COMP 231
Lab 5 - Interrupt Proccessing

This lab consists of four subproblems. For each one, you will need to write a short ARM assembly language program and create a matching Altera Monitor Program project. You will submit your work with GitHub Classroom. Your lab submission should consist of four folders named `part1`, `part2`, etc.

The purpose of this assignment is to gain familiarity with interrupt handling and more efficient device usage. You should turn in your work using GitHub Classroom.

Getting Started

Before you begin this section, you should read through the following documents that are on Canvas and provide important information about the environment and hardware that you will be using for this lab. Specifically:

- **DE10-Standard Computer System** – this document covers the various hardware on the system. You will need to understand how to use the interrupt controller, timers, key buttons, LEDs, and seven-segment displays. This document is mostly for reference.
- **Using the ARM Generic Interrupt Controller** – this document details the specifics of how interrupts work on the ARM system as well as the interrupt controller hardware. You will need to understand this document fairly well to complete this lab. You can skip the sections that focus on assembly language.

This program will involve a new way for software and hardware to work together. Rather than having loops that check device registers to see if something has happened, we can program many devices to generate *interrupts* when their status has changed. This frees up the CPU to work on other things or go to sleep, while waiting for an event. All of your programs in this assignment will use an *interrupt vector*, which is a block of function calls stored *before* the program code. They must be located here in order for the CPU to find the functions that should be called when an interrupt happens.

For the first part of this project, we will be starting off by taking a sample program that is provided by the Monitor Program and modifying it slightly. The sample program sets up the system to generate interrupts when a key button is pressed and to light up the corresponding LED light.

You should first spend some time looking through the `gic_example` folder to understand how to use the GIC to setup and handle interrupts. You should not start working on the programming components without having a good understanding of this example. The project contains the following files:

1. **main.s** – this file contains three important components
   (a) **interrupt vector** – this section contains a fixed sequence of branch instructions that are used directly by the hardware when an interrupt is received. In particular, the `service_irq` function is the main handler we will use to deal with general hardware interrupts (as opposed to problem interrupts and priority interrupts)
   (b) **_start** – this is the `main()` function which configures interrupt handling and initializes the stack pointers for the different CPU modes. The CPU has separate stack pointers for different operating modes (user, supervisor, interrupts). **NOTE:** this code also contains code to tell the KEY device to generate interrupts when pressed. This needs to be done for *each* device you are using with interrupts.

   (c) **service_irq()** – this is the main function that is called when an interrupt has occurred. It is mostly responsible for checking to see which interrupt occurred and calling the handler for that type of interrupt. For this case, it only checks for keypress interrupts.

2. **config.s** – this file configures the GIC hardware for the interrupts that you want to handle in your programs. The example program only cares about the interrupts that will be generated when a pushbutton key is pressed.

   (a) **config_gic()** – this function calls the next function, `config_interrupt()` for each device interrupt that we want to handle. After the per-device interrupts have been configured, the GIC itself is setup and configured to listen to interrupts and send them on to the CPU.

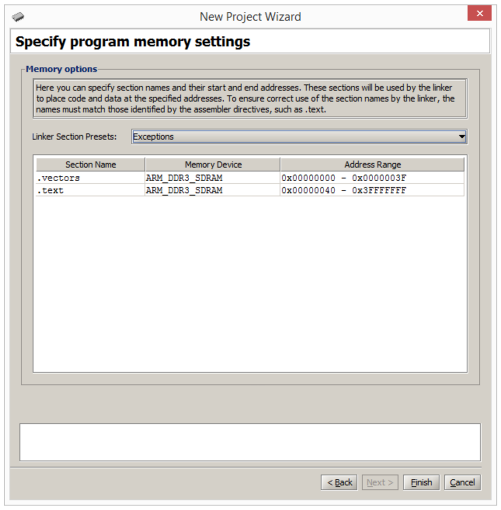
   (b) **config_interrupt()** – this function takes an interrupt ID (see `interrupt_ID.s` and a CPU ID to forward to. We always forward interrupts to CPU0.

3. **keyisr.s** – this is the function that is called by `service_irq()`, above, when a keypress interrupt occurs. In this example code, we check the GPIO device register to see which button was pressed and light up the matching LEDs.

Part 1 - Key Interrupts and Seven-Segment Displays

For this part of the assignment, start off by copying the assembly source files from the example code into the `part1` directory. There is already a file in the `part1` folder, `util.s`, which contains code to deal with the seven-segment displays from previous labs. To start your project open the Monitor Program, and head up to the Edit menu and enable "Source-Level Debugging". Next go back to the File menu and create a new project, as usual. You should add multiple assembly files to this project (not all of them): `main.s`, `config.s`, `keyisr.s`, and `util.s`. Add them in that order.

We also need to make a change to the project memory settings that is different from our previous projects. We need to tell the CPU that we are using interrupts and not to put the `_start()` function right at the beginning of memory. On the page that looks like Fig. 1.



Specify program memory settings

Memory options

Here you can specify section names and their start and end addresses. These sections will be used by the linker to place code and data at the specified addresses. To ensure correct use of the section names by the linker, the names must match those identified by the assembler directives, such as .text.

Linker Section Presets: Exceptions

Section Name	Memory Device	Address Range
.vectors	ARM_DDR3_SDRAM	0x00000000 - 0x0000003F
.text	ARM_DDR3_SDRAM	0x00000040 - 0x3FFFFFFF

Figure 1: Project Memory Settings in the Monitor Program

When you move through adding the project files, you should see the screen shown in Fig. 1. It should be setup for *Exceptions*, which creates a short block at the beginning of the computer memory that holds the *interrupt* *vector*. These are the addresses of functions to jump to when the CPU receives an interrupt.

The sample program waits for a key to be pressed, which causes an interrupt to be sent to the CPU which calls the main interrupt handler, `service_irq()`. This function then calls the key interrupt handler, (`key_isr()`), the function which turns on one of the LED lights.

Your task for this part is to update the `key_isr()` code to write the number of the key that was pressed to the first seven-segment display. The first four seven-segment displays (SSD) are controlled by writing a single 32-bit value to the address `HEX3_HEX0_BASE`, the same as in previous labs.

The four keys are numbered `KEY0, KEY1, KEY2,` and `KEY3`. Update your program to light up a zero on the SSD when `KEY0` is pressed, a one when `KEY1` is pressed, etc. You may use the helper functions in `util.s` to generate the SSD patterns.

Part 2 - Timer Interrupts

For the second part of this assignment, you will find some starter code in the `part2` folder. Go back and look at the DE10 documentation in Chapters 2 and 3 for information on the HPS Timer and using it with interrupts. Your program will use the timer to generate an interrupt every 0.25 seconds to increment a counter. Here are the specific things you need to implement:

1. Implement `config_hps_timer()` in `config.s`. You need to disable the timer, setup the timer, and the start the timer and its interrupts
2. Add code to the `config_gic()` function to configure the GIC to listen for interrupts from the timer
3. Update `service_irq()` to call `hpstimer_isr()` when an HPS timer interrupt is received
4. Implement `key_isr()` to toggle (between 0 and 1) the value of the global variable `RUN` whenever any of the `KEY` buttons are pressed
5. Implement `hpstimer_isr()` to increment the global variable `COUNT` by the value of `RUN` every time the timer interrupt is received

There are two global variables, `run` and `count`. In the main function, the program executes an infinite loop that writes the value stored in `count` out to the red LEDs every time through the loop. When a timer interrupt is received, the timer ISR should increment `count` by the value stored in `run`, which will either be zero or one.

When any of the `KEY` buttons are pressed, you should toggle the value in `run`. This has the effect of pausing the timer display. When `run` is 1, the LEDs should show a count on the red lights that increments every 0.25 seconds. Otherwise, the red LEDs should display a static count value. The program should begin with the timer paused.

Create a new project file called `part2`, add the `main.s`, `config.s`, and `isr.s` files and make sure to use the Exceptions memory setup. Once your timer code is working, you can move to the next part.

Part 3 - Variable Speed Timer Interrupts

Start this part by copying the `.s` files from `part2` to the `part3` folder. In this step, you will be adding functionality to change the speed of the counter with the `KEY` buttons. You should create a new global variable, `SPEED`, to track the current speed of the counter. As before, initially the counter should increment every 0.25 seconds.

Modify your program to use only KEY_0 to start/stop the timer. When KEY_2 is pressed, the timer speed should double and when KEY_1 is pressed, the timer speed should be halved. Move onto the next section when you have a program with a variable speed timer fully functioning,

Part 4 - Multiple Interrupt Sources

In this part, we will add another timer source to the program, the A9 Private Timer. This timer should be configured to interrupt every $1/100^{th}$ of a second. Every time this timer goes off, you will calculate a value that can be displayed on the seven-segment displays to show the time in **SS:DD** format, where `SS` is seconds, and `DD` is hundredths of seconds. This timer can be stopped and started by using the KEY_3 button.

Start by copying your program from `part3`. Modify your code to configure the GIC to listen for interrupts from the A9 private timer. You should also create a new function, `config_private_timer()`, which should be called from `_start()` and initializes the timer.

You will need to add four additional global variables, `rtrun`, `time`, and `hexcode3_0` in `main.s`. The `rtrun` variable is used to toggle counting on/off. The `time` global is used to store the current time (you can use this 32-bit value however you'd like to store the time). The last two globals, should be properly formatted bit string patterns that will be written directly to the seven-segment displays (in the main loop, similar to part 1). These should be updated every time the timer interrupt goes off. There are helper functions for the seven-segment displays in `util.s`.

Lastly, update the `main()` loop so that the `HEX_3_0` device is updated with the corresponding pattern in the global variables. Make a new monitor program project and test your program until both timers work properly. You should also verify that your timer is relatively accurate (i.e. your timer should show approximately 60 seconds when one minute of actual time has elapsed.