Computer Architecture and Operating System

HackOSsim Project

Master's Degree in Cybersecurity

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1 Introduction

The Goal of this Project

1 Introduction

The goal of this project consists in analysing and using the real time OS FreeRTOS exploiting the QEMU[1] simulator. In the following you find a detailed tutorial for the **installation** and usage procedures and some **practical examples** and **new implementations** to demonstrate the functionality of the operating system.

[1] It allows to virtualize several types of hardware architecture.

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2 Environment Setup

Installation

2 Environment Setup

To setup the environment the following steps has been followed:

- Downloading the `FreRTOS` repository;
- Downloading of `QEMU` emulator;
- Setup of other tools:
  - `ARM GNU Toolchain`;
  - `CMake`;
  - `Make`;
- Finally we proceed with the environment configuration;

Intro to the Demo Applications

2 Environment Setup

In this project, each single demo application can be selected by properly setting the `mainCREATE_SIMPLE_DEMO` value in the `main.c` file.

```c
/* The mainCREATE_SIMPLE_DEMO setting is described at the top
 * of this file. It selects the proper demo application */
#if ( mainCREATE_SIMPLE_DEMO == 1 )
{
    main_three_tasks_CRUDE();
}
#elif ( mainCREATE_SIMPLE_DEMO == 2 )
{
    main_three_tasks();
}
#elif ( mainCREATE_SIMPLE_DEMO == 3 )
{
    main_priority();
}
#elif ( mainCREATE_SIMPLE_DEMO == 4 )
{
    main_queue();
}
#elif ( mainCREATE_SIMPLE_DEMO == 5 )
{
    main_semaphore();
}
#elif ( mainCREATE_SIMPLE_DEMO == 6 )
{
    main_semaphore2();
}
#elif ( mainCREATE_SIMPLE_DEMO == 7 )
{
    main_memManagement();
}
#endif
```

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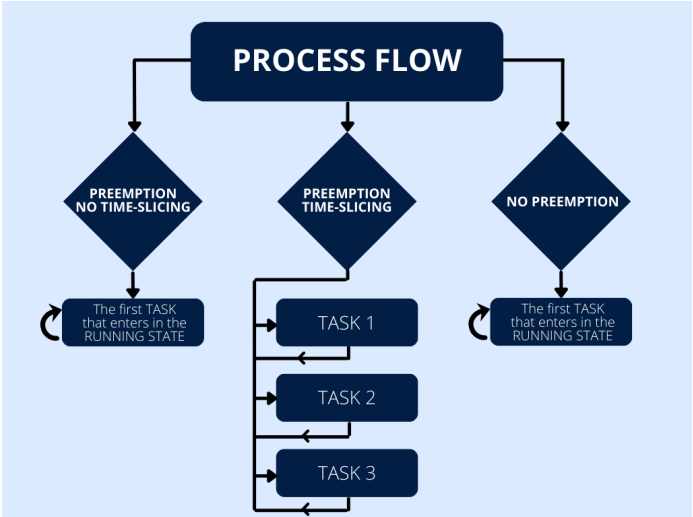
Demo Applications

3 Task Management

- **main_three_task_CRUDE.c**
  - Tasks with the **SAME priority**.
  - Each task implements the same function that **prints a message**.
  - After printing the message, the task enters in a **loop** whose the unique functionality is the implementation of a **CRUDE delay**, i.e., which does not move the task in the `waiting list`.
- **main_three_task.c**
  - **NO CRUDE DELAY**!
  - API function `VTaskDelayUntil()`.
  - This function just moves the task in the blocked state, making room for tasks in the ready state.
- **main_priority.c**
  - More advanced example to show how **FreeRTOS scheduler** works.
  - One of the two tasks has dynamic priority.

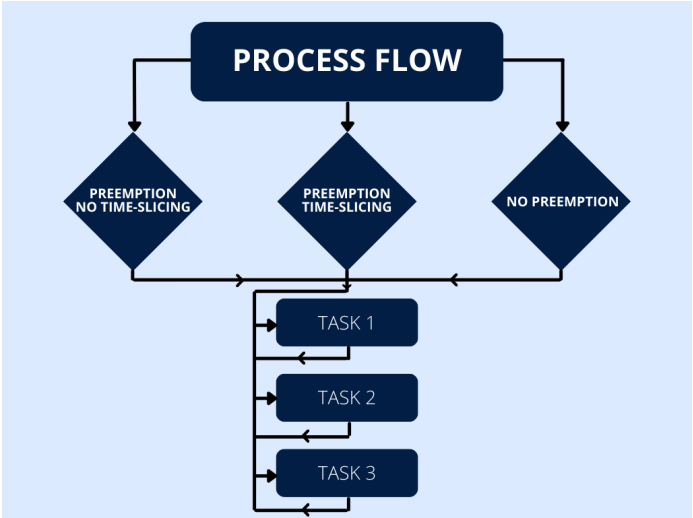
Process Flow - main_three_task_CRUDE.c

3 Task Management



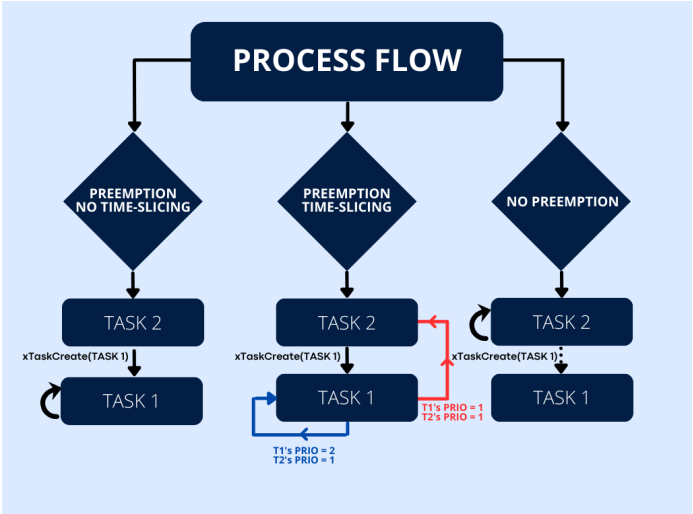
Process Flow - main_three_task.c

3 Task Management



Process Flow - main_priority.c

3 Task Management



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4 Queue and Task Synchronization

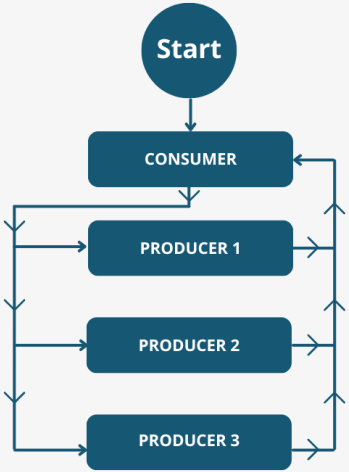
Demo Applications

4 Queue and Task Synchronization

- **main_queue.c**
  - Three **PRODUCERS** and one **CONSUMER** (**highest priority**).
  - The **CONSUMER** is blocked when the queue is empty, unblocking the **PRODUCERS**.
- **main_semaphore.c**
  - Three **PRODUCERS** and one **CONSUMER** handled with **two binary semaphores**.
  - At the beginning the **PRODUCERS** enter in the critical section **until the queue is fulfilled**.
  - Then the **CONSUMER** reads out all the data.
  - **Any priority can be used**! Semaphores synchronize the tasks.
- **main_semaphore2.c**
  - Three **PRODUCERS** and one **CONSUMER** handled with **four semaphores** (3 binary and 1 counting).
  - Each **PRODUCER** inserts its value and unblocks the next task.
  - Once all the **PRODUCERS** inserted their values, the **CONSUMER** reads out all the items, then unblocks the first **PRODUCER**.
  - **Any priority can be used**! Semaphores synchronize the tasks.

Precedence Diagrams - main_queue.c

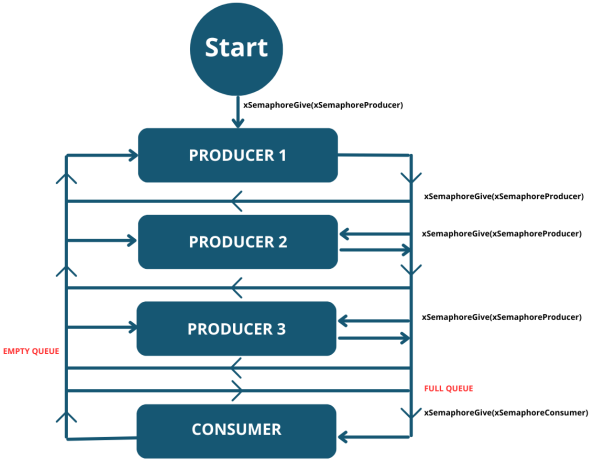
4 Queue and Task Synchronization




```
QEMU RTOSdemo started
Queue created
-----------------------------------------------
Queue is empty - waiting for data...
-----------------------------------------------
-----------------------------------------------
Producer 1 about to send 100 to the queue
-----------------------------------------------
-----------------------------------------------
Consumer Received = 100
-----------------------------------------------
-----------------------------------------------
Queue is empty - waiting for data...
-----------------------------------------------
-----------------------------------------------
Producer 2 about to send 200 to the queue
-----------------------------------------------
-----------------------------------------------
Consumer Received = 200
-----------------------------------------------
-----------------------------------------------
Queue is empty - waiting for data...
-----------------------------------------------
-----------------------------------------------
Producer 3 about to send 300 to the queue
-----------------------------------------------
```

Precedence Diagrams - main_semaphore.c

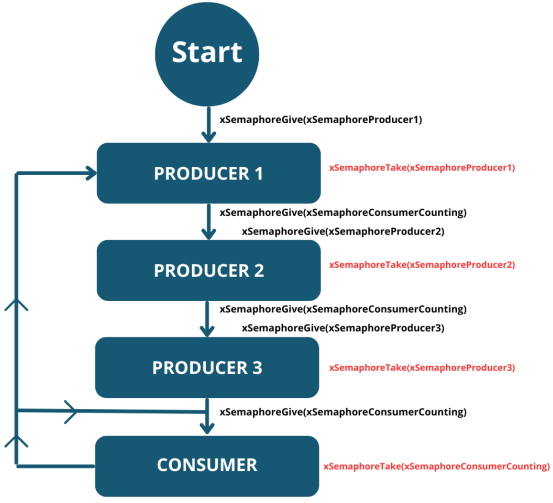
4 Queue and Task Synchronization




```
Producer 3 sent: 30
Producer 1 sent: 10
The queue is full, consumer can start. 20
Consumer received: 10
Consumer received: 20
Consumer received: 30
Consumer received: 10
Consumer received: 20
Consumer received: 30
```

Precedence Diagrams - main_semaphore2.c

4 Queue and Task Synchronization




```
Producer 1 sent: 10
------------------------
------------------------
Producer 2 sent: 20
------------------------
------------------------
Producer 3 sent: 30
------------------------
------------------------
Consumer received: 10
------------------------
------------------------
Consumer received: 20
------------------------
------------------------
Consumer received: 30
------------------------
------------------------
Producer 1 sent: 10
------------------------
------------------------
Producer 2 sent: 20
------------------------
```

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5 Memory Management

Implementation

5 Memory Management

To better analyze the Memory Management the provided `heap_4.c` file was revised to implement:

- **Best-Fit**: The process is allocated in smallest available memory block that is large enough for the process.
- **Worst-Fit**: The process is allocated in the largest available memory block.
- **First-Fit**: The process is allocated in the first available memory block.

Perfomance Evaluation

5 Memory Management

The main perform the following steps:

1. **Allocates 1000 bytes**
2. **Allocates 1000 bytes**
3. **Allocates 1500 bytes**
4. **Allocates 100 bytes**
5. **Allocates 100 bytes**
6. **Allocates 100 bytes**
7. **Allocates 100 bytes**
8. **De-allocates 1000 bytes (second block)**
9. **De-allocates 100 bytes (fourth block)**
10. **De-allocates 100 bytes (fifth block)**
11. **De-allocates 100 bytes (sixth block)**
12. **Allocates 300 bytes**
13. **Allocates 1000 bytes**
14. **Creates a task (TASK 1)**

First-Fit and Worst-Fit output 1/2

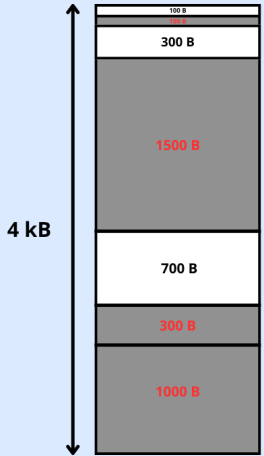
5 Memory Management

```
QEMU RTOSdemo started
Message                          | Free Heap (bytes) | Minimum Ever Free Heap (bytes)
---------------------------------------------------------------------------------
Before allocating memory blocks | 0                 | 0
After allocated 1000 bytes       | 3072              | 3072
After allocated 1000 bytes       | 2064              | 2064
After allocated 1500 bytes       | 552               | 552
After allocated 100 bytes        | 440               | 440
After allocated 100 bytes        | 328               | 328
After allocated 100 bytes        | 216               | 216
After allocated 100 bytes        | 104               | 104
After deallocated the second block (1000 bytes) | 1112            | 104
After deallocated the fourth block (100 bytes) | 1224             | 104
After deallocated the fifth block (100 bytes) | 1336              | 104
After deallocated the sixth block (100 bytes) | 1448              | 104
After allocated 300 bytes        | 1136              | 104


 Ooops...Malloc failed
```

First-Fit and Worst-Fit output 2/2

5 Memory Management



Best-Fit output 1/2

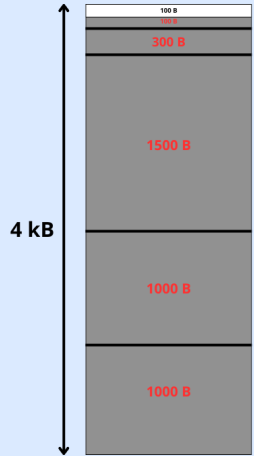
5 Memory Management

```
QEMU RTOSdemo started
Message                          | Free Heap (bytes) | Minimum Ever Free Heap (bytes)
---------------------------------------------------------------------------------
Before allocating memory blocks | 0                 | 0
After allocated 1000 bytes      | 3072              | 3072
After allocated 1000 bytes      | 2064              | 2064
After allocated 1500 bytes      | 552               | 552
After allocated 100 bytes       | 440               | 440
After allocated 100 bytes       | 328               | 328
After allocated 100 bytes       | 216               | 216
After allocated 100 bytes       | 104               | 104
After deallocated the second block (1000 bytes) | 1112              | 104
After deallocated the fourth block (100 bytes) | 1224             | 104
After deallocated the fifth block (100 bytes) | 1336            | 104
After deallocated the sixth block (100 bytes) | 1448            | 104
After allocated 300 bytes       | 1136              | 104
After allocated 1000 bytes      | 128               | 104


 Ooops...Malloc failed
```

Best-Fit output 2/2

5 Memory Management



Thanks for listening