed in the sleep list, a task’s wake-up time is calculated according to the specified sleep duration and is then attached to the task structure. Subsequently, the task is removed from the scheduler and transferred to the sleep list through the ‘wait task’ SVC interrupt.

### Wake-up Mechanism

During each context switch, the scheduler examines the root of the sleep list to determine if the system tick counter has reached the specified wake-up time for any tasks. When it is time to wake a task, the scheduler removes the task from the sleep list and reintegrates it into the scheduler, making it ready to resume task execution.

### Re-entrant Mutex (Compulsory Task)

### Purpose

A re-entrant mutex ensures exclusive access to a shared resource in a multi-tasking environment. This mechanism permits only one task, the owner, to access the resource at a time, preventing interference from other tasks. The re-entrancy feature allows the owner task to re-enter the critical section, even if it already holds the mutex, facilitating nested locking without risking deadlock. This is particularly valuable in situations where a task invokes a function requiring the same mutex.

### Obtaining Mutex

Before utilizing a resource prone to race conditions, a task can acquire a mutex for that resource. Upon attempting to obtain the mutex, the task checks its lock status. If unclaimed, the task becomes the owner, with an internal counter set to 1. For a task already holding the mutex, the counter increments. If the mutex is owned by another task, the current task is temporarily removed from the scheduler and sent to a wait list, awaiting mutex availability. Once obtained, the task can use the resource exclusively, safeguarding against unintended race conditions.

### Releasing Mutex

Upon completing the critical section requiring a mutex, the task releases the mutex, decrementing the internal counter. If the counter reaches zero after multiple releases, signalling completion of mutex use, ownership is relinquished. This prompts notification of the wait list, enabling the highest priority waiting task to rejoin the scheduler. This task can then attempt to acquire the mutex and utilize the resource it guards once again.

### Mutex Wait List Operation

The Mutex Wait List employs a binary min-heap, facilitating notification and removal of only the root task when the mutex becomes available. This heap is organized based on both task priority and the time a task joined the wait list. In the event of two tasks sharing the same priority, the task added earlier takes precedence for notification and release from the wait list. This approach ensures fairness by favouring the task that has been waiting longer when priorities are equal.

### Priority inheritance for mutexes (Optional Task)

### Purpose

In scenarios where a high-priority task seeks access to a mutex held by a lower-priority task, the higher-priority task may experience prolonged wait times on the mutex wait-list. This delay, caused by the lower-priority task's ongoing execution, poses a risk to the efficient operation of the system.

To mitigate this, the mutex identifies when a higher-priority task is queued in the wait list. In response, the mutex dynamically elevates the priority of the current owner to match that of the waiting task. This adjustment allows the lower-priority task to release the mutex promptly, treating it with the same urgency as the waiting task. Consequently, this mechanism prevents the blocking behaviour of mutexes in a priority scheduler and ensures timely execution of high-priority tasks.

### Implementation

In our scheduler implementation, we incorporate an SVC interrupt for task priority adjustment. By regularly assessing the priority of the mutex owner in relation to the root task in the wait list during each insert operation, as the root task holds the highest priority among waiting tasks, this process ensures that the owner task receives an elevated priority when necessary. Upon releasing the mutex, the priority of the owner task is reset to its original value established at the beginning of runtime.

### Wait and notify system (Optional Task)

### Purpose

### Memory pool (Optional Task)

### Purpose

### Task communication (Optional Task)

### Purpose

### Generic Binary min-heap library (Generic Library)

### Purpose

## Demonstration

Use mutex for printing.

Every second, create eight random 0-1 values and add to memory pool with high priority. Then read with another task and print.

## Conclusion