



Secure Timeout System NXP S32K3X8EVB

Beamer for the CAOS Project

Andrea Botticella

Fabrizio Emanuel

Elia Innocenti

Renato Mignone

Simone Romano

February 5, 2025



**Politecnico
di Torino**



Table of Contents

1 Project Overview

- ▶ Project Overview
- ▶ QEMU Board Emulation
- ▶ FreeRTOS Porting
- ▶ Test Application
- ▶ Memory Protection Unit (MPU) Implementation
- ▶ Conclusion



Project Overview

1 Project Overview

- The assignment consists of FOUR parts:
 - **Part 1: QEMU board emulation**
 - Generating a custom QEMU version to emulate the NXP S32K3X8EVB board.
 - Ensuring that QEMU emulates the proper CPU, memory map, and the peripherals assigned.
 - **Part 2: FreeRTOS porting**
 - Ensuring that FreeRTOS runs on the emulated board.
 - **Part 3: Writing a simple application**
 - Writing a simple application implementing different tasks to test the setup.



Project Overview

1 Project Overview

- The assignment consists of FOUR parts:
 - **Part 4: Documentation and presentation**
 - Creating a tutorial to run and test your code.
 - Documentation of the code.
- What we've actually done:
 - *Secure Timeout System* application on the **NXP S32K3X8EVB board** using **FreeRTOS**, emulated with **QEMU**.
 - Refer to the dedicated markdown files in the repository: `README.md` and `GUIDE.md`. These files contain all the implementation details and the tutorial to replicate the project.



Table of Contents

2 QEMU Board Emulation

- ▶ Project Overview
- ▶ **QEMU Board Emulation**
- ▶ FreeRTOS Porting
- ▶ Test Application
- ▶ Memory Protection Unit (MPU) Implementation
- ▶ Conclusion



Custom QEMU Version

2 QEMU Board Emulation

- Emulate the **NXP S32K3X8EVB** board, which is not natively supported by QEMU.
- Ensure proper emulation of the **CPU (ARM Cortex-M7)**, memory map, and peripherals.





Technical Details

2 QEMU Board Emulation

- Added a new machine model to **QEMU** for the **S32K3X8EVB** board.
- Used previous QEMU implementations as reference (**ARMv7-M** architecture).
- Implemented custom initialization routines for memory and peripherals.
- **S32K358EVB** board has the following specification:
 - ARM Cortex-M7 CPU.
 - ~8MB Flash memory, 768KB SRAM, 256KB DTCM, and 128KB ITCM.
 - NVIC with 256 IRQs and 4 priority bits.
 - Multiple peripherals: 16 LPUART, 3 PIT timers, 16 MPU regions.
 - System clock running at 240MHz.



Memory Regions Initialization

2 QEMU Board Emulation

- **Flash Memory:** Configured multiple blocks:
 - Block0: Base Address: 0x00400000, Size: 2 MB
 - Block1: Base Address: 0x00600000, Size: 2 MB
 - Block2: Base Address: 0x00800000, Size: 2 MB
 - Block3: Base Address: 0x00A00000, Size: 2 MB
 - Block4: Base Address: 0x10000000, Size: 128 KB
 - Utest: Base Address: 0x18000000, Size: 8 KB
- **SRAM Memory:**
 - Block0: Base Address: 0x20400000, Size: 256 KB
 - Block1: Base Address: 0x20440000, Size: 256 KB
 - Block2: Base Address: 0x20480000, Size: 256 KB
- **DTCM and ITCM Memory:**
 - DTCMo: Base Address: 0x20000000, Size: 128 KB
 - ITCMo: Base Address: 0x00000000, Size: 64 KB



Peripherals and Interrupts Setup

2 QEMU Board Emulation

- **NVIC (Nested Vectored Interrupt Controller):**
 - Configured with 256 IRQs and 4 priority bits.
 - Interrupt vectors mapped in system memory.
- **LPUART (Low Power UART):**
 - Base Address: 0x4006A000
 - The board has **16 LPUART instances**.
They are mapped starting from the UART base address.
 - Connected to NVIC and clocked by AIPS_PLAT_CLK and AIPS_SLOW_CLK.
- **PIT Timers (Periodic Interrupt Timer):**
 - Timer1: Base Address: 0x40037000
 - Timer2: Base Address: 0x40038000
 - Timer3: Base Address: 0x40039000
- **MPU: 16 regions.**



System Clocks and Interrupts

2 QEMU Board Emulation

- **System Clock:**

- Primary System Clock: 240MHz frequency, 4.16ns period.
- AIPS Platform Clock: 80MHz
- AIPS Slow Clock: 40MHz

- **Interrupt Handling:**

- Configured NVIC to handle exceptions and IRQs.
- Supports up to 256 IRQs with 4 priority levels.
- NVIC is connected to system and reference clocks.
- Interrupt sources include timers, UARTs, and peripheral events.



Firmware Loading

2 QEMU Board Emulation

- Function: `s32k3x8_load_firmware`
- Parameters:
 - `cpu`: The ARM CPU instance.
 - `ms`: The machine state.
 - `flash`: The memory region representing the flash memory.
 - `firmware_filename`: The filename of the firmware to be loaded.
- Functionality:
 - Reads the firmware file and loads its contents into the specified flash memory region.



Class initialization

2 QEMU Board Emulation

- s32k3x8_class_init:

```
static void s32k3x8_class_init(ObjectClass *oc, void *data) {  
    MachineClass *mc = MACHINE_CLASS(oc);  
    mc->name = g_strdup("s32k3x8evb");  
    mc->desc = "NXP S32K3X8 EVB (Cortex-M7)";  
    mc->init = s32k3x8_init;  
    mc->default_cpu_type = ARM_CPU_TYPE_NAME("cortex-m7");  
    mc->default_cpus = 1;  
    mc->min_cpus = mc->default_cpus;  
    mc->max_cpus = mc->default_cpus;  
    mc->no_floppy = 1;  
    mc->no_cdrom = 1;  
    mc->no_parallel = 1;  
}
```



Table of Contents

3 FreeRTOS Porting

- ▶ Project Overview
- ▶ QEMU Board Emulation
- ▶ **FreeRTOS Porting**
- ▶ Test Application
- ▶ Memory Protection Unit (MPU) Implementation
- ▶ Conclusion



Overview

3 FreeRTOS Porting

- To test the **FreeRTOS Porting** on **QEMU**, a very simple application was created.
- The application runs a basic task that prints a message every second.
- If everything works correctly, it means that the **FreeRTOS Porting** has been successfully implemented.





Setting Up FreeRTOS

3 FreeRTOS Porting

1. **Cloning** the FreeRTOS repository.
2. Creating the directory **structure**: App/ and App/Peripherals/.
3. Creating and implementing the following files in the App/ directory:
 - s32_startup.c, s32_linker.ld
 - FreeRTOSConfig.h
 - Makefile
 - main.c
 - Peripherals/: uart.c, printf-stdarg.c with their respective header files



Running FreeRTOS on QEMU

3 FreeRTOS Porting

- main.c:

```
xTaskCreate(vTask1, "Task1", configMINIMAL_STACK_SIZE, NULL,
            mainTASK_PRIORITY, NULL);

void vTask1(void *pvParameters)
{
    (void) pvParameters;

    for (;;)
    {
        printf("Task1 is running...\n");
        vTaskDelay(1000);
    }
}
```




Running FreeRTOS on QEMU

3 FreeRTOS Porting

- Run the **Test**:
 - `cd App && make run`

```
Ready to run the scheduler ...  
Task1 is running ...  
Task1 is running ...  
Task1 is running ...  
Task1 is running ...
```

Figure: FreeRTOS Porting Test.



Table of Contents

4 Test Application

- ▶ Project Overview
- ▶ QEMU Board Emulation
- ▶ FreeRTOS Porting
- ▶ **Test Application**
- ▶ Memory Protection Unit (MPU) Implementation
- ▶ Conclusion



Secure Timeout System Application

4 Test Application

- The application is a simple implementation of a *Secure Timeout System*.
- It consists of **multiple tasks** that simulate events, monitor activities, and handle alerts.
- **Hardware timers** are used to generate **periodic interrupts** for activity detection.





Task Implementation

4 Test Application

- **Event Task:**

- Periodically generates events that can be either user activities or suspicious activities.
- Uses a pseudo-random number generator to decide the type of event.
- Logs the generated event and updates the respective counters.

```
[EVENT SIMULATOR] ——— New Cycle Started —————  
[EVENT SIMULATOR] Generated: User Activity      | Count: 1
```

```
[EVENT SIMULATOR] ——— New Cycle Started —————  
[EVENT SIMULATOR] Generated: Security Event    | Count: 1
```

Figure: Generation of a user activity and a suspicious activity.



Hardware Timer Initialization

4 Test Application

- **Timer 0:**
 - Configured to generate periodic interrupts.
 - Interrupt handler checks for **user activities** and sets the user activity detection flag.
- **Timer 1:**
 - Configured to generate periodic interrupts.
 - Interrupt handler checks for **suspicious activities** and sets the suspicious activity detection flag.



Task Implementation

4 Test Application

- **Monitor Task:**

- Checks for user activity detection.
- Logs the status of user activity.
- Resets the user activity detection flag after logging.

- **Alert Task:**

- Checks for suspicious activity detection.
- Logs the status of the system security.
- Initiates security protocols if suspicious activity is detected.
- Resets the suspicious activity detection flag after logging.



Implementation Details

4 Test Application

- **Global Variables:**

- Four main **flags**:

- `userActivity`, `userActivityDetection`,
`suspiciousActivity`, `suspiciousActivityDetection`

- **Task Priorities:**

- Event Task has the highest priority to ensure timely event generation.
- Monitor Task and Alert Task have lower priorities.

- **Timer Frequency:**

- Timer 0 and Timer 1 are configured to generate periodic interrupts at a frequency of 2 Hz.



Implementation Details

4 Test Application

- **Task Priorities:**

```
// filepath: /App/SecureTimeoutSystem/secure_timeout_system.c
#define MONITOR_TASK_PRIORITY (tskIDLE_PRIORITY + 2)
#define ALERT_TASK_PRIORITY   (tskIDLE_PRIORITY + 3)
#define EVENT_TASK_PRIORITY   (tskIDLE_PRIORITY + 4)
```

- **Timer Frequency:**

```
// filepath: /App/Peripherals/IntTimer.c
#define tmrTIMER_0_FREQUENCY (2UL)
#define tmrTIMER_1_FREQUENCY (2UL)
```




Run Example

4 Test Application

```
[EVENT SIMULATOR] ——— New Cycle Started ———
[EVENT SIMULATOR] Generated: Security Event | Count: 1

Timer 0 Interrupt: looking for user activities ...
Timer 1 Interrupt: looking for suspicious activities ...
[SECURITY ALERT] Suspicious activity detected | Status: ALARM
[SECURITY ALERT] Initiating security protocols...
[USER MONITOR] No activity | Status: IDLE
Timer 0 Interrupt: looking for user activities ...
Timer 1 Interrupt: looking for suspicious activities ...
Timer 0 Interrupt: looking for user activities ...
Timer 1 Interrupt: looking for suspicious activities ...
[SECURITY ALERT] Suspicious activity detected | Status: ALARM
[SECURITY ALERT] Initiating security protocols...
[USER MONITOR] No activity | Status: IDLE
Timer 0 Interrupt: looking for user activities ...
Timer 1 Interrupt: looking for suspicious activities ...
Timer 0 Interrupt: looking for user activities ...
Timer 1 Interrupt: looking for suspicious activities ...
[SECURITY ALERT] Suspicious activity detected | Status: ALARM
[SECURITY ALERT] Initiating security protocols...
[USER MONITOR] No activity | Status: IDLE
Timer 0 Interrupt: looking for user activities ...
Timer 1 Interrupt: looking for suspicious activities ...
Timer 0 Interrupt: looking for user activities ...
Timer 1 Interrupt: looking for suspicious activities ...
[SECURITY ALERT] Suspicious activity detected | Status: ALARM
[SECURITY ALERT] Initiating security protocols...
[USER MONITOR] No activity | Status: IDLE
Timer 0 Interrupt: looking for user activities ...
Timer 1 Interrupt: looking for suspicious activities ...
Timer 0 Interrupt: looking for user activities ...
Timer 1 Interrupt: looking for suspicious activities ...
[SECURITY ALERT] Suspicious activity detected | Status: ALARM
[SECURITY ALERT] Initiating security protocols...
[USER MONITOR] No activity | Status: IDLE
Timer 0 Interrupt: looking for user activities ...
Timer 1 Interrupt: looking for suspicious activities ...
```

Alt+F2 to open

How can I see the result of the terminal with you?

Alt+F2 to open

Alt+F2 to open

To take a screenshot of the terminal in two ways, you can use the keyboard shortcut or the screenshot tool.

1. Open the Terminal. Open the terminal window that you want to take a screenshot of.

Using Keyboard Shortcut. Press Alt+F2 to open the terminal.

2. Press Alt+F2 to open the terminal window.

Using the Screenshot Tool.

1. Open the screenshot tool by clicking the icon in the taskbar.

2. Select the window to capture the current window.

3. Click Take Screenshot and select the terminal window.

4. Save the screenshot. Save the screenshot to a location of your choice.

5. Include the screenshot in your LaTeX Document. Place the screenshot and reference it in your LaTeX document.

6. Compile your LaTeX document to generate the PDF file.

7. View the screenshot of how to include the screenshot in your LaTeX document.

8. Compile your LaTeX document to generate the PDF file.

9. View the screenshot of how to include the screenshot in your LaTeX document.

10. Compile your LaTeX document to generate the PDF file.

11. View the screenshot of how to include the screenshot in your LaTeX document.

12. Compile your LaTeX document to generate the PDF file.

13. View the screenshot of how to include the screenshot in your LaTeX document.



Table of Contents

5 Memory Protection Unit (MPU) Implementation

- ▶ Project Overview
- ▶ QEMU Board Emulation
- ▶ FreeRTOS Porting
- ▶ Test Application
- ▶ **Memory Protection Unit (MPU) Implementation**
- ▶ Conclusion



Overview

5 Memory Protection Unit (MPU) Implementation

- The MPU enhances security by restricting memory access based on region configurations.
- The ARM Cortex-M7 processor supports up to 16 MPU regions.
- FreeRTOS provides built-in MPU support for ARM Cortex-M4, which can be theoretically adapted for Cortex-M7.
 - **Errata 837070:** Requires workarounds for Cortex-M7 ropo and rop1 revisions.



Theoretical Steps for Implementation

5 Memory Protection Unit (MPU) Implementation

- **Define MPU Region Count in `FreeRTOSConfig.h`:**
 - Set `configENABLE_MPU` to 1.
 - Set `configTOTAL_MPU_REGIONS` to 16.
 - Set `configENABLE_ERRATA_837070_WORKAROUND` to 1.
- **Enable Errata Workaround:** Apply fix for Cortex-M7 ropo and rop1 by modifying `port.c`.
- **Integrate FreeRTOS Changes:** Adapt `ARM_CM4_MPU/port.c` to support Cortex-M7.



MPU Configuration

5 Memory Protection Unit (MPU) Implementation

- Each MPU region is configured with:
 - Base address
 - Region size
 - Access permissions (privileged/unprivileged, read/write/execute)
- Enables separation of kernel and user-mode tasks.





Table of Contents

6 Conclusion

- ▶ Project Overview
- ▶ QEMU Board Emulation
- ▶ FreeRTOS Porting
- ▶ Test Application
- ▶ Memory Protection Unit (MPU) Implementation
- ▶ Conclusion



Conclusion

6 Conclusion

- The `s32k3x8evb_board.c` file plays a crucial role in the emulation of the **NXP S32K3X8EVB board** within **QEMU**.
- It provides the necessary functions to load firmware, initialize memory regions, set up hardware components, and manage system clocks and interrupts.
- All the implementations and detailed information about the project are contained in the repository.
- Repository link: <https://baltig.polito.it/caos2024/group2.git>



Thank you for listening!
Any questions?