California State University, Fresno
Lyles College of Engineering
Electrical and Computer Engineering Department

TECHNICAL REPORT

Assignment: Number 6
Experiment Title: EDS-SBT For Eclipse I/o Communication and Interrupt Processing
Course Title: ECE 178 (Embedded Systems)
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INSTRUCTOR SECTION

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Final Grade: ____________________

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Objective

Upon the completion of this lab, one will understand how to develop the DE2-115 board in QSys and Quartus Prime in order to handle interrupts. Along with this, we will have developed the comprehension of the Interrupts in the C/C++ enviroment Eclipse Software Build tools.

Hardware Requirements

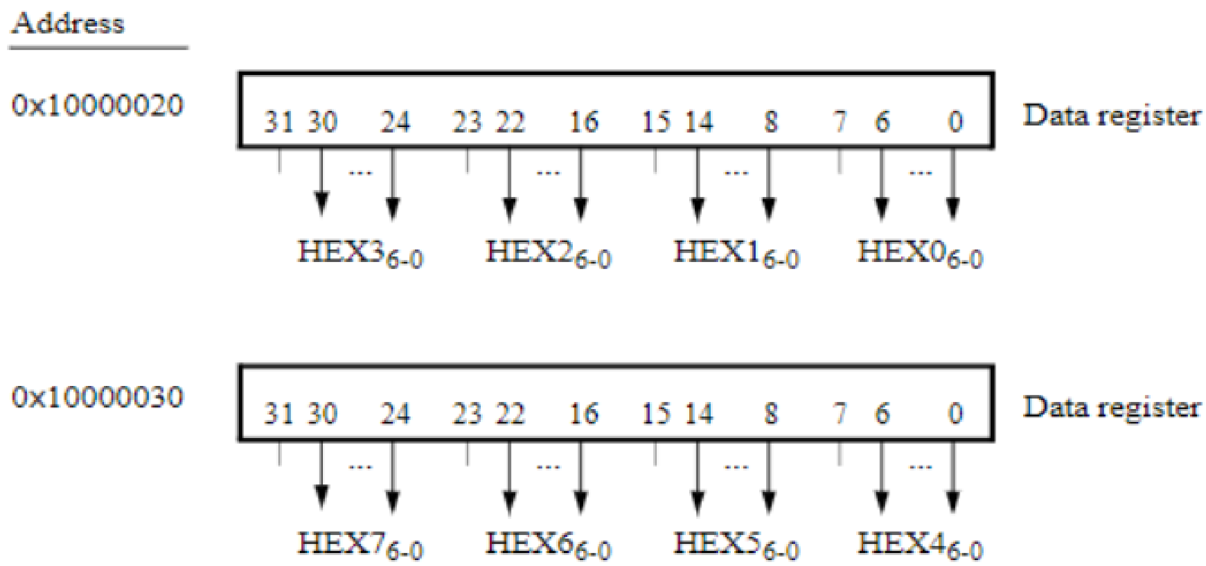
- Computer with Intel FPGA Monitor program 16.1
- Computer with Quartus Prime 16.1.
- DE2-115 Board
- A-B USB Cable

Software Requirements

- Quartus Prime with Qsys, version 16.1.

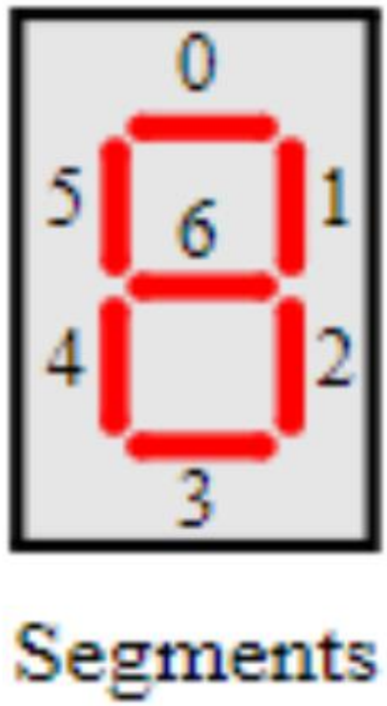
Background

In order to write to a 7-segment display, we have two address spaces, one is for the four most significant bits and the second for the four least significant bits. This is because the DE2-115 board has eight 7-Segment displays. From the design in the last lab, the address spaces for these were, 0x2020 and 0x2030. The typical address spaces for the DE2-115 board can be seen below.



1. 7-Segment Display Address Spaces

Now, from this, we also need to know how to manipulate the 7-Segments in the way that we want. So, being that the display is an active low device, in order to light up a certain display we must pass a 1 into the bit that we want to light up. Now, the segments are controlled individually, so, passing a 7 bit value of 0b1111000 will turn on the bits corresponding to bit zero, one, and two. How these bits correspond to the actual 7 segment display can be seen below.



2. 7-Segment Display Breakdown

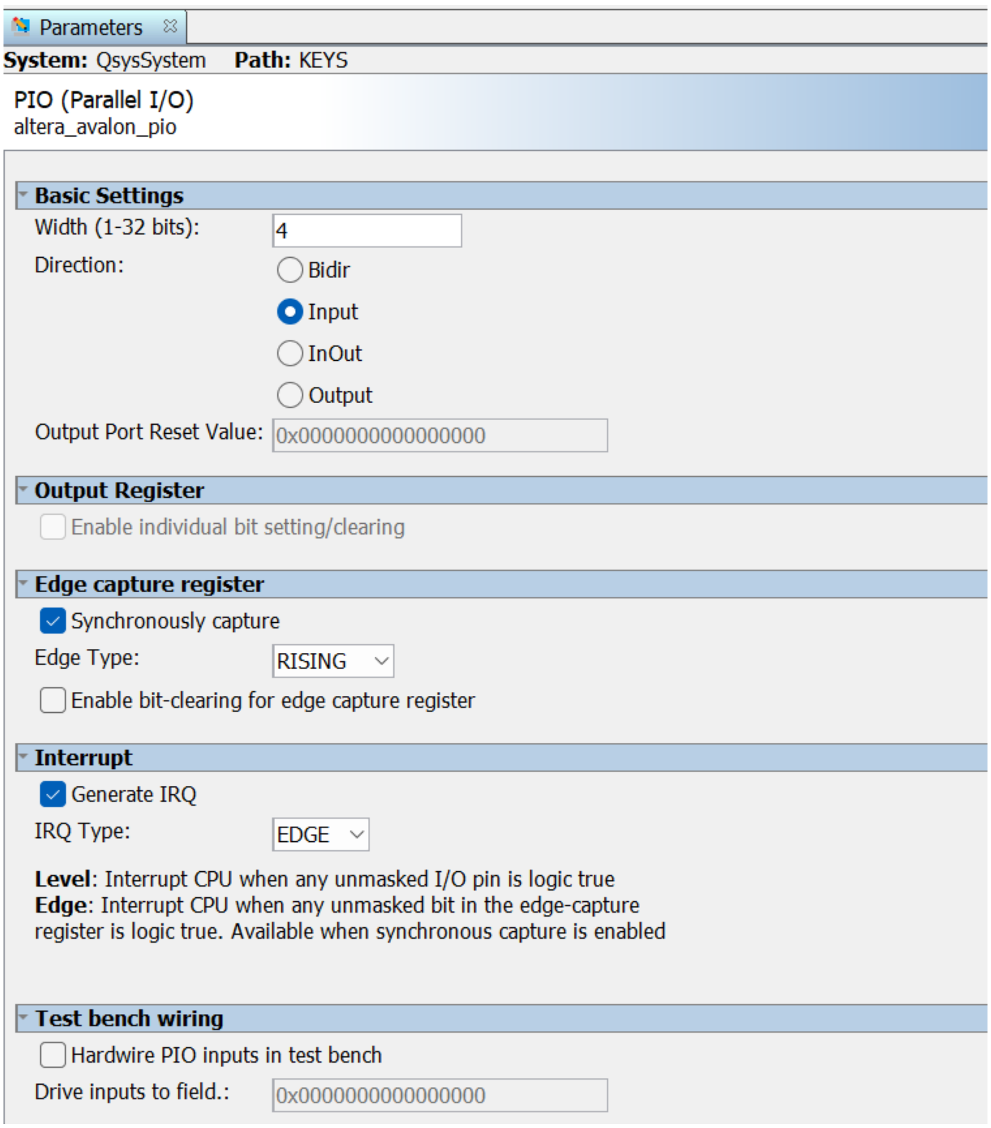
In order to generate an interrupt, there is three main steps that must be accomplished. First is the initialization. Here we set the edge capture pointer, the IRQ Mask, reset the edge capture register, and register the ISR. Setting the IRQ mask is done with the IOWR_ALTERA_AVALON_PIO_IRQ_MASK function. This function takes two arguments, the base address and the mask. So for the keys, using the base address and 0b1100 will enable key 3 and 2. Registering the IRQ is also important which is set with alt_irq_register function which takes the IRQ, edge capture pointer, and the function name that we are trying to call with the interrupt. We then have the interrupt handler, and the function for the ISR program.

Project Overview

For this lab, we will be using the soft-core embedded system that was developed in a previous project with a couple modifications to perform a variety of tasks on the DE2-115 board using a C/C++ runtime enviroment. First, alter the system using Quartus Prime In order to incorporate interrupts. Next, there will be two main code sections. The first section of code will use key 2 and key 3 interrupts. Key 2 will set the value on first 4 green LED bits to 1. Key 3 will count up if pressed and the first switch is high, and down if the first switch is low. The second program will display a two digit number on the first two HEX displays. Key 1 will set the number to 0. Key 2 will increment the number, and Key 3 will decrement the number.

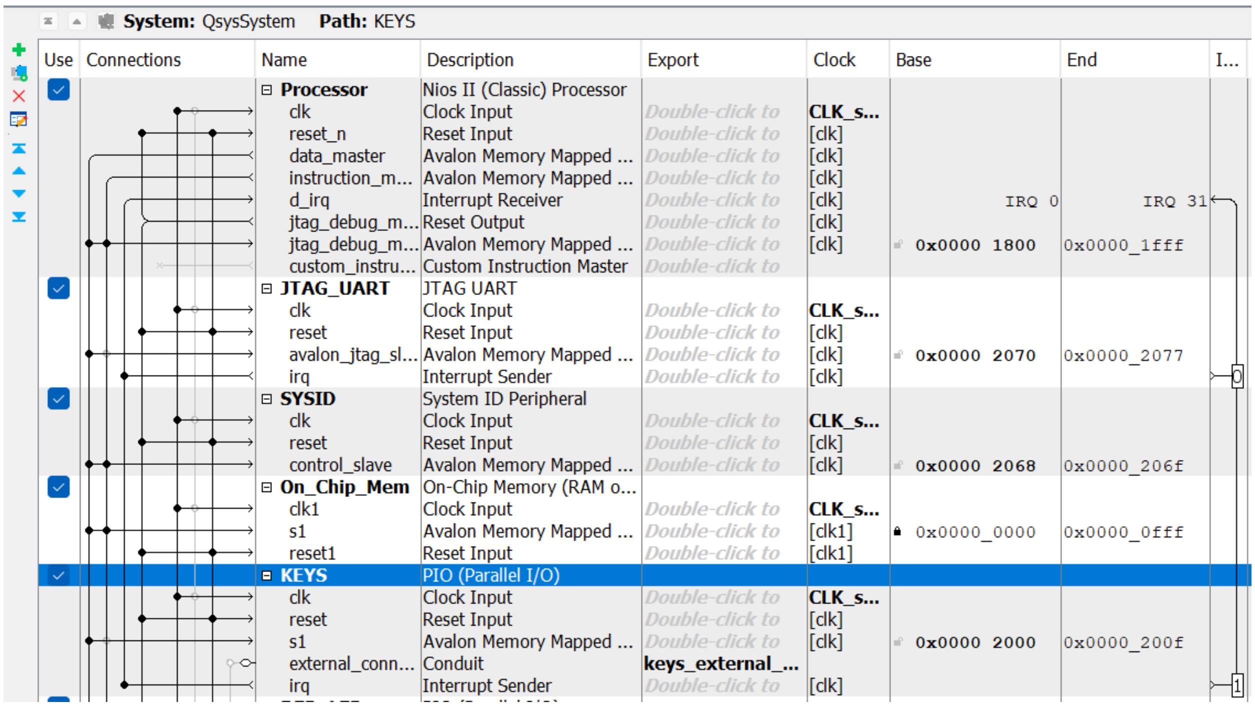
Project Procedure

To begin this lab, we first open the QSys, and edit a few things from the softcore embedded system design from Lab 3. First, the KEYS are set to a 4 bit width enabling all four keys, as well as the edge capture register turned on to the rising edge of the clock, and the IRQ generation on with the "Edge" type.



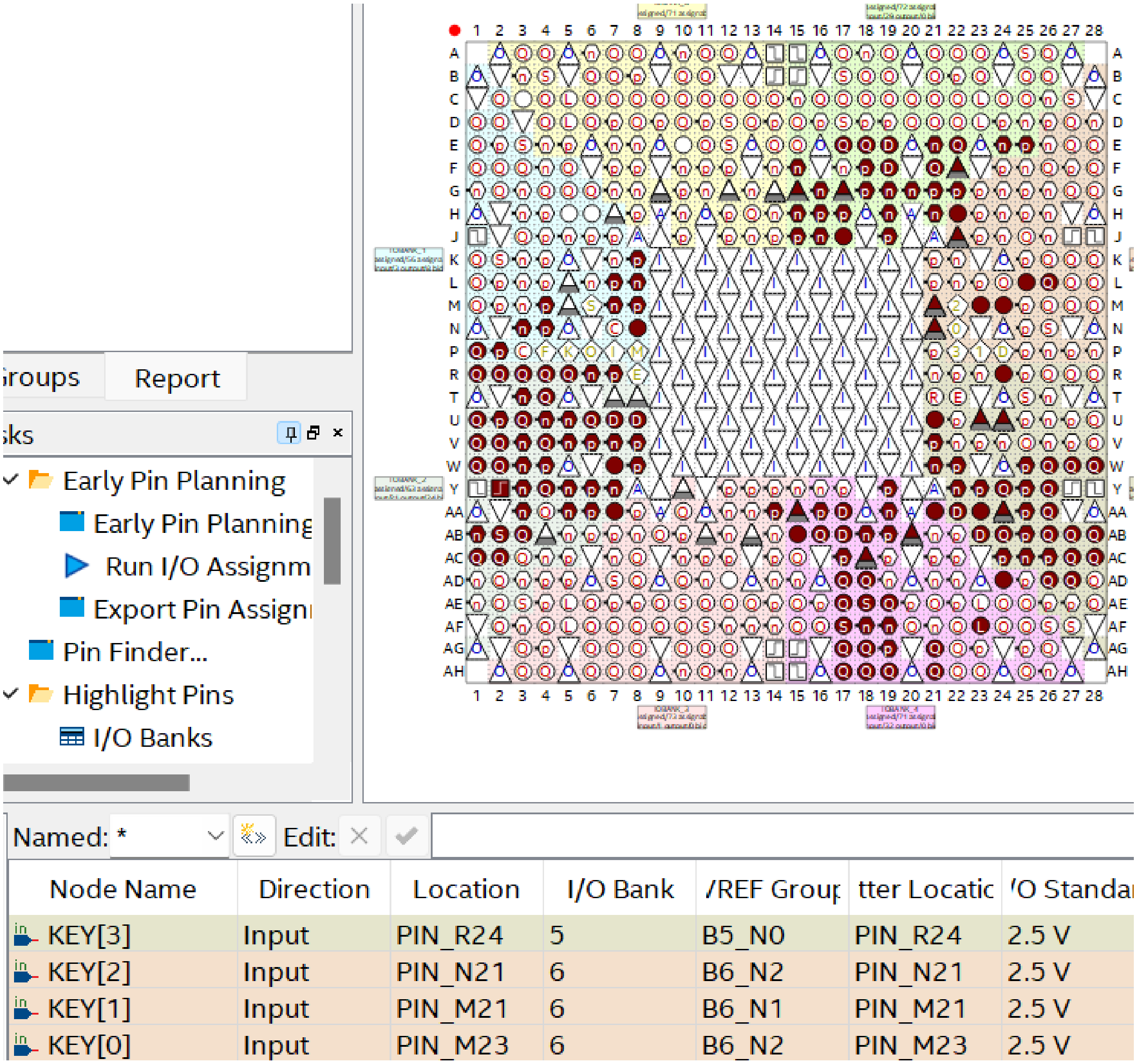
3. QSys Keys Properties

Along with the KEY properties we must ensure that the KEYS are set and have an Interrupt ID, which is shown to the right of the PIO device. We can see in the figure below that for the KEYS PIO, the Interrupt is labeled number 1.



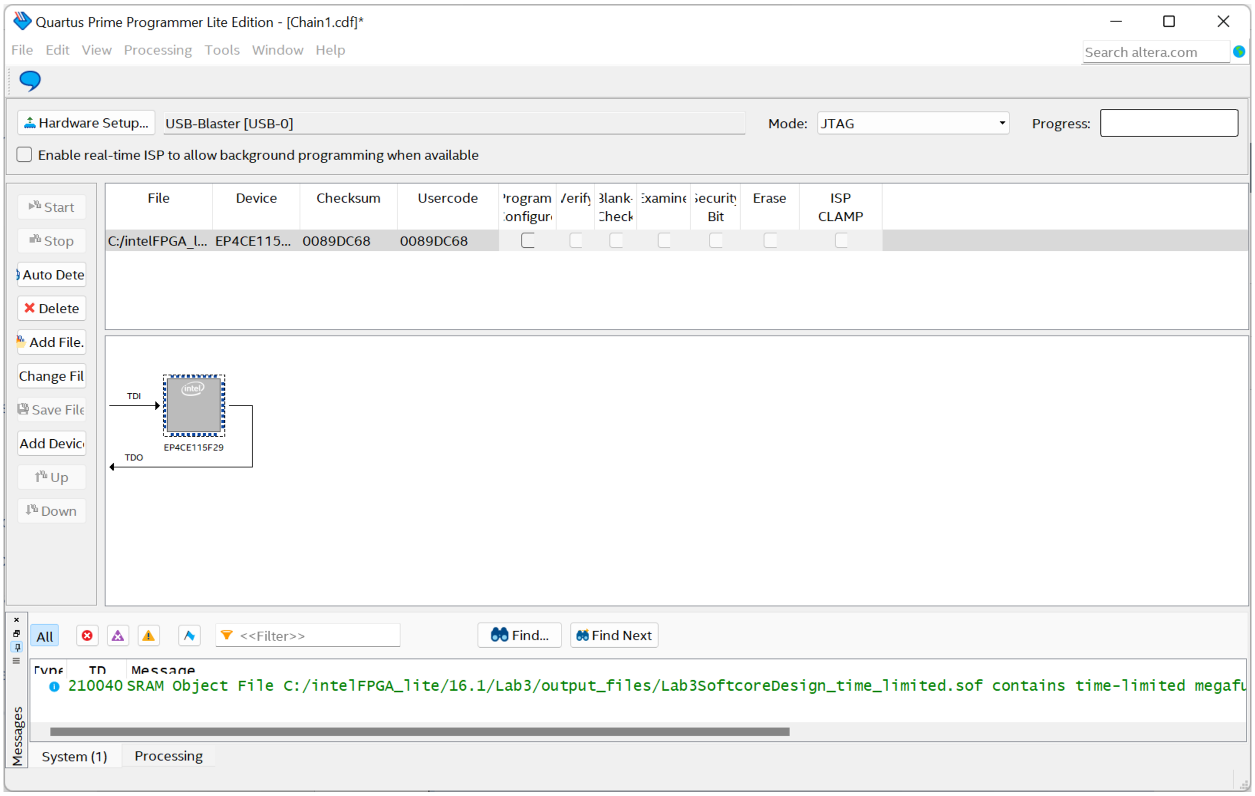
4. QSys KEYS PIO Connections

Next, after this is set, we generate the Verilog system file from this. We must also alter the top-level design in order to instantiate the module. This Top-level instantiation can be seen in appendix A. After compiling this, we must then set the pins for the KEYs. In order to do this, we go into the pin planner in Quartus Prime, and set the pins to the addresses seen in the figure below.



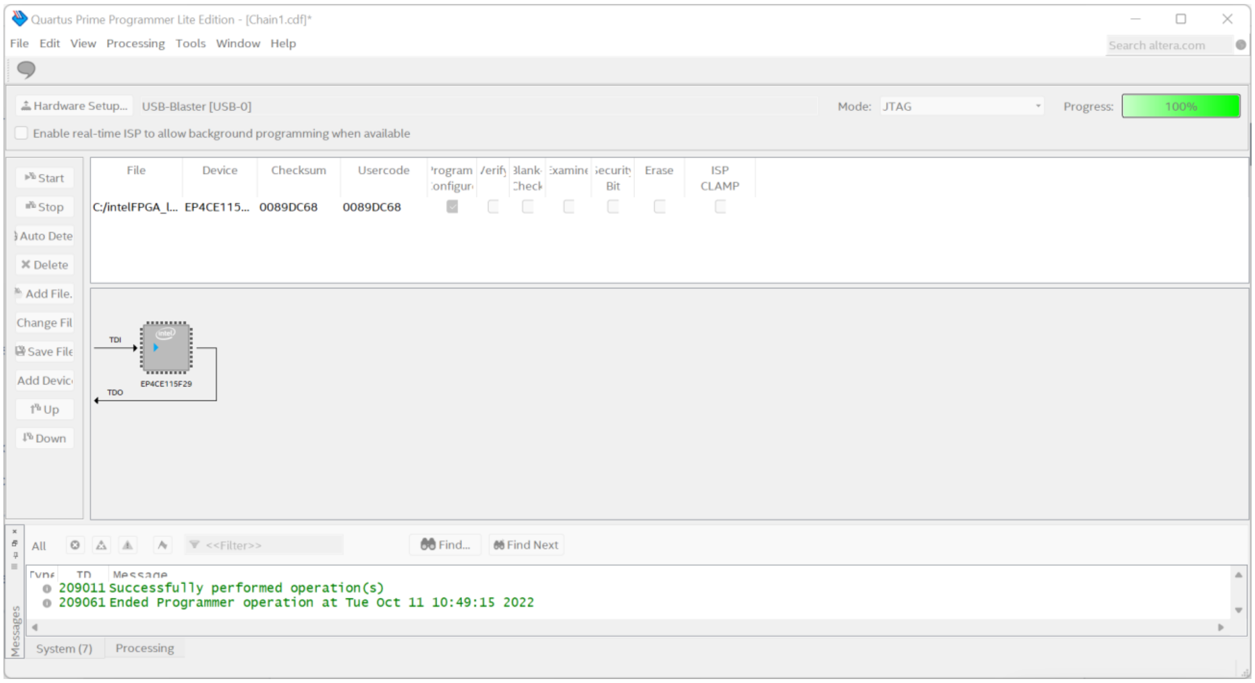
5. Pin Planner for KEYS

Next, we must download the sof file onto the board. So, we double click in the file section and add the sof file from a previous lab, Lab 3. Next we download the system onto the board, the process can be shown in the following figures, starting at adding the file to the Quartus Prime Programmer.



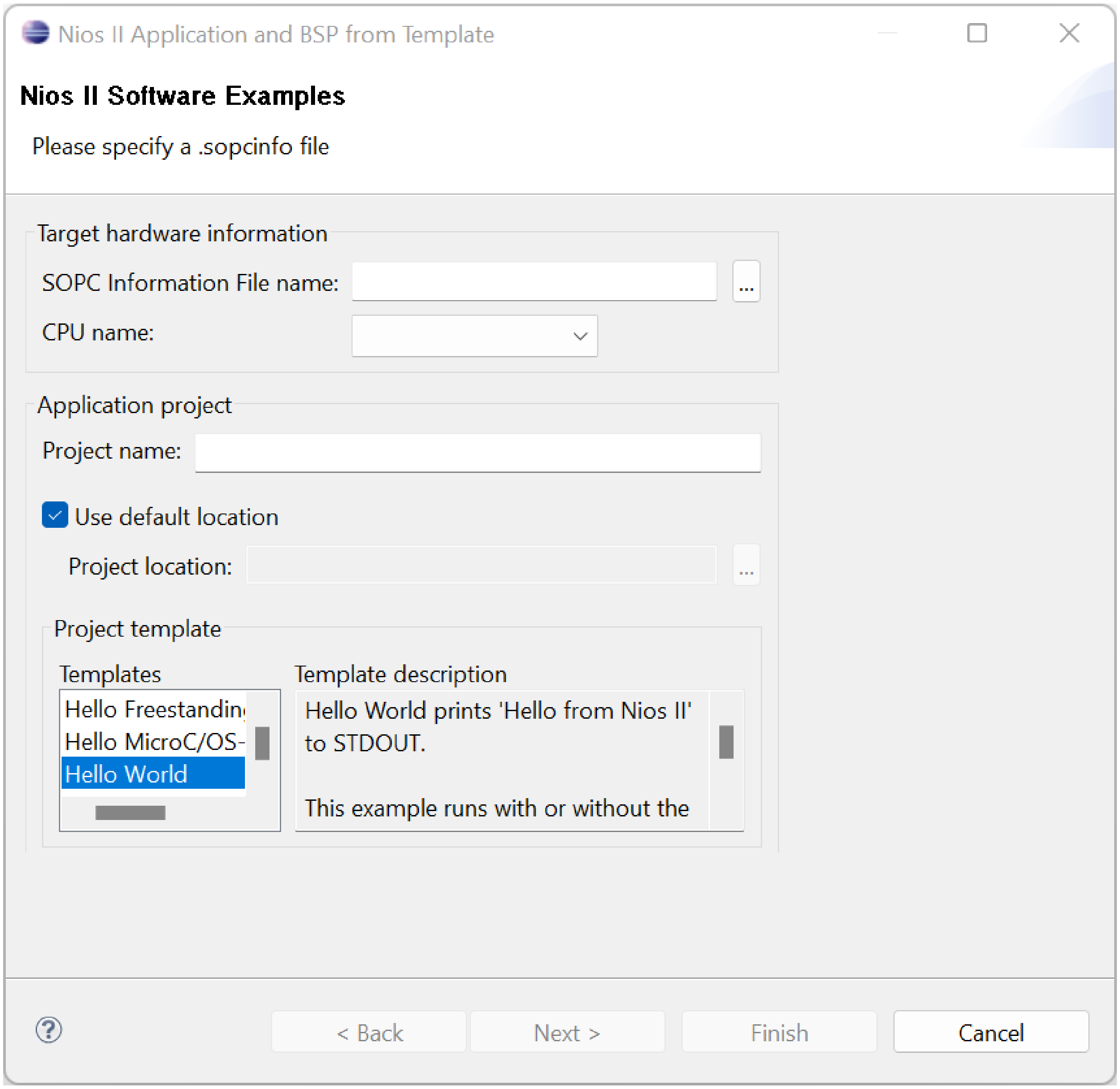
6. Adding the File to be Downloaded onto the Board

After adding the sof file, it is simple, we must next check the program configuration box, and click start. This will download the system onto the DE2-115 board. A successful download can be seen in the figure below, marked by the progress bar in the top right being at 100%, and the successes in the console.



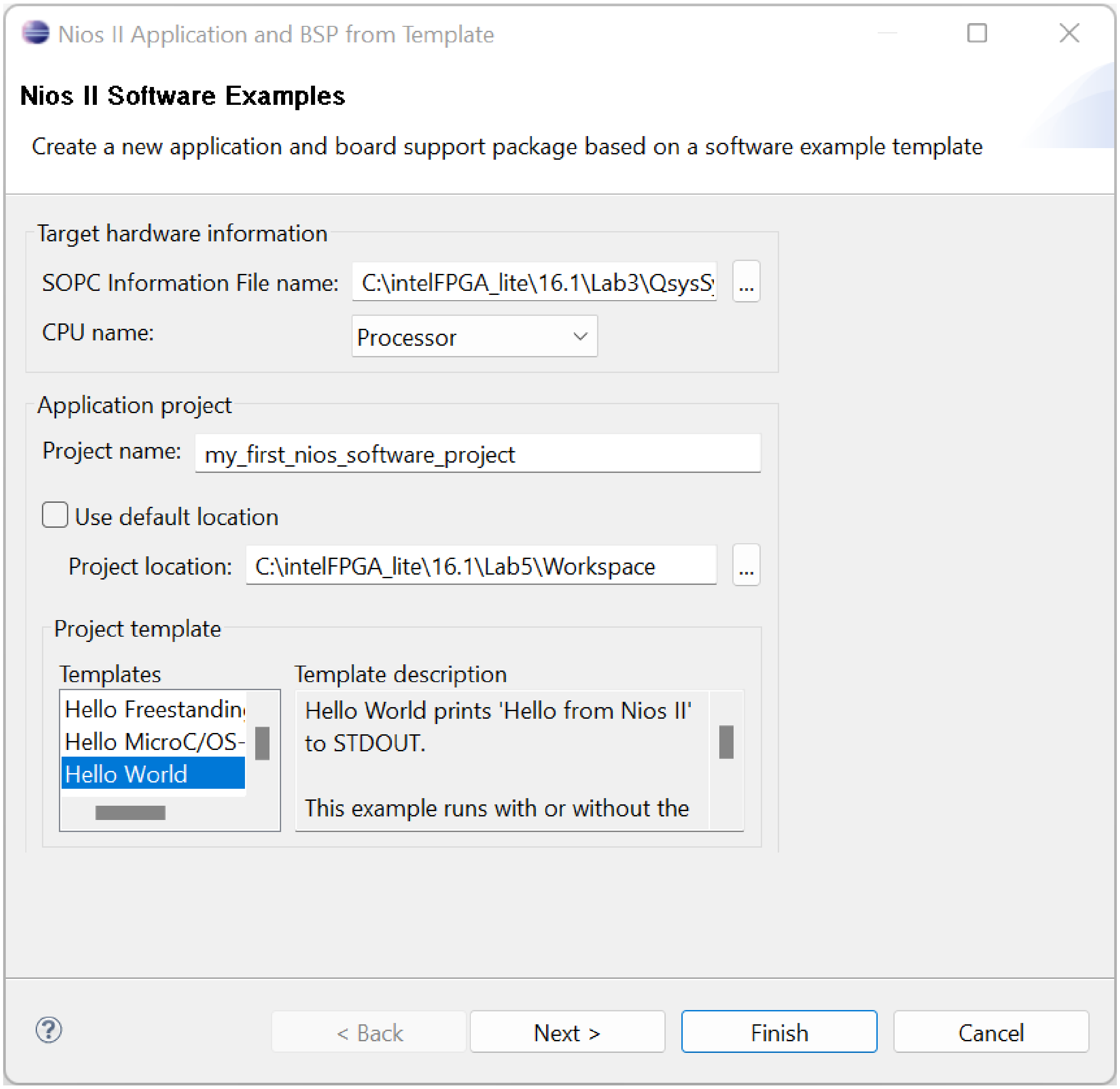
7. Completed Download onto the Board

After downloading the system on the board, we then launch NIOS II Software Build tools for Eclipse. This program can be found in the tools drop down menu in Quartus Prime. From here, we create a NIOS II Application and BSP from template, and the pop-out window can be seen below.



8. NIOS II Application and BSP from Template

After setting the SOPC Info file to the correct one corresponding to our board, setting the CPU Name, as well as the project name, and location, we select the Hello World from the project templates. This will be our base Project template that we will edit to accomplish our design goals. We can see this in the figure below.



9. NIOS II Application and BSP From Template Settings

After creating the NIOS II application and BSP, we are then able to implement our project design specifications. The first part of this project's code can be seen in Appendix B. For this design we have a few functions. The first two of these is the incr and decr function. Seen in the figure below. These functions read the LED value and will either increment or decrement until the counter reaches 9 or 1 and write the output to the Green LEDs.

```c
void incr(){
	int LEDVal = 0;
	LEDVal = IORD(GREEN_LEDS_BASE, 0);

	for (int i = LEDVal; i <= 9; i++){
		IOWR(GREEN_LEDS_BASE, 0, i);
		delayfn();
	}
	return;
}

void decr(){
	int LEDVal = 0;
		LEDVal = IORD(GREEN_LEDS_BASE, 0);

		for (int i = LEDVal; i >= 1; i--){
			IOWR(GREEN_LEDS_BASE, 0, i);
			delayfn();
		}
		return;
}
```

10. Incr and Decr functions

These functions also call the delayfn function in order to leave some time between each count. The delay function is simply a while loop. This can be seen in the figure below.

```c
void delayfn(){
	int delay = 0;
		while(delay < 2000000)
		{
			delay++;
		}
}
```

11. Delay Function

The next functions are the Key3 and Key2 ISRs. The Key3 function loads the value of Sw0 into Sw0 integer value. This is then checked and if it is 1 it will call the incr function and if it is 0 it will call the decr function. Key 2 simply writes 1 to the LEDs and writes to the edge capture register to reset it, as well as reads the PIO to delay the ISR exit. These two functions can be seen below.

```
void key3_isr(){
	// Program
	int Sw0 = 0;
		Sw0 = IORD(SWITCHES_BASE, 0);

	if (Sw0 == 0){
		decr();
	}
	else if (Sw0 == 1){
		incr();
	}

	IOWR_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE, 0);
	IORD_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE);
	return;
}

void key2_isr(){
	// Program
	IOWR(GREEN_LEDS_BASE, 0, 0x1);

	IOWR_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE, 0);
	IORD_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE);
	return;
}
```

12. Key2 and Key3 ISR Functions

The next function in our program is handle_key_interrupts. This function is passed with context. Which is used in the function that is called when the interrupt is triggered. So, this function’s main purpose is to check the edge capture ptr, comparing this with the value of 8 first, which will call Key3_isr if true, and Key2_isr if true when compared with 4. This function can be seen below.

```c
void handle_key_interrupts(void* context){
    volatile int *edge_capture_ptr = (volatile int*) context;
    *edge_capture_ptr = IORD_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE);
    if (*edge_capture_ptr & 0x8){
        key3_isr();
    }
    else if (*edge_capture_ptr & 0x4){
        key2_isr();
        }
    return;
}
```

13. Handle_key_interrupts Function

The last two functions are the pio_init and the main function. the pio_init function resets the edge capture to match the altera irq register, enables the keys as the interrupts, resets the edge capture register, and registers the ISR. Lastly, the main function calls the initialization, prints the instructions for the user, writes a random number to the LEDs, and sticks in an infinite loop.

```c
void pio_init(){
    void* edge_capture_ptr = KEYS_EDGE_TYPE;
    IOWR_ALTERA_AVALON_PIO_IRQ_MASK(KEYS_BASE, 0xC);
    IOWR_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE, 0x0);
    alt_irq_register(KEYS_IRQ, edge_capture_ptr, handle_key_interrupts);

    return;
    }

int main(){
    pio_init();
    printf("Key3: \n     Sw0 High: Increment to 9\n     Sw0 Low: Decrement to 1\nKey2: Se
    IOWR(GREEN_LEDS_BASE, 0, 0b00001010);
    while(1){

    }
  return 0;
}
```

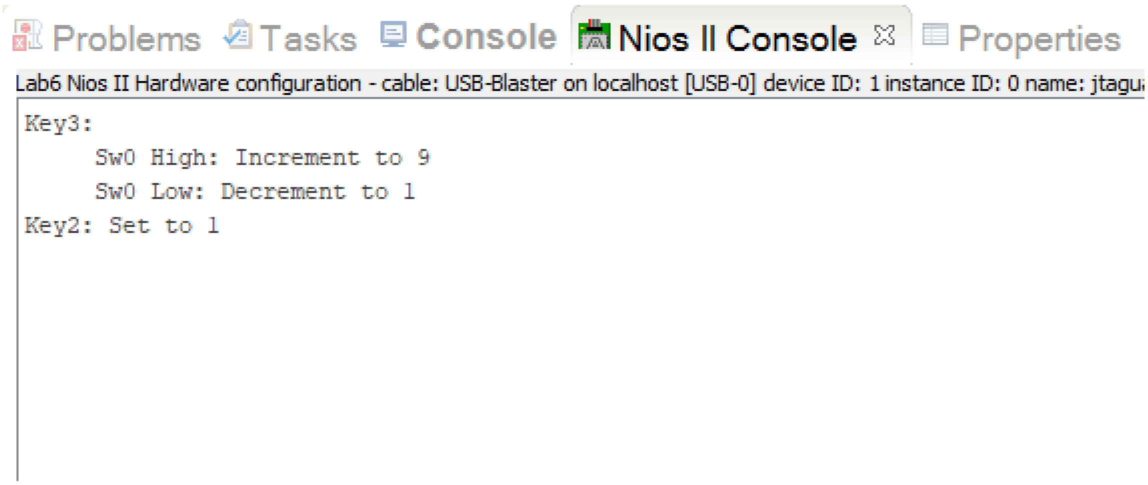
14. Pio_init and Main Functions

With this part completed, we can move into Part 2. The code for this part can be seen in Appendix C. Here, we add a global variable IncDec. This sets allows for us to increment and decrement in the main loop and not within the ISRs. So, the ISRs simply set the IncDec Value and resets the edge capture. The handle key interrupts function does the same thing as in the previous part except now with key 1 being a part as well. The pio_init also does the same as in the previous part. We have a few new functions display, which displays the value passed into in the HexDisplays as well as masking the other bits so that the seven segment displays are off. As well as the DecodeHex, which passes a value which will first be in the form of the what is the 7-

Segment Display form of the value. It then finds the integer value of those numbers. This is used in order to keep the value currently displayed when switching from incrementing to decrementing. Lastly, the main value will do the same as the last, except in the while loop, checks IncDec integer and will increment or decrement accordingly.

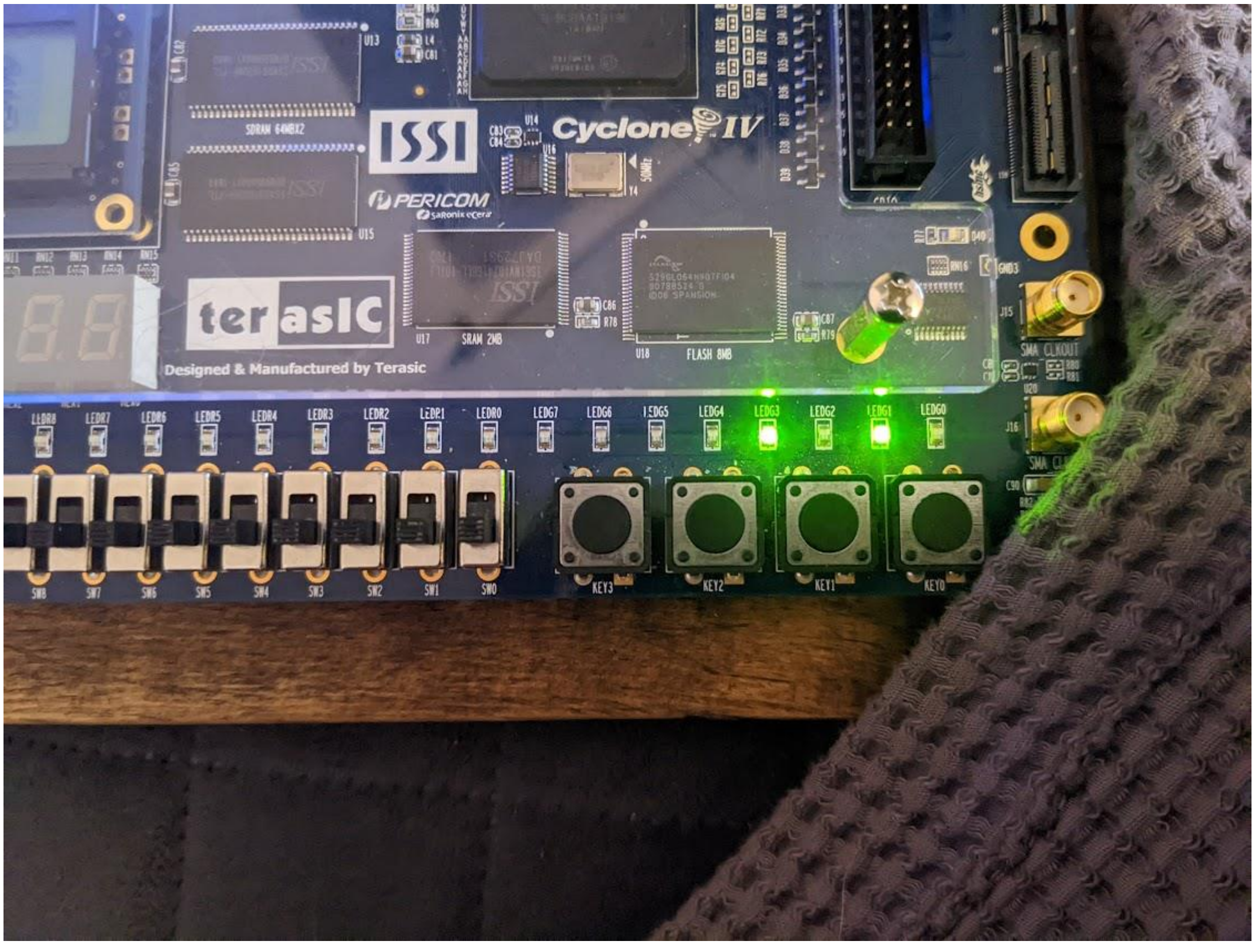
Data Analysis

Upon beginning the first part of the code, the following is displayed in the NIOSII Console.



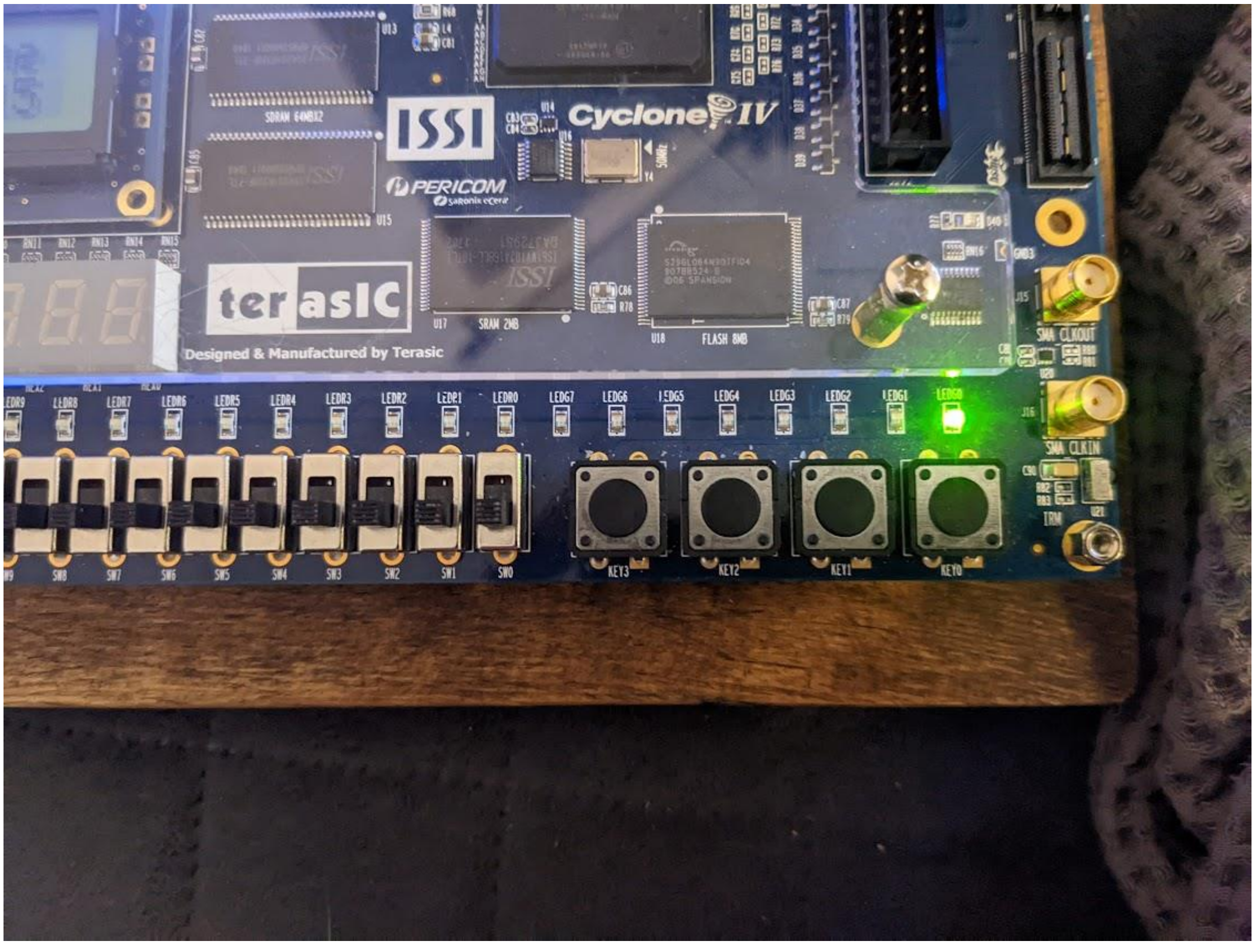
15. NiosII Console for Part 1

After starting the following pattern is shown on the LEDs this is hard coded in the main program.



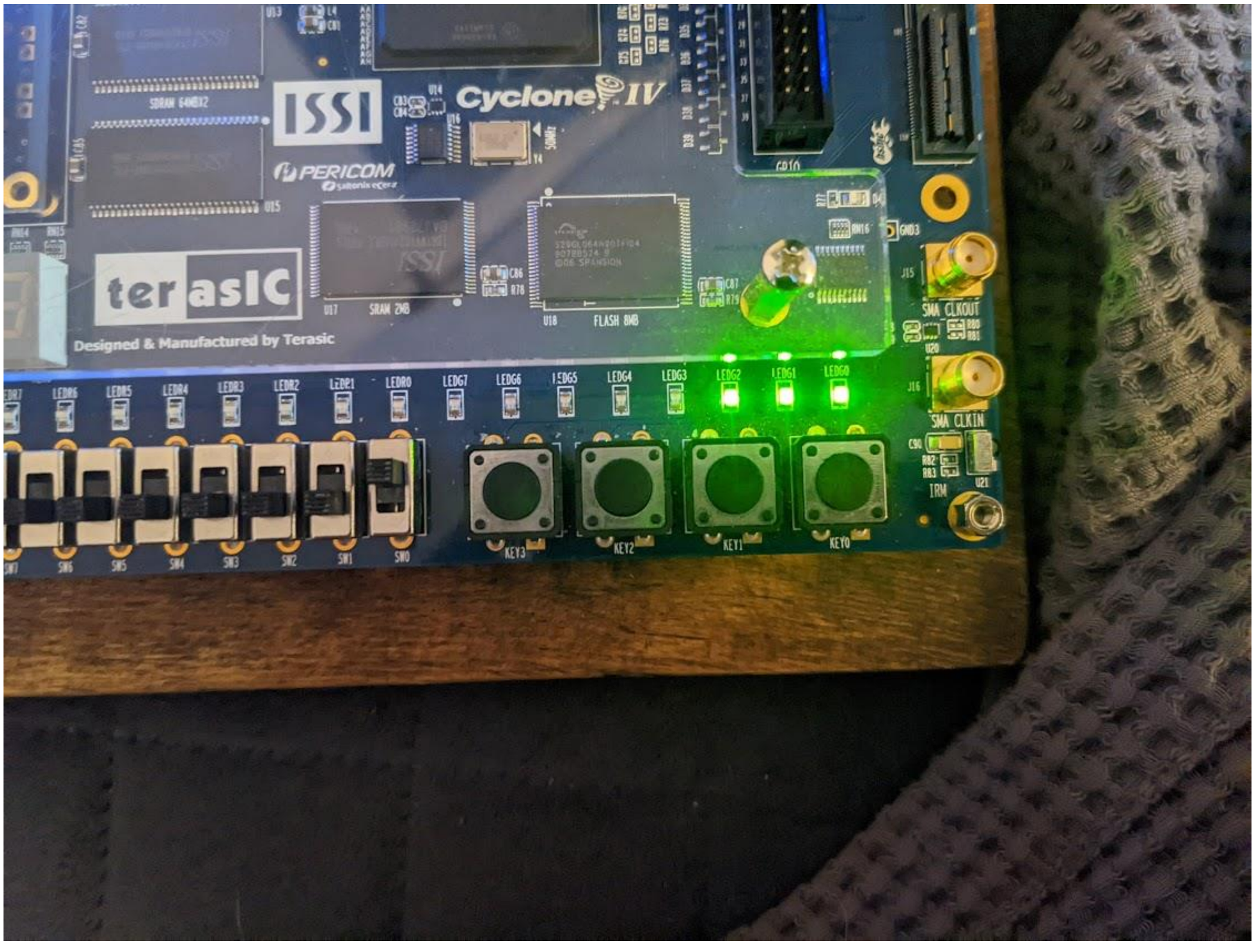
16. Initial Green LED value

Next, after hitting Key2, it sets the LED to the value of 1 immediately. This can be seen in the figure below.



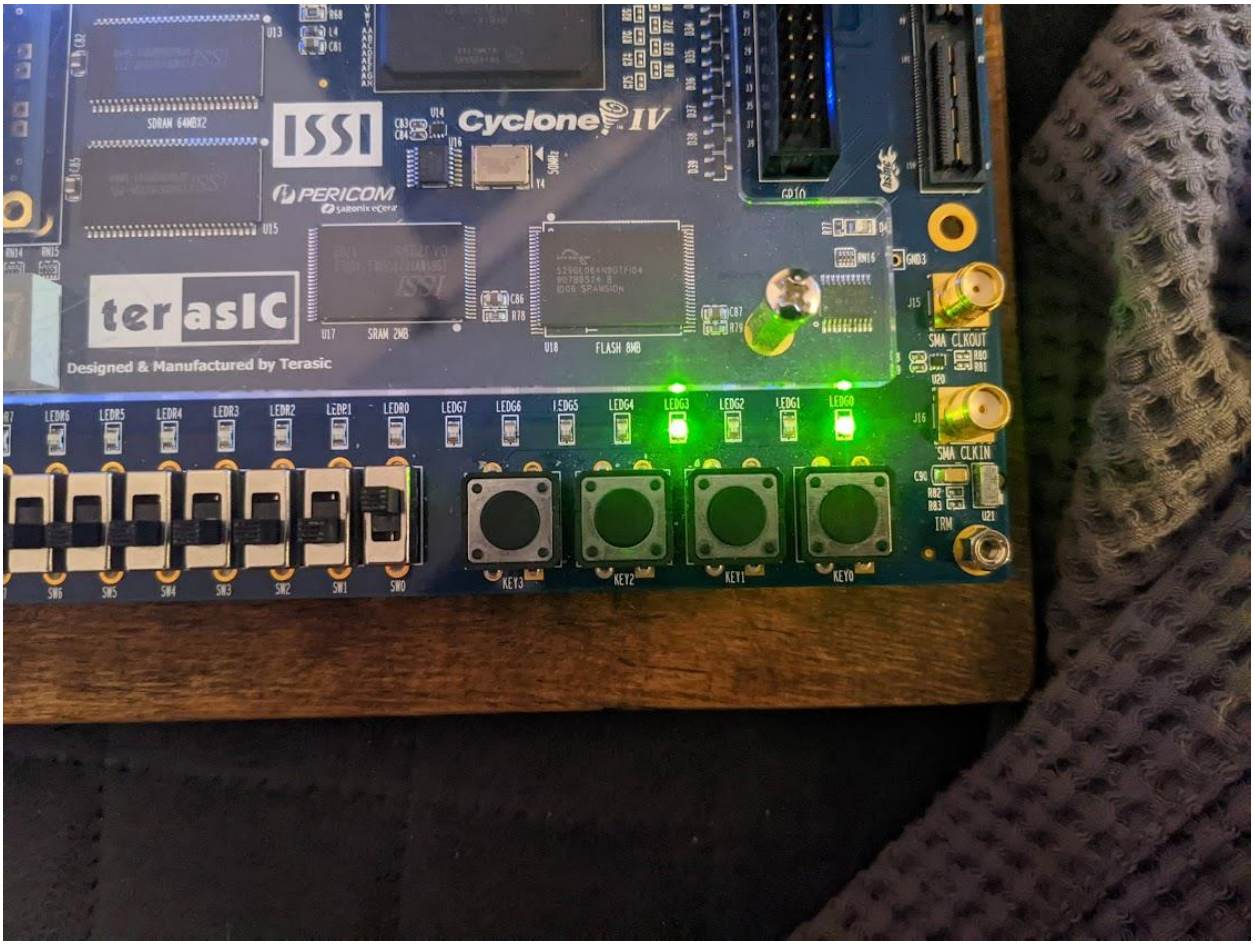
17. Set Value to 1 Using Key2

Following this, we can hit Key3 with Sw0 high, and see that it starts to count, In the following figure it is mid count.



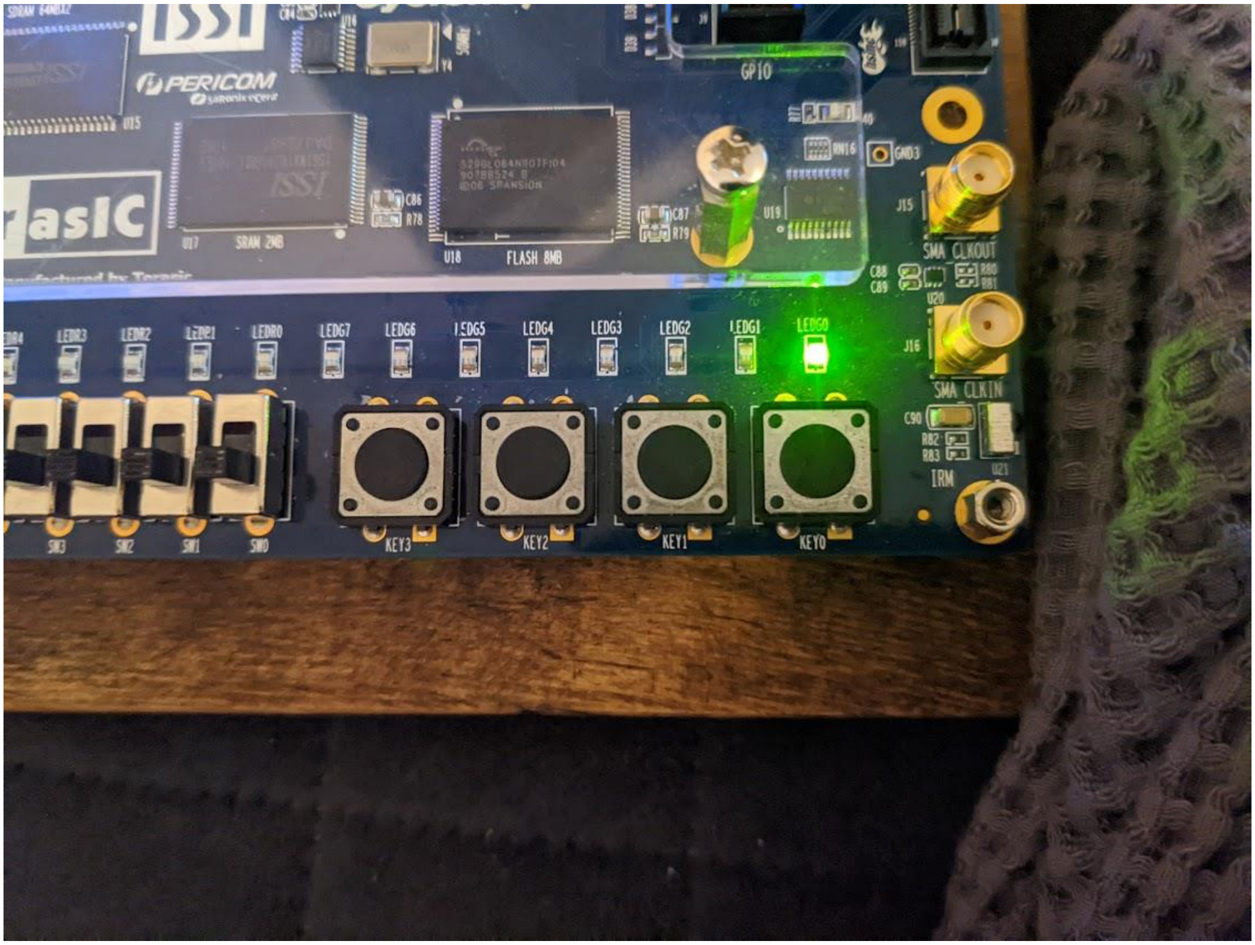
18. Count up using Key3 Sw0 High (Mid Count)

It finishes its count at the value of 9 which is shown in the figure below.



19. Finished Count up using Key3 Sw0 High

Then we can press Key3 with Sw0 low and it will count down to 1 again seen in the figure below.

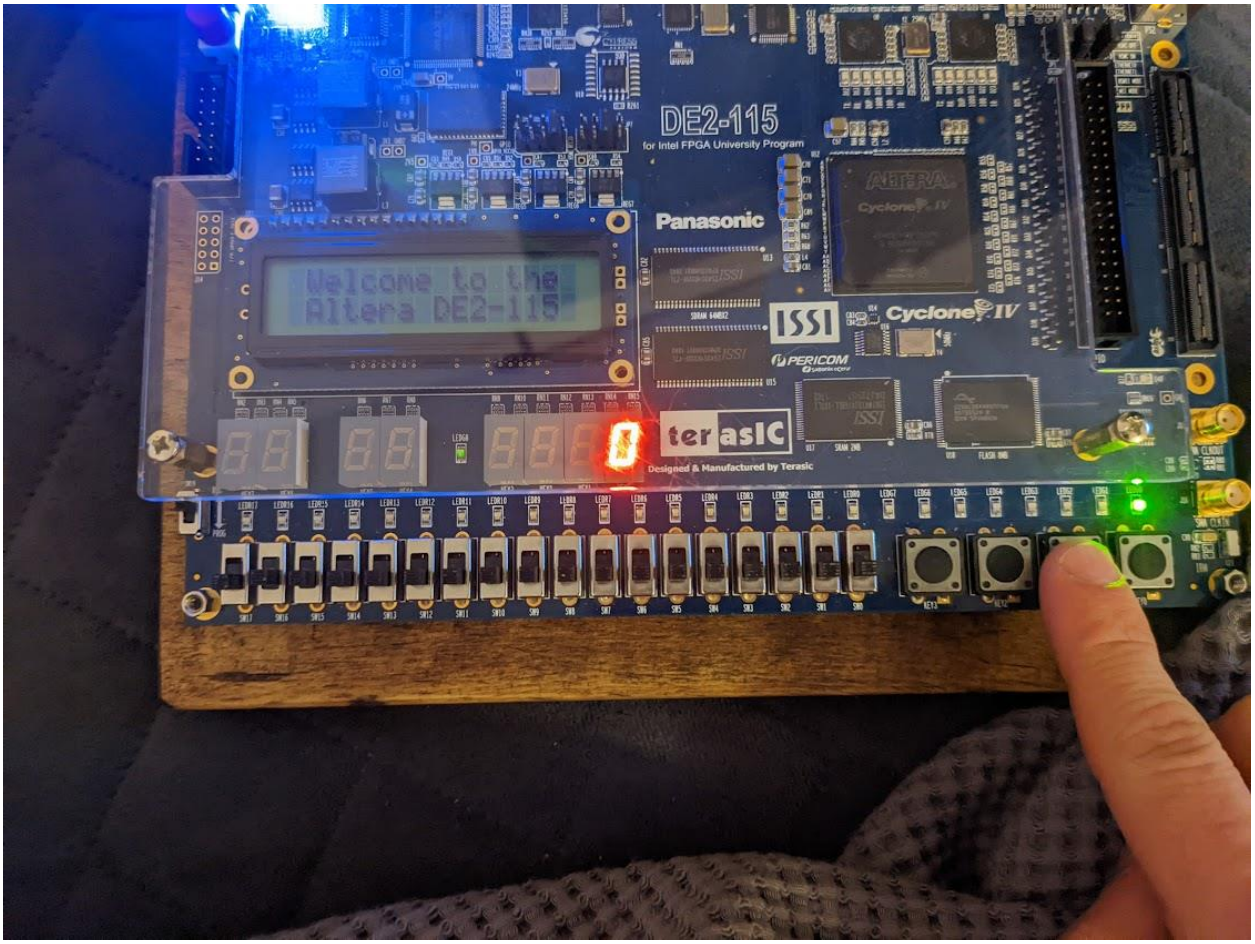


20. Finished Counting Down to 1

Next for Part 2, the following dialog is first displayed in the Nios II Console.

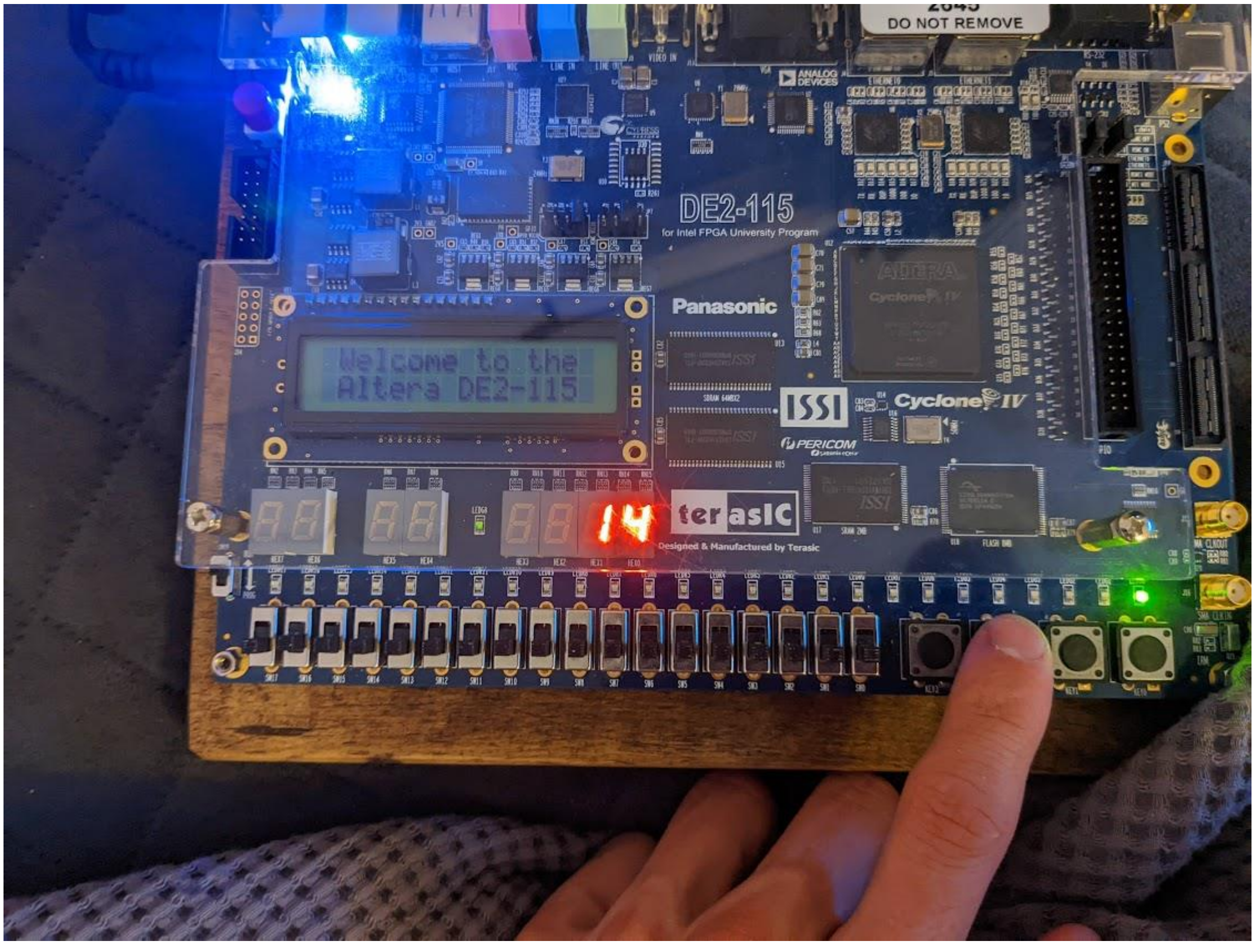
21. Nios II Output for Part 2

After this, we set the value to zero using the Key 1. This can be seen in the figure below.



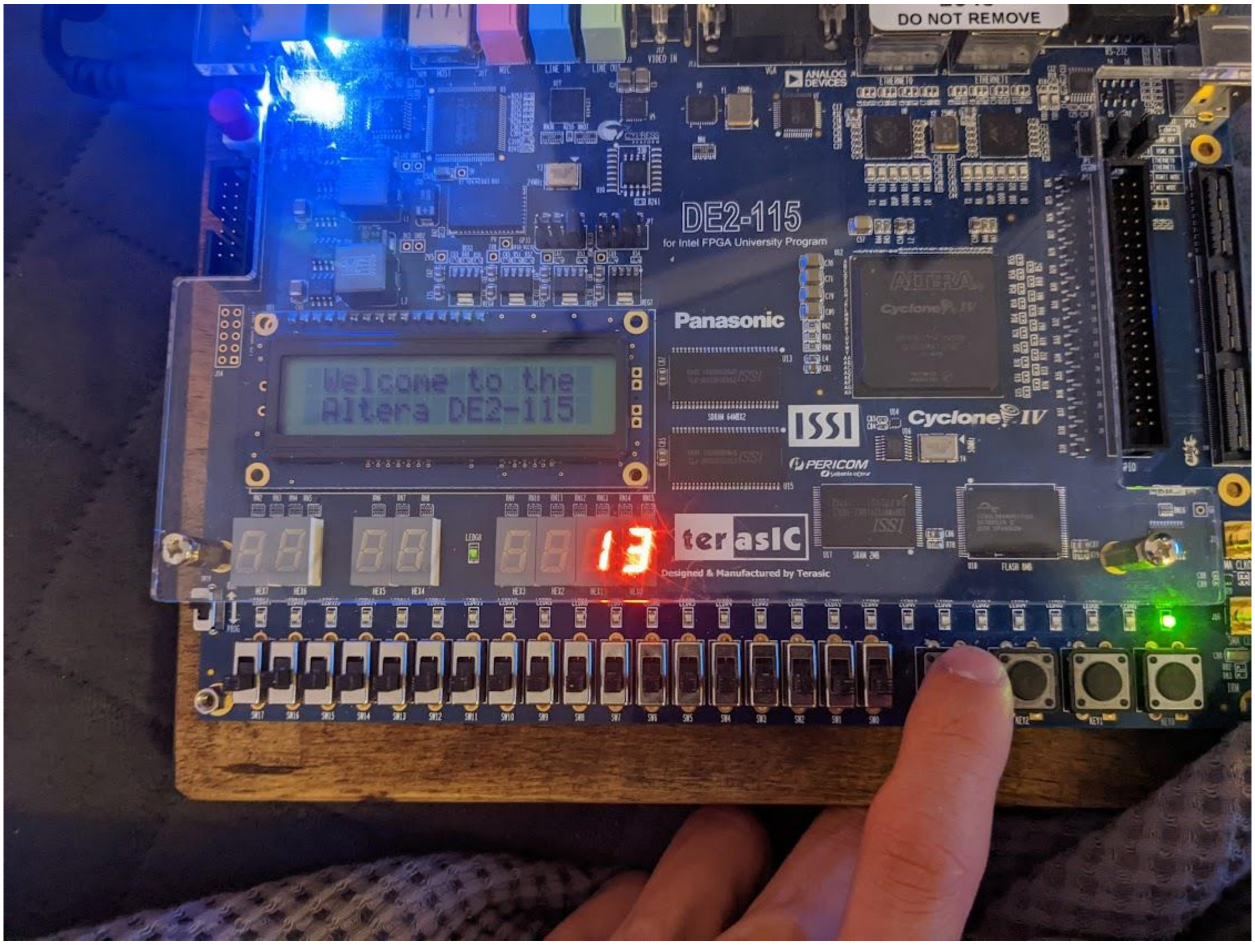
22. Set the value on the Seven Segment to 0

Next, we can use key 2 to begin incrementing. This will start counting until reaching 99 which is the max value when just using the two displays.



23. Counting up

At any point, we can set the value back to zero, which will stop incrementing or change to decrementing. The switch to decrementing can be seen below.



24. Switch from Incrementing to Decrementing

With all of this, we can see that the code accomplished its goals and works as intended. The project was a success.

Conclusion

This lab accomplished its goals to further the understanding of implementing Interrupts in a C++ runtime enviroment. This Lab was very beneficial for going forward, as interrupts are a vital part of embedded systems engineering, and understanding their full potential is coming to fruition. This lab was essential in accomplishing this goal and did so in an interactive and intuitive way.

Appendix A (Top Level Instantiation)

```
module Lab3SoftcoreDesign (CLOCK_50, SW, KEY, LEDR, LEDG,
DRAM_CLK, SevMSB, SevLSB, sdram_wire_addr, sdram_wire_ba,
sdram_wire_cas_n, sdram_wire_cke, sdram_wire_cs_n,
sdram_wire_dq, sdram_wire_dqm, sdram_wire_ras_n,
sdram_wire_we_n);
input CLOCK_50;
input [17:0] SW;
input [3:0] KEY;
output [7:0] LEDG;
output [17:0] LEDR;
output [31:0] SevMSB;
output [31:0] SevLSB;
output [12:0] sdram_wire_addr;
output [1:0]  sdram_wire_ba;
output sdram_wire_cas_n;
output sdram_wire_cke;
output sdram_wire_cs_n;
inout  [31:0] sdram_wire_dq;
output DRAM_CLK;
output [3:0] sdram_wire_dqm;
output sdram_wire_ras_n;
output sdram_wire_we_n;

QsysSystem Softcore (
.clk_clk(CLOCK_50),
.reset_reset(KEY),
.green_leds_external_connection_export(LEDG),
.red_leds_external_connection_export(LEDR),
.switches_external_connection_export(SW),
.sevseg4msb_external_connection_export(SevMSB),
.sevsegment_4lsb_external_connection_export(SevLSB),
.keys_external_connection_export(KEY),
.sdram_wire_addr(sdram_wire_addr),
.sdram_wire_ba(sdram_wire_ba),
.sdram_wire_cas_n(sdram_wire_cas_n),
.sdram_wire_cke(sdram_wire_cke),
.sdram_wire_cs_n(sdram_wire_cs_n),
.sdram_wire_dq(sdram_wire_dq),
.sdram_wire_dqm(sdram_wire_dqm),
.sdram_wire_ras_n(sdram_wire_ras_n),
.sdram_wire_we_n(sdram_wire_we_n),
```

```
.sdram_clk_clk(DRAM_CLK));
endmodule
```

Appendix B (Part 1 Code)

```
// Program for Generating an Interrupt

#include <stdio.h>
#include <system.h>
#include <alt_types.h>
#include "altera_avalon_pio_regs.h"
#include <stdio.h>


void incr(){
	int LEDVal = 0;
	LEDVal = IORD(GREEN_LEDS_BASE, 0);

	for (int i = LEDVal; i <= 9; i++){
		IOWR(GREEN_LEDS_BASE, 0, i);
		delayfn();
	}
	return;
}

void decr(){
	int LEDVal = 0;
		LEDVal = IORD(GREEN_LEDS_BASE, 0);

		for (int i = LEDVal; i >= 1; i--){
			IOWR(GREEN_LEDS_BASE, 0, i);
			delayfn();
		}
		return;
}

void delayfn(){
	int delay = 0;
		while(delay < 2000000)
		{
			delay++;
		}
}



void key3_isr(){
	// Program
	int Sw0 = 0;
```

```
          Sw0 = IORD(SWITCHES_BASE, 0);

     if (Sw0 == 0){
          decr();
     }
     else if (Sw0 == 1){
          incr();
     }

     IOWR_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE, 0);
     IORD_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE);
     return;
}

void key2_isr(){
     // Program
     IOWR(GREEN_LEDS_BASE, 0, 0x1);

     IOWR_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE, 0);
     IORD_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE);
     return;
}

void handle_key_interrupts(void* context){
     volatile int *edge_capture_ptr = (volatile int*) context;
     *edge_capture_ptr =
IORD_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE);
     if (*edge_capture_ptr & 0x8){
          key3_isr();
     }
     else if (*edge_capture_ptr & 0x4){
          key2_isr();
          }
     return;
}

void pio_init(){
     void* edge_capture_ptr = KEYS_EDGE_TYPE;
     IOWR_ALTERA_AVALON_PIO_IRQ_MASK(KEYS_BASE, 0xC);
     IOWR_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE, 0x0);
     alt_irq_register(KEYS_IRQ, edge_capture_ptr,
handle_key_interrupts);

     return;
     }

int main(){
```

```
	pio_init();
	printf("Key3: \n	Sw0 High: Increment to 9\n	Sw0 Low: Decrement to 1\nKey2: Set to 1\n");
	IOWR(GREEN_LEDS_BASE, 0, 0b00001010);
	while(1){

	}
  return 0;
}
```

Appendix C (Part 2 Code)

```
#include <stdio.h>
#include <system.h>
#include <alt_types.h>
#include "altera_avalon_pio_regs.h"
#include <stdio.h>

int IncDec = 0;

void delayfn(){
	int delay = 0;
		while(delay < 2000000)
		{
			delay++;
		}
}



void key3_isr(){
	// Decrement the Num to 0
	IncDec = 2; //Turns IncDec to 2 in order to run Decrement
in main

	IOWR_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE, 0);
	IORD_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE);
	return;
}

void key2_isr(){
	// Increment to 99
	IncDec = 1; //Turns IncDec to 1 in order to run in main

	IOWR_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE, 0);
	IORD_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE);
	return;
}

void key1_isr(){
	// Set to 0
	IOWR(SEVSEGMENT_4LSB_BASE, 0, 0xFFFFFF40); //Sets to 0
	IncDec = 0; //Stops inc or dec
```

```
	IOWR_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE, 0);
	IORD_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE);
	return;
}

void handle_key_interrupts(void* context){
	volatile int *edge_capture_ptr = (volatile int*) context;
	*edge_capture_ptr =
IORD_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE);
	if (*edge_capture_ptr & 0x8){
		key3_isr();
	}
	else if (*edge_capture_ptr & 0x4){
		key2_isr();
		}
	else if (*edge_capture_ptr & 0x2){
		key1_isr();
	}
	return;
}

void pio_init(){
	void* edge_capture_ptr = KEYS_EDGE_TYPE;
	IOWR_ALTERA_AVALON_PIO_IRQ_MASK(KEYS_BASE, 0xE);
	IOWR_ALTERA_AVALON_PIO_EDGE_CAP(KEYS_BASE, 0x0);
	alt_irq_register(KEYS_IRQ, edge_capture_ptr,
handle_key_interrupts);

	return;
	}

void display(int Value){
	int SEVENSEGLUT[10] = {0b01000000, 0b01111001, 0b00100100,
0b00110000, 0b00011001, 0b00010010, 0b00000010, 0b01111000,
0b10000000, 0b00010000};
	int R;
	int toDisplay = 0;
	int shiftVal = 0;
	int FourthSeg = 0b11111111;
	int toDisplayMask =0;

	while (Value != 0){ //Displays the value on the Hex Masks
are for 0 values to not be displayed unless the LSB
	R = Value % 10;
	toDisplay = toDisplay + (SEVENSEGLUT[R] << shiftVal);
	Value = (Value - R) / 10;
	shiftVal = shiftVal + 8;
```

```
	}
	toDisplay = toDisplay | 0xFFFF0000;
	toDisplayMask = toDisplay & 0x0000FF00;

	if (toDisplayMask == 0){
		toDisplay = toDisplay | 0xFFFFFF00;
	}
	toDisplayMask = toDisplay & 0x000000FF;
	if (toDisplayMask == 0){
		toDisplay = 0xFFFFFF40;
	}

	IOWR(SEVSEGMENT_4LSB_BASE, 0, toDisplay);
	return;
}

int DecodeHex(int Val){ //Decodes the HEX from the Seven Seg
into an Integer, Used as Starting Point for Inc and Dec
	int SEVENSEGLUT[10] = {0b01000000, 0b01111001, 0b00100100,
0b00110000, 0b00011001, 0b00010010, 0b00000010, 0b01111000,
0b00000000, 0b00010000};
	int i;
	int MASK = 0b01111111;
	int Output = 0;
	int Lookup = Val & MASK;
	int ShiftAmt = 0;
	int Count = 1;

	while (Lookup != 0b1111111){
	for (i = 0; Lookup != SEVENSEGLUT[i]; i++){};
	Output = Output + (i*Count);
	Count = Count * 10;
	ShiftAmt = ShiftAmt + 8;
	Lookup = Val & (MASK << ShiftAmt);
	Lookup = Lookup >> ShiftAmt;
	}
	return Output;
}

void incr(){ //Increments from where the Hex Display is to 99
	int HexVal = 0;
	HexVal = IORD(SEVSEGMENT_4LSB_BASE, 0);
	HexVal = DecodeHex(HexVal);
	for (int i = HexVal; i <= 99 && IncDec == 1; i++){
		display(i);
		delayfn();
	}
```

```
    return;
}

void decr(){ //Decrements from Current val of hex display to 0
    int HexVal = 0;
    HexVal = IORD(SEVSEGMENT_4LSB_BASE, 0);
    HexVal = DecodeHex(HexVal);
    for (int i = HexVal; i >= 0 && IncDec == 2; i--){
        display(i);
        delayfn();
    }
    return;
}

int main(){ //Initializes the 7 Segment
    pio_init();
    int outSevenSeg = 0xFFFFFFFF;
    IOWR(SEVSEG4MSB_BASE, 0, outSevenSeg);
    IOWR(SEVSEGMENT_4LSB_BASE, 0, outSevenSeg);

    printf("Key3: Decrement\nKey2: Increment\nKey1: Set to 0");
    while(1){ //Loops through Calling Incr function if IncDec
changes to 1 and Decr if to 0. Doing this here allows for these
fns to be interrupted.
        if (IncDec == 1) incr();
        else if (IncDec == 2) decr();
    }

  return 0;
}
```