

ECE385

DIGITAL SYSTEMS LABORATORY

Introduction to NIOS II and Qsys

Abstract and Goals

The goal of this lab is create a NIOS II based system on the Altera Cyclone IV device. The NIOS II is an IP based 32-bit CPU which can programmed using a high level language (in this class, we'll be using C). A typical use case scenario is to have the NIOS II be the system controller and handle tasks which do not need to be high performance (for example, user interface, data input and output) while an accelerator peripheral in the FPGA logic (designed using SystemVerilog) handles the high performance operations.

The following will give you a walkthrough of the Qsys wizard, which is used to instantiate IP blocks (including the NIOS II). We will set up a minimal NIOS II device with an SDRAM (Synchronous Dynamic RAM) controller and a PIO (Parallel I/O) block to blink some LEDs using a C program running on the NIOS II to confirm it is working. You will then be asked to write a program which reads 8-bit numbers from the switches on the DE2 board and sums into an accumulator, displaying the output using the green LEDs via the NIOS II. This will involve instantiating another PIO block to read data from the switches and modifying the C program to input data, add, and display the data.

Goals (to demonstrate to your TA):

The TA will test the following functionality:

The green LEDs should always display the value of the accumulator in binary and the accumulator should be 0 on startup (all LEDs off). The accumulator should overflow at 255 to 0. Pressing the second to the left pushbutton at any time clears the accumulator to 0 and updates the display accordingly (turns all the LEDs off)

Pressing the left most pushbutton loads the number represented by the switches into the CPU, adding it to the accumulator. The 8 right-most switches are read as an 8-bit, unsigned, binary number with up being 1, down being 0.

Push buttons should only react once to a single actuation.

Be prepared to give answers to any of the italicized questions in this document from your TA when demoing. This is to ensure that you make an effort to research what the settings do instead of simply trying to “make the picture look like your screen”.

Hints:

Unit test the input and output. The output should already work, but make sure you can turn on and off every segment. If you have problems, check the schematic for the DE2, and make sure you are actually toggling the correct pins.

For this, and the rest of the class, you may use the C standard libraries (stdlib.h) or the C++ equivalents, this can save you a lot of work when coding in C.

Set up the System Combining the FPGA with the Nios II Processor:

Create a New Project:

- Start Quartus II.
- From the **File** menu select **New Project Wizard**. Click *Next* to go through the intro screen, if it appears.
- The window in Figure 1 will appear. Fill in the fields from figure 1 (make sure there are no spaces in any of your entries). The program will ask you if it should create the specified directory if it does not exist; choose *yes*.
- Select *Next* on page 2 without adding any files.
- On page 3, select **Cyclone IV E** for the device family, make sure the second option under Target device is selected, and chose **EP4CE115F29C7** in the available devices list. See Figure 2.

Click *Next* on page 4. Select *ModelSim-Altera* as the simulation tool name, and *SystemVerilog HDL* as the simulation format. See Figure 3. Click **Finish** on page 5.

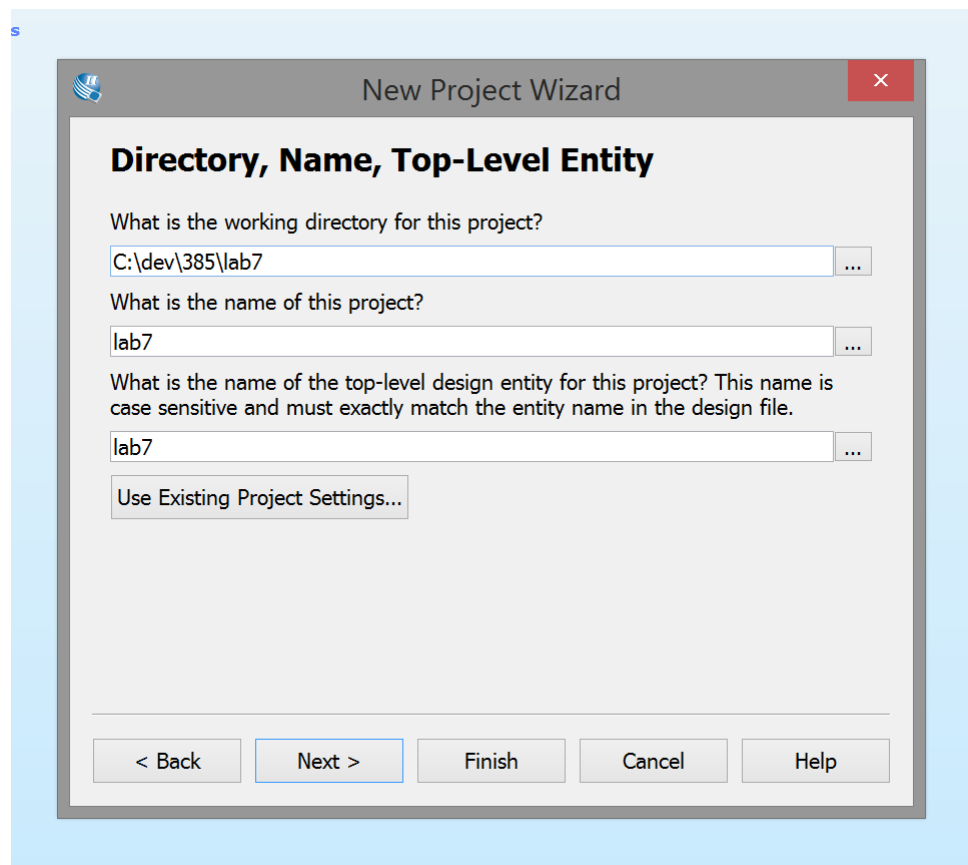


Figure 1

New Project Wizard

Family & Device Settings [page 3 of 5]

Select the family and device you want to target for compilation.
You can install additional device support with the Install Devices command on the Tools menu.

To determine the version of the Quartus II software in which your target device is supported, refer to the [Device Support List](#) webpage.

Device family

Family: **Cyclone IV E**

Devices: **All**

Target device

☐ Auto device selected by the Fitter

☒ Specific device selected in 'Available devices' list

☐ Other: n/a

Show in 'Available devices' list

Package: **Any**

Pin count: **Any**

Core Speed grade: **Any**

Name filter:

☒ Show advanced devices

Available devices:

Name	Core Voltage	LEs	User I/Os	Memory Bits	Embedded multiplier 9-bit element
EP4CE115F23I8L	1.0V	114480	281	3981312	532
EP4CE115F29C7	1.2V	114480	529	3981312	532
EP4CE115F29C8	1.2V	114480	529	3981312	532
EP4CE115F29C8L	1.0V	114480	529	3981312	532
EP4CE115F29C9L	1.0V	114480	529	3981312	532

< Back Next > Finish Cancel Help

Figure 2

New Project Wizard

EDA Tool Settings [page 4 of 5]

Specify the other EDA tools used with the Quartus II software to develop your project.

EDA tools:

Tool Type	Tool Name	Format(s)	Run Tool Automatically
Design Entry/Synt...	<None>	<None>	<input type="checkbox"/> Run this tool automatically to synthesize the current design
Simulation	ModelSim-Altera	SystemVerilog HDL	<input type="checkbox"/> Run gate-level simulation automatically after compilation
Formal Verification	<None>		
Board-Level	Timing	<None>	
	Symbol	<None>	
	Signal Integrity	<None>	
	Boundary Scan	<None>	

< Next > Finish Cancel Help

Figure 3

Create the SoC with Qsys:

Now we can set up the SoC with Qsys. In the **Tools** menu, select **Qsys** to launch Qsys. Immediately save the qsys file as **lab7_soc.qsys**. This is the name of the hardware block which will contain the CPU and the supporting hardware (peripherals, memory, etc). A window shown in Figure 4 should pop up. Here, you can see a predefined clock signal. If needed, the clock frequency can be modified in **the Clock Settings** tab, as shown in Figure 5. In this lab, we will work with the default 50 MHz clock. If the **Clocks** tab is not available by default, then you can find it by selecting **View > Clocks** from the main menu.

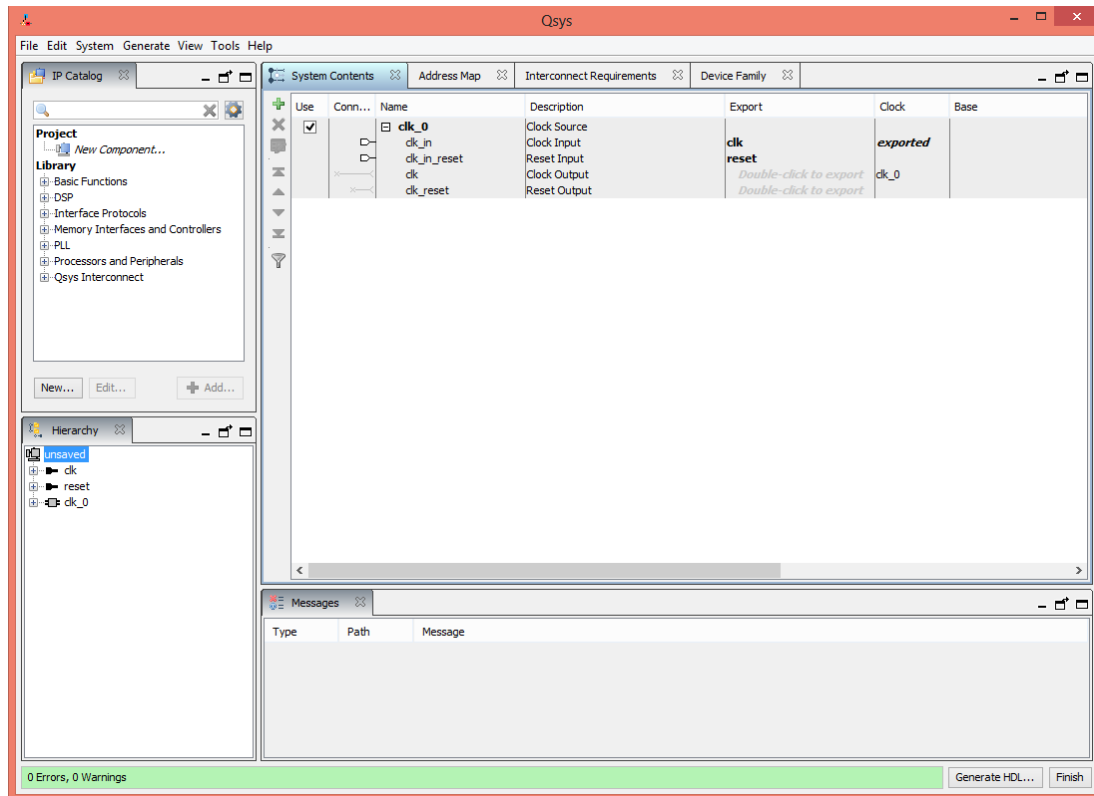


Figure 4

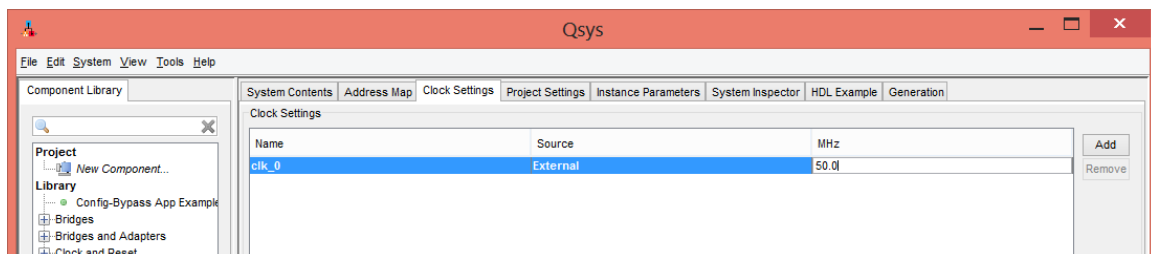


Figure 5

Next, specify the processor on the left side of the Qsys window by selecting **Processors and Peripherals > Embedded Processors > Nios II Processor** and clicking **Add**. A window should pop up, as shown in Figure 6. In this window, select **Nios II/e**, which is the economy version of

the processor. Note that error messages regarding reset and exception vectors are shown on the bottom. This is because we haven't specified memory components in the system. Ignore the messages for now as we will provide the necessary information later. Click **Finish**. Now we have included the Nios II processor, as shown in Figure 7.

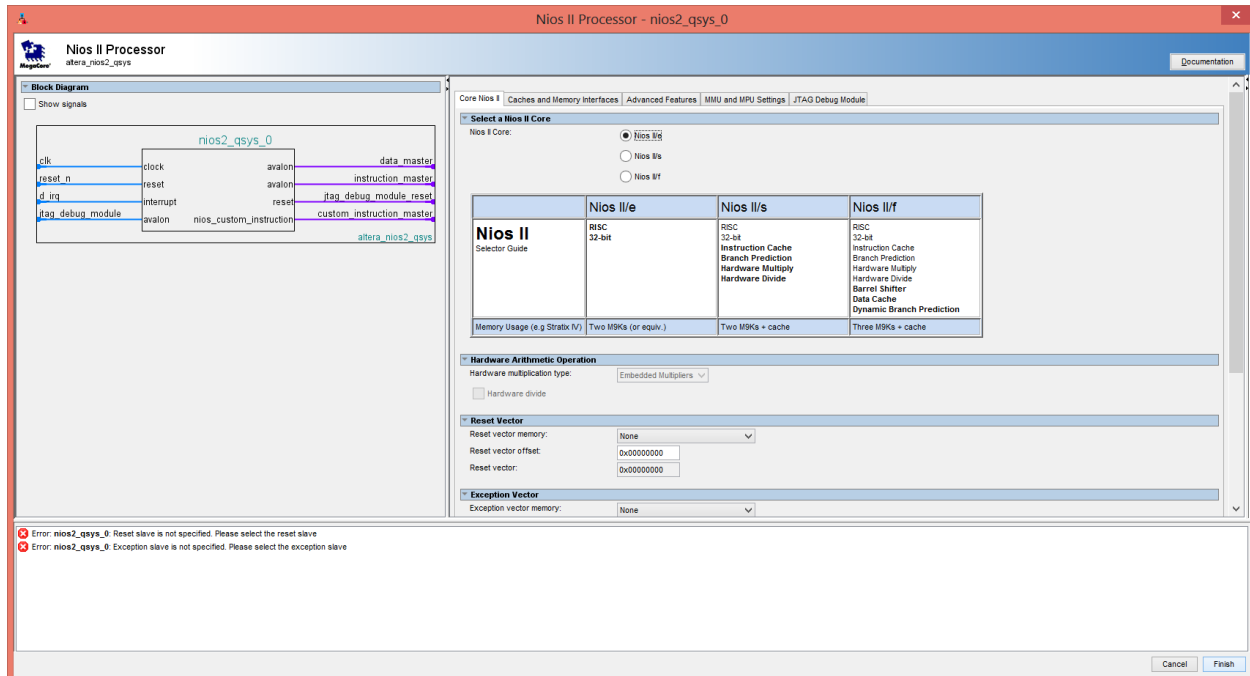


Figure 6

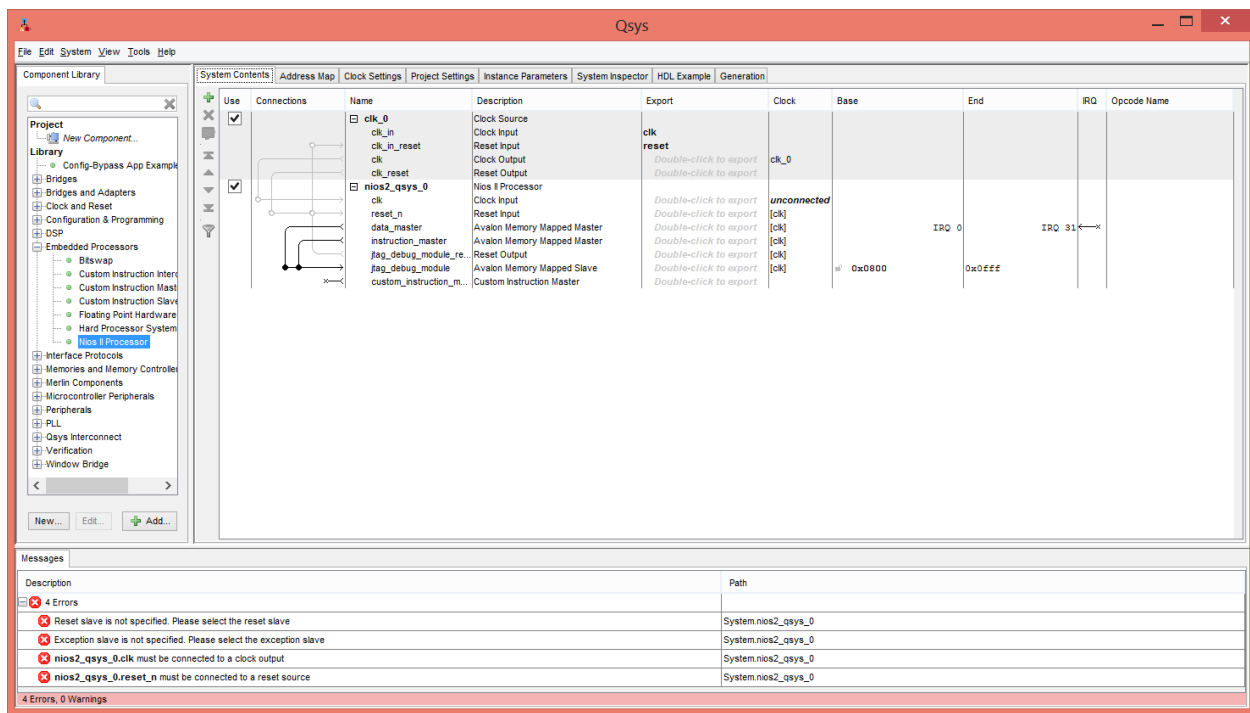


Figure 7

Next, we're going to instantiate an on-chip memory block. On the left side of the Qsys window, select **Basic Functions > On Chip Memory > On-Chip Memory (RAM or ROM)**, and click **Add**. A window as shown in Figure 8 should pop up. Choose Memory Type to be **RAM (Writable)** and Total memory size to be 16 bytes. We do this to save valuable on-chip memory and instead execute NIOS II programs from the DRAM, however, without any on-chip memory, the system cannot function. *What advantage might on-chip memory have for program execution?* Note that you can get the datasheet for any IP block by clicking on documentation (top right). Click **Finish**.

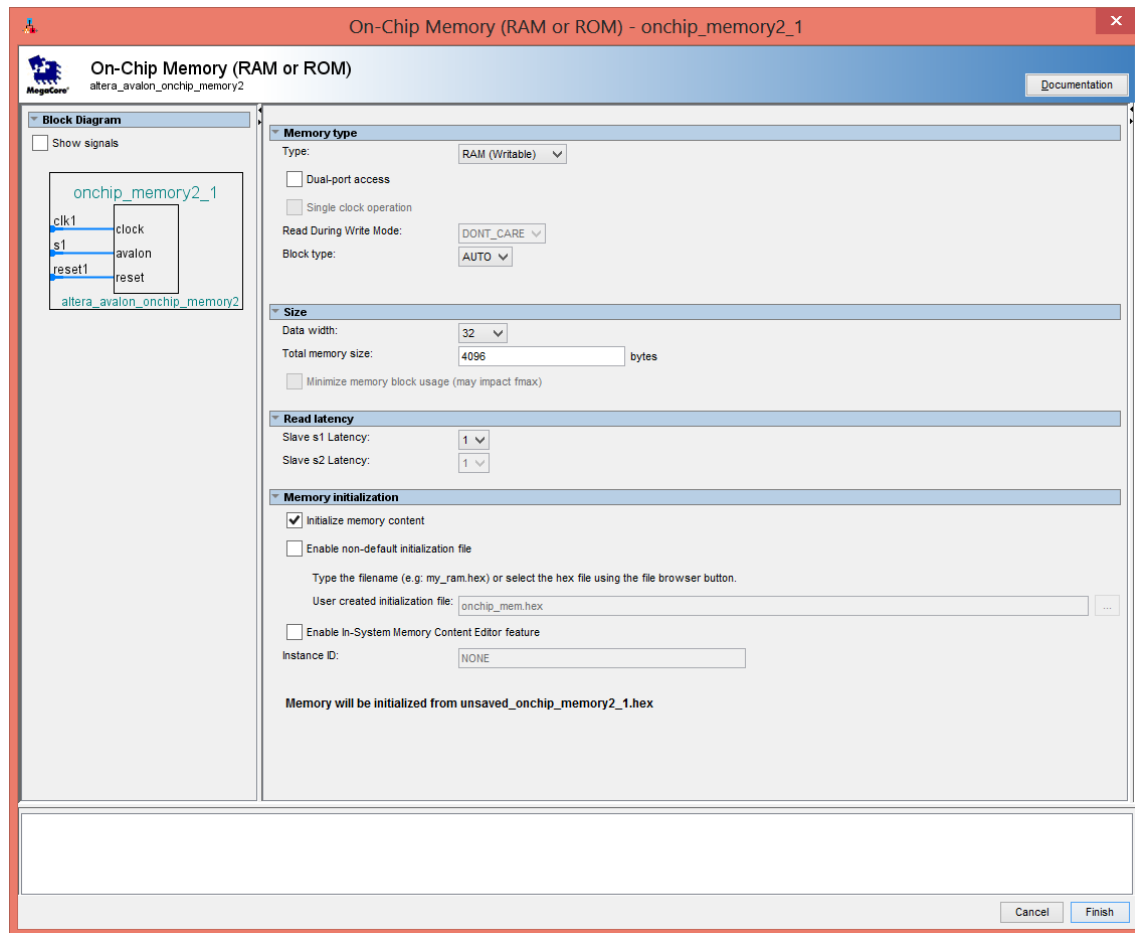


Figure 8

Next, we establish the connections between the Nios II processor and the on-chip memory. In the **Connections** column of the Qsys window, click on the empty circles to make a connection. Make sure you connect the NIOS II and on-chip memory clock and reset to the external clock and reset. *Note the bus connections coming from the NIOS II; is it a Von Neumann, “pure Harvard”, or “modified Harvard” machine and why?*

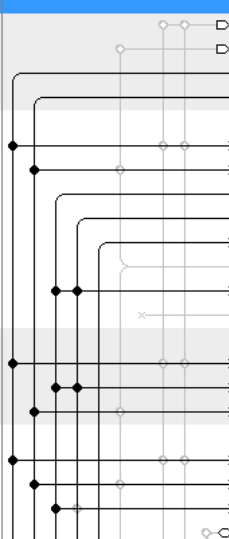
Use	Connections	Name	Description	Export	Clock
<input checked="" type="checkbox"/>		clk_0	Clock Source		
		clk_in	Clock Input	clk	exported
		clk_in_reset	Reset Input	reset	
		clk	Clock Output	Double-click to export	clk_0
		clk_reset	Reset Output	Double-click to export	
<input checked="" type="checkbox"/>		nios2_qsys_0	Nios II (Classic) Processor		
		clk	Clock Input	Double-click to export	clk_0
		reset_n	Reset Input	Double-click to export	[clk]
		data_master	Avalon Memory Mapped Master	Double-click to export	[clk]
		instruction_master	Avalon Memory Mapped Master	Double-click to export	[clk]
		d_irq	Interrupt Receiver	Double-click to export	[clk]
		jtag_debug_module_reset	Reset Output	Double-click to export	[clk]
		jtag_debug_module	Avalon Memory Mapped Slave	Double-click to export	[clk]
		custom_instruction_master	Custom Instruction Master	Double-click to export	
<input checked="" type="checkbox"/>		onchip_memory2_0	On-Chip Memory (RAM or ROM)		
		clk1	Clock Input	Double-click to export	clk_0
		s1	Avalon Memory Mapped Slave	Double-click to export	[clk1]
		reset1	Reset Input	Double-click to export	[clk1]
<input checked="" type="checkbox"/>		led	PIO (Parallel I/O)		
		clk	Clock Input	Double-click to export	clk_0
		reset	Reset Input	Double-click to export	[clk]
		s1	Avalon Memory Mapped Slave	Double-click to export	[clk]
		external_connection	Conduit	led_wire	

Figure 9

Next, we specify the input parallel I/O interface. This will be used to drive the LEDs and tell us that the system is working correctly. On the left side of the Qsys window, select **Processors and Peripherals > Peripherals > PIO (Parallel I/O)** and click **Add**. Specify the width of the port to be 8 bits. Choose the direction of the port to be **Output**. Click **Finish**.

Rename the **PIO** block **led**, so we can keep track of what it is for. Create all the bus connections as shown below between the PIO (led) peripheral and the NIOS II through the Avalon bus. Make the required connections as shown in Figure 9. Note that while the on-chip memory needs access to both the data and program bus, the led peripheral only needs access to the data bus. *Why might this be the case?*

Since the on-chip memory has limited storage capacity, we will use the off-chip SDRAM to store the software program. SDRAM cannot be interfaced to the bus directly, as it has a fairly complex row/column addressing scheme and requires constant refreshing to retain data. We will use a SDRAM controller IP core to interface the SDRAM to the Avalon bus. *Why does SDRAM require constant refreshing?*

You will need to determine the following parameters to instantiate the SDRAM controller. Refer to the DE2-115 schematic and the ISSIIS16320D SDRAM (note there are two on the board) [datasheet \(PDF\)](#). Make sure you are looking at the correct part of the datasheet (the two chips each provide 16 bits)

SDRAM parameter	Short name	Parameter value (fill in from datasheet)
Data Width	[width]	
# of Rows	[nrows]	
# of Columns	[ncols]	
# of Chip Selects	[ncs]	
# of Banks	[nbanks]	

Note that there are two 32M*16 chips, so the total amount of memory should be 1Gbit (128 Mbytes), *make sure this is consistent with your above numbers; you will need to justify how you came up with 1 Gbit to your TA.*

On the left side of the Qsys window, select **Memory Interfaces and Controllers > SDRAM > SDRAM Controller** and click **Add**. A window should pop up, as shown in Figure 14. On the **Memory Profile** tab, set the **Data Width** to be *[width]* bits, **Address Width** to be *[nrows]* rows and *[ncols]* columns. Make sure *[ncs]* and *[nbanks]* are correct as well. In general, we would have to also research all the SDRAM timings from the datasheet; however this has been done for you. On the **Timing** tab, enter the numbers according to Figure 10. *What is the maximum theoretical transfer rate to the SDRAM according to the timings given?* Click **Finish**. Rename the component as *sdram*.

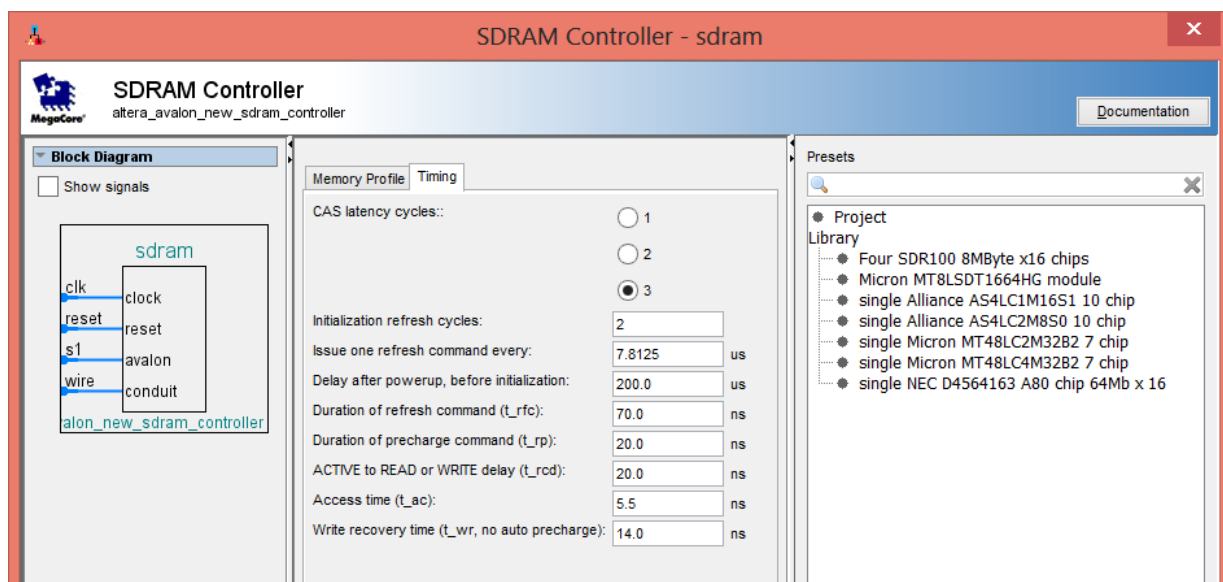


Figure 10

Next, we add a PLL component to provide the required clock signal for the SDRAM chip. This is because the SDRAM requires precise timings, and the PLL allows us to compensate for clock skew due to the board layout. The SDRAM also cannot be run too slowly (below 50 MHz). *Why might this be the case?* A block diagram for how we will use the SDRAM controller is shown in Figure 11.

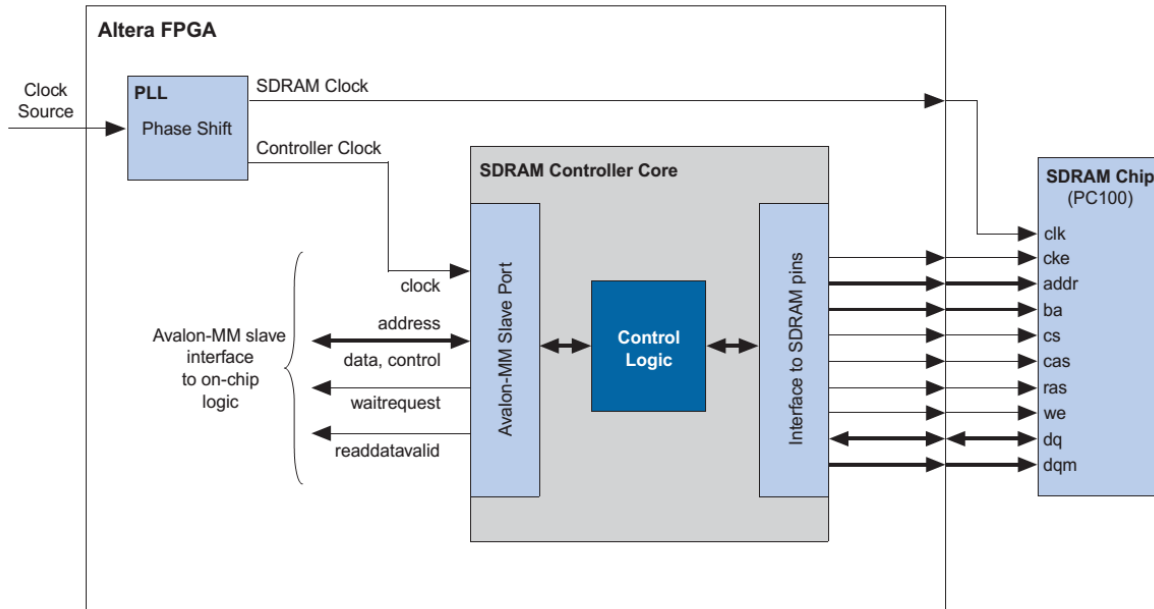


Figure 11

On the left side of the Qsys window, select **Basic Functions > Clocks; PLLs and Resets > PLL > Avalon ALTPLL** and click **Add**. A window should pop up as shown in Figure 12. Choose device speed to be **7**, and the frequency of the **inclk0** input (input clock) to be **50** MHz. Click **Next**.

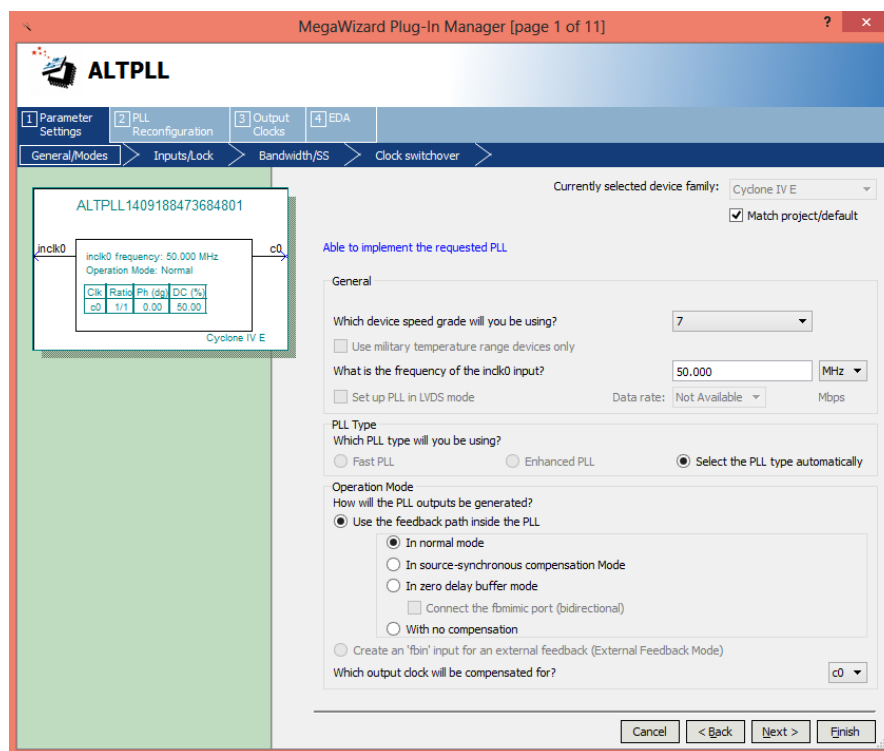


Figure 12

On page 2 (Inputs/Lock), deselect all the checked boxes because we do not need these additional ports (e.g. locked status) in this lab, as shown in Figure 17. Skip Bandwidth/SS and Clock Switchover and the entire [2] PLL Reconfiguration tab by clicking *Next* until you get to [3] **Output Clocks**.

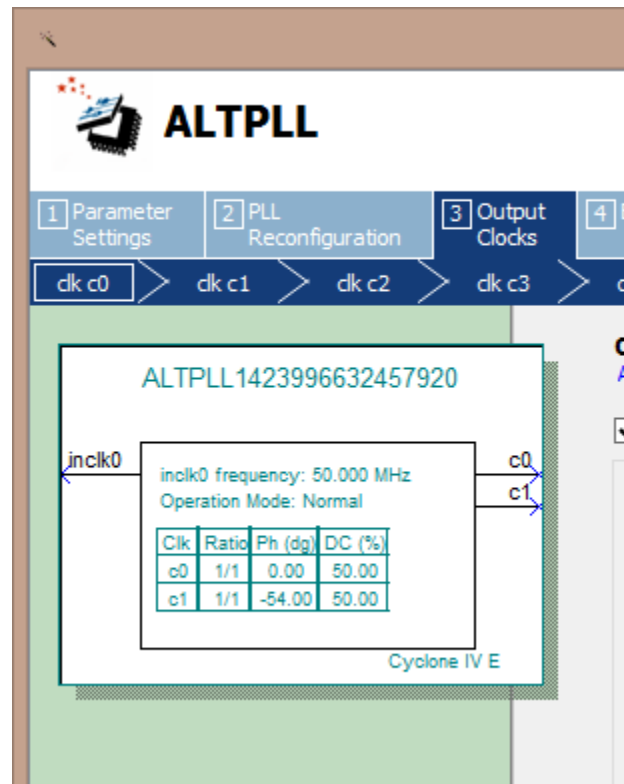


Figure 13

On page [3] **Output Clocks** for **clk c0**, make sure the actual clock frequency is 50 MHz, and set the clock phase shift to be **0ns**. On the left, observe that the *Ph (dg)* (phase in degrees) is now -50. This is the clock which goes to the SDRAM controller, and should be synchronous to the rest of the design, this is the *controller clock*, as shown in Figure 11.

You must now make a second clock, which goes out to the SDRAM chip itself, as recommended by Figure 11. Make another output by clicking **clk c1**, and verify it has the same settings, except that the phase shift should be **-3ns**. This puts the clock going out to the SDRAM chip (**clk c1**) 3ns ahead of the controller clock (**clk c0**). *Why do we need to do this? Hint, check [Altera Embedded Peripheral IP datasheet](#) under SDRAM controller.* The configuration for **clk c1** should look like Figure 14. Now complete the rest of the wizard by clicking **Finish** and the **Finish** again. Name your new module *sdram_pll*, to remind us what this is for. Verify that there are indeed two ports as shown in Figure 13, one with 0 degrees shift, going out to the controller, one with -54 degrees shift, going out to the SDRAM chip.

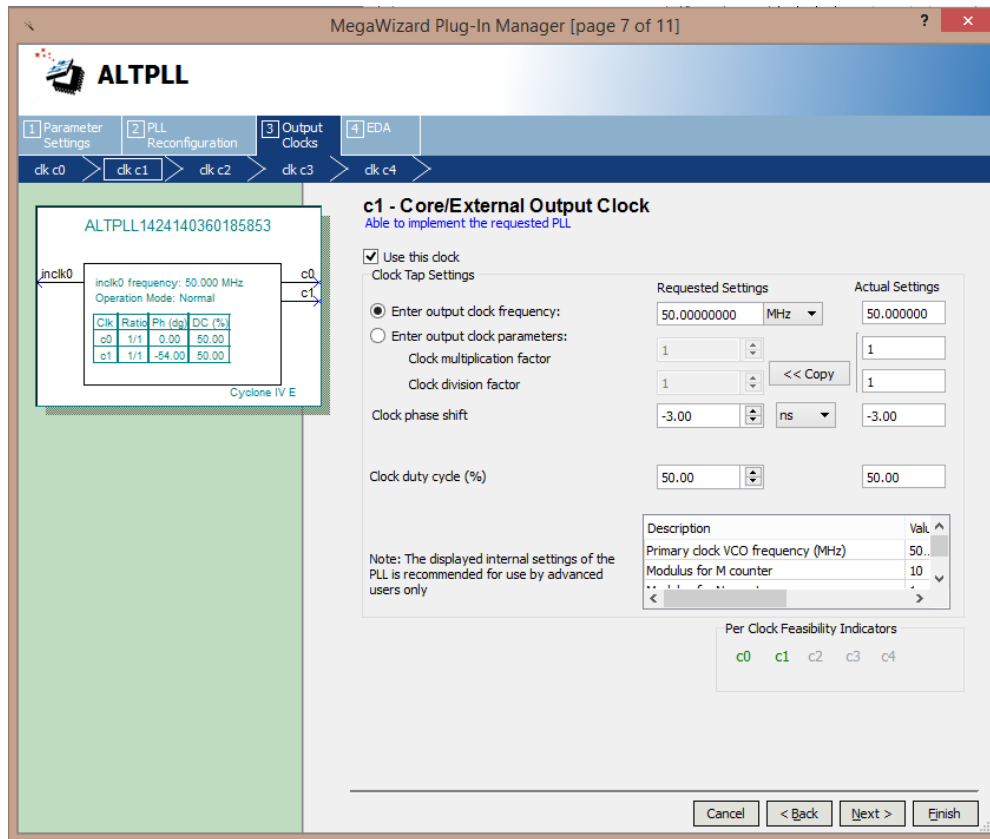


Figure 14

Next, we add a system ID checker to ensure the compatibility between hardware and software. This module gives us a serial number (we'll assign it to 0), which the software loader checks against when we start the software. This prevents us from loading software onto an FPGA which has an incompatible NIOS II configuration (or an FPGA without a NIOS II at all). For example, if we had added a new NIOS II peripheral and forgot the regenerate/reprogram the FPGA, this block would prevent us from trying to load software from the old configuration onto our incompatible NIOS II. On the left side of the Qsys window, select **Basic Functions** > **Simulation; Debug and Verification** > **System ID Peripheral** and click **Add**. Accept the default settings and click **Finish**, as per Figure 15.

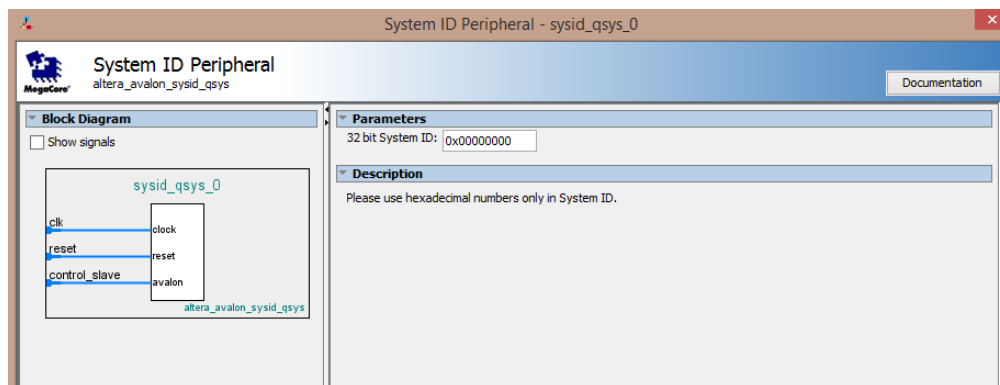


Figure 15

Use	Connections	Name	Description	Export	Clock	Base	End	IRQ	Tags	Opco
<input checked="" type="checkbox"/>		clk_0	Clock Source	clk_0	exported					
<input checked="" type="checkbox"/>		clk_in	Clock Input	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		clk_in_reset	Reset Input	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		clk	Clock Output	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		clk_reset	Reset Output	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		nios2_qsys_0	Nios II (Classic) processor							
<input checked="" type="checkbox"/>		clk	Clock Input	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		reset_n	Reset Input	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		data_master	Avalon Memory Mapped Master	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		instruction_master	Avalon Memory Mapped Master	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		d_irq	Interrupt Receiver	Double-click to export	clk_0			IRQ 0	IRQ 31	
<input checked="" type="checkbox"/>		jtag_debug_module_reset	Reset Output	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		jtag_debug_module	Avalon Memory Mapped Slave	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		custom_instruction_master	Custom Instruction Master	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		onchip_memory2_0	On-Chip Memory (SRAM or ROM)							
<input checked="" type="checkbox"/>		clk1	Clock Input	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		s1	Avalon Memory Mapped Slave	Double-click to export	clk_0	0x0000_0000	0x0000_000f			
<input checked="" type="checkbox"/>		reset1	Reset Input	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		led	PIO (Parallel I/O)	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		clk	Clock Input	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		reset	Reset Input	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		s1	Avalon Memory Mapped Slave	Double-click to export	clk_0	0x0000_0020	0x0000_002f			
<input checked="" type="checkbox"/>		external_connection	Conduit	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		sdram	SDRAM Controller							
<input checked="" type="checkbox"/>		clk	Clock Input	Double-click to export	sdram_pll_c0					
<input checked="" type="checkbox"/>		reset	Reset Input	Double-click to export	sdram_pll_c0					
<input checked="" type="checkbox"/>		s1	Avalon Memory Mapped Slave	Double-click to export	sdram_pll_c0	0x1000_0000	0x17ff_ffff			
<input checked="" type="checkbox"/>		wire	Conduit	Double-click to export	sdram_pll_c0					
<input checked="" type="checkbox"/>		sdram_pll	Avalon ALTPLL							
<input checked="" type="checkbox"/>		indk_interface	Clock Input	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		indk_interface_reset	Reset Input	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		pll_slave	Avalon Memory Mapped Slave	Double-click to export	clk_0	0x0000_0030	0x0000_003f			
<input checked="" type="checkbox"/>		c0	Clock Output	Double-click to export	sdram_pll_c0					
<input checked="" type="checkbox"/>		c1	Clock Output	Double-click to export	sdram_pll_c1					
<input checked="" type="checkbox"/>		areset_conduit	Conduit	Double-click to export	sdram_pll_c1					
<input checked="" type="checkbox"/>		locked_conduit	Conduit	Double-click to export	sdram_pll_c1					
<input checked="" type="checkbox"/>		phasedone_conduit	Conduit	Double-click to export	sdram_pll_c1					
<input checked="" type="checkbox"/>		sysid_qsys_0	System ID Peripheral							
<input checked="" type="checkbox"/>		clk	Clock Input	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		reset	Reset Input	Double-click to export	clk_0					
<input checked="" type="checkbox"/>		control_slave	Avalon Memory Mapped Slave	Double-click to export	clk_0	0x0000_0040	0x0000_004f			

Figure 16

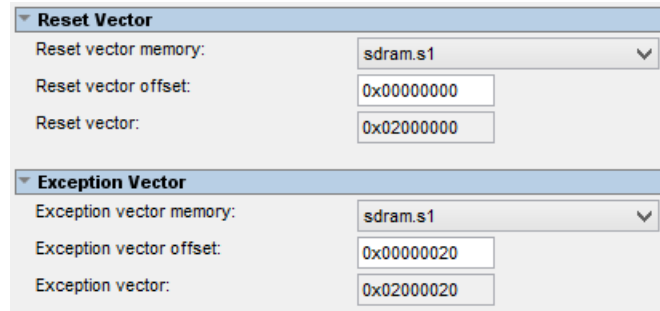
Next, we make the necessary connections for the newly added components, as shown in Figure 16. **Note that the *sdram* is connected to the *sdram_pll_c0* instead of the main clock**, as per Figure 11. Next, enable external access to the clock, reset, PIO, SDRAM, and the other clock out from the PLL (to the physical SDRAM chip). Do this by clicking on the **Double-click to export** in the **Export** column. Name the PIO(led) port **led_wire**. Also, click on the **Double-click to export** on the right of the *sdram* wire. Type in the name **sdram_wire**. This “breaks out” the connections to the rest of the world for the SDRAM controller (to the SDRAM chips, which are external to the FPGA itself), the PIO block, the reset, and the second port of the PLL. Export the second output of the PLL (*sdram_pll_c0*) as **sdram_clk**. When you are done, make sure following connections are exported:

<i>sdram_wire</i>	<i>led_wire</i>	<i>reset</i>	<i>clk</i>	<i>sdram_clk</i>
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These are the connections your SystemVerilog top-level needs to connect to the appropriate external hardware.

Finally, we assign memory addresses to each component. This can be done automatically in Qsys, but we want to make sure that the on-chip memory gets the base address of 0x0000_0000. Click on the base address of on-chip memory and enter **0x0000_0000**, and then click on the lock symbol on the left to make it fixed. On the menu, click on **System > Assign Base Addresses** to have Qsys automatically assign memory addresses to the other peripherals. The resulting Qsys should be similar (but maybe not identical) to Figure 16. Note that these addresses will be used in the software program later in this tutorial.

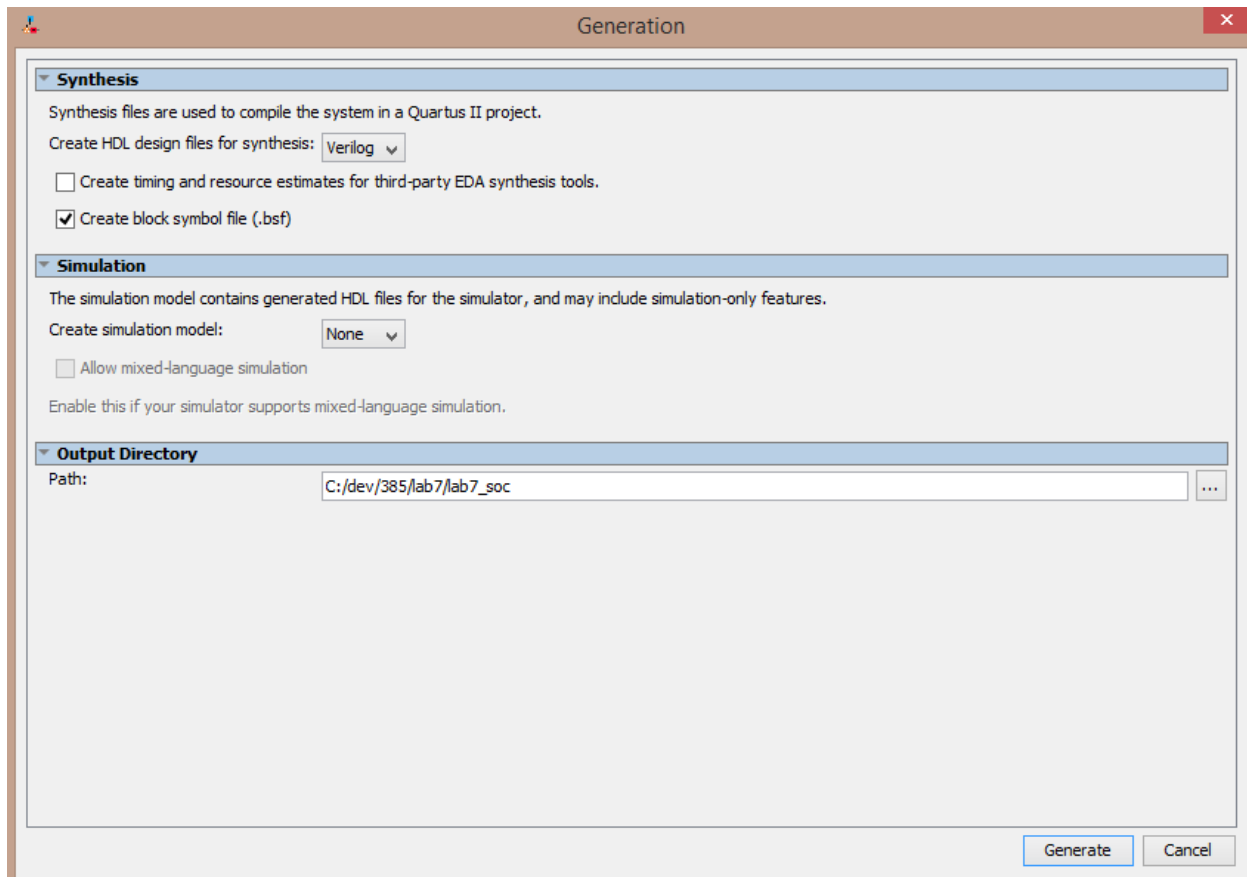
After we have the memory set up, we can assign the reset and exception vectors for the Nios II processor. Right click on *nios2_qsys_0* and click **Edit**. For both reset and exception vectors, choose *sdram.s1*, as shown in Figure 17. Do not change default settings for offsets. Click **Finish**. *What address does the NIOS II start execution from? Why do we do this step after assigning the addresses?*



The screenshot shows the configuration for the Nios II processor. It is divided into two sections: 'Reset Vector' and 'Exception Vector'. In the 'Reset Vector' section, 'Reset vector memory' is set to 'sdram.s1', 'Reset vector offset' is '0x00000000', and 'Reset vector' is '0x02000000'. In the 'Exception Vector' section, 'Exception vector memory' is set to 'sdram.s1', 'Exception vector offset' is '0x00000020', and 'Exception vector' is '0x02000020'.

Figure 17

Now, we have specified all the necessary components. Save the system as *nios_system*. Then, go to the **Generate > Generate HDL** from the main menu. Specify the settings as shown in Figure 18, and then click **Generate**.



The screenshot shows the 'Generation' dialog box in Quartus II. It has three main sections: 'Synthesis', 'Simulation', and 'Output Directory'. In the 'Synthesis' section, 'Create HDL design files for synthesis' is set to 'Verilog'. There are checkboxes for 'Create timing and resource estimates for third-party EDA synthesis tools' (unchecked) and 'Create block symbol file (.bsf)' (checked). In the 'Simulation' section, 'Create simulation model' is set to 'None'. There is a checkbox for 'Allow mixed-language simulation' (unchecked) and a note: 'Enable this if your simulator supports mixed-language simulation.' In the 'Output Directory' section, the 'Path' is set to 'C:/dev/385/lab7/lab7_soc'. At the bottom right, there are 'Generate' and 'Cancel' buttons.

Figure 18

After generation is complete, we can find the synthesized NIOS II system-on-chip component in lab7\lab7_soc\synthesis\nios_system.v. It is synthesized in Verilog, but the module interface is compatible with the SystemVerilog design we are going to create in this project.

Integration of the Nios II System into a Quartus II Project:

In Quartus II, go to the **Files** tab on the left. Right click on **Files** and select **Add/Remove Files in Project**. Add lab7_soc\synthesis\lab7_soc.qip into the project, which gives the required information for Quartus II to include the system we created. Then, add the lab7 top-level SystemVerilog file *lab7.sv* (given on the course website) as a new file. An instance of the **lab7** top level module is now created, as shown in Figure 19.

```

module lab7(
    input        CLOCK_50,
    input [1:0]  KEY,
    output [7:0]  LEDG,
    output [12:0] DRAM_ADDR,
    output [1:0]  DRAM_BA,
    output        DRAM_CAS_N,
    output        DRAM_CKE,
    output        DRAM_CS_N,
    inout [31:0]  DRAM_DQ,
    output [3:0]  DRAM_DQM,
    output        DRAM_RAS_N,
    output        DRAM_WE_N,
    output        DRAM_CLK
);

```

Figure 19

Open the generated Verilog file for the Nios II system, lab7/nios_system/synthesis/lab7_soc.v to take a look at the SoC module you created. This will have ports and names based on what you exported from Qsys. Make sure the names are consistent with what is expected in the top-level (lab7.sv) as in Figure 20. At this point, if your names are consistent, you should be able to synthesize your design without any errors (but not necessarily implement, since we have no pin assignments yet).

```

`timescale 1 ps / 1 ps
module lab7_soc (
    input wire      clk_clk,          //      clk.clk
    output wire [7:0] led_wire_export, //      led_wire.export
    input wire      reset_reset_n,    //      reset.reset_n
    output wire     sdram_clk_clk,     //      sdram_clk.clk
    output wire [12:0] sdram_wire_addr, // sdram_wire.addr
    output wire [1:0] sdram_wire_ba,   //      .ba
    output wire     sdram_wire_cas_n,  //      .cas_n
    output wire     sdram_wire_cke,    //      .cke
    output wire     sdram_wire_cs_n,   //      .cs_n
    inout wire [31:0] sdram_wire_dq,   //      .dq
    output wire [3:0] sdram_wire_dqm,  //      .dqm
    output wire     sdram_wire_ras_n,  //      .ras_n
    output wire     sdram_wire_we_n   //      .we_n
);

```

Figure 20

Do the necessary pin assignments as follows. (Hint: Download DE2-115.qsf from the course website. In Quartus II, go to **Assignments** > **Import Assignments** to load the default DE2 pin assignment settings. Make modifications as needed. Note that these names are from our top-level SystemVerilog file, even though for this lab, our top level doesn't do more than wire the NIOS II module (lab7_soc) to the outside world.

Port Name	Location	Comments
CLOCK_50	PIN_Y2	50 MHz Clock from the on-board oscillators
KEY[1]	PIN_M21	On-board push button
KEY[0]	PIN_M23	On-board push button
LEDG[7]	PIN_G21	On-board LED
LEDG[6]	PIN_G22	On-board LED
LEDG[5]	PIN_G20	On-board LED
LEDG[4]	PIN_H21	On-board LED
LEDG[3]	PIN_E24	On-board LED
LEDG[2]	PIN_E25	On-board LED
LEDG[1]	PIN_E22	On-board LED
LEDG[0]	PIN_E21	On-board LED
DRAM_ADDR[12]	PIN_Y7	On-board SDRAM
DRAM_ADDR[11]	PIN_AA5	On-board SDRAM
DRAM_ADDR[10]	PIN_R5	On-board SDRAM
DRAM_ADDR[9]	PIN_Y6	On-board SDRAM
DRAM_ADDR[8]	PIN_Y5	On-board SDRAM
DRAM_ADDR[7]	PIN_AA7	On-board SDRAM
DRAM_ADDR[6]	PIN_W7	On-board SDRAM
DRAM_ADDR[5]	PIN_W8	On-board SDRAM
DRAM_ADDR[4]	PIN_V5	On-board SDRAM
DRAM_ADDR[3]	PIN_P1	On-board SDRAM
DRAM_ADDR[2]	PIN_U8	On-board SDRAM
DRAM_ADDR[1]	PIN_V8	On-board SDRAM
DRAM_ADDR[0]	PIN_R6	On-board SDRAM
DRAM_BA[1]	PIN_R4	On-board SDRAM
DRAM_BA[0]	PIN_U7	On-board SDRAM

DRAM_CAS_N	PIN_V7	On-board SDRAM
DRAM_CKE	PIN_AA6	On-board SDRAM
DRAM_CLK	PIN_AE5	On-board SDRAM
DRAM_CS_N	PIN_T4	On-board SDRAM
DRAM_DQ[31]	PIN_U1	On-board SDRAM
DRAM_DQ[30]	PIN_U4	On-board SDRAM
DRAM_DQ[29]	PIN_T3	On-board SDRAM
DRAM_DQ[28]	PIN_R3	On-board SDRAM
DRAM_DQ[27]	PIN_R2	On-board SDRAM
DRAM_DQ[26]	PIN_R1	On-board SDRAM
DRAM_DQ[25]	PIN_R7	On-board SDRAM
DRAM_DQ[24]	PIN_U5	On-board SDRAM
DRAM_DQ[23]	PIN_L7	On-board SDRAM
DRAM_DQ[22]	PIN_M7	On-board SDRAM
DRAM_DQ[21]	PIN_M4	On-board SDRAM
DRAM_DQ[20]	PIN_N4	On-board SDRAM
DRAM_DQ[19]	PIN_N3	On-board SDRAM
DRAM_DQ[18]	PIN_P2	On-board SDRAM
DRAM_DQ[17]	PIN_L8	On-board SDRAM
DRAM_DQ[16]	PIN_M8	On-board SDRAM
DRAM_DQ[15]	PIN_AC2	On-board SDRAM
DRAM_DQ[14]	PIN_AB3	On-board SDRAM
DRAM_DQ[13]	PIN_AC1	On-board SDRAM
DRAM_DQ[12]	PIN_AB2	On-board SDRAM
DRAM_DQ[11]	PIN_AA3	On-board SDRAM
DRAM_DQ[10]	PIN_AB1	On-board SDRAM
DRAM_DQ[9]	PIN_Y4	On-board SDRAM
DRAM_DQ[8]	PIN_Y3	On-board SDRAM
DRAM_DQ[7]	PIN_U3	On-board SDRAM
DRAM_DQ[6]	PIN_V1	On-board SDRAM
DRAM_DQ[5]	PIN_V2	On-board SDRAM
DRAM_DQ[4]	PIN_V3	On-board SDRAM
DRAM_DQ[3]	PIN_W1	On-board SDRAM
DRAM_DQ[2]	PIN_V4	On-board SDRAM
DRAM_DQ[1]	PIN_W2	On-board SDRAM
DRAM_DQ[0]	PIN_W3	On-board SDRAM
DRAM_DQM[3]	PIN_N8	On-board SDRAM
DRAM_DQM[2]	PIN_K8	On-board SDRAM
DRAM_DQM[1]	PIN_W4	On-board SDRAM
DRAM_DQM[0]	PIN_U2	On-board SDRAM
DRAM_RAS_N	PIN_U6	On-board SDRAM
DRAM_WE_N	PIN_V6	On-board SDRAM

For timing analysis purposes, add the timing constraint file lab7.sdc (given on the course website). The lines in the file describe the main clock and the SDRAM clock, and the external SDRAM clock. Also, the maximum input and output pin delays are specified and checked against. You may need to modify the file to account for your different signal names. ***If you add additional inputs/outputs (which you will need to) you must add additional constraints to this file. Any unconstrained paths in your final demo will cause you to lose points, since there is no guarantee your design will actually work.***

Finally, compile the project. In the **Programmer**, find the .sof file in lab7/output_files. Program the circuit onto the FPGA.

Software Setup:

In Quartus II, go to **Tools > Nios II Software Build Tools for Eclipse** to launch the software development environment.

The Eclipse window will show up, as in Figure 21.

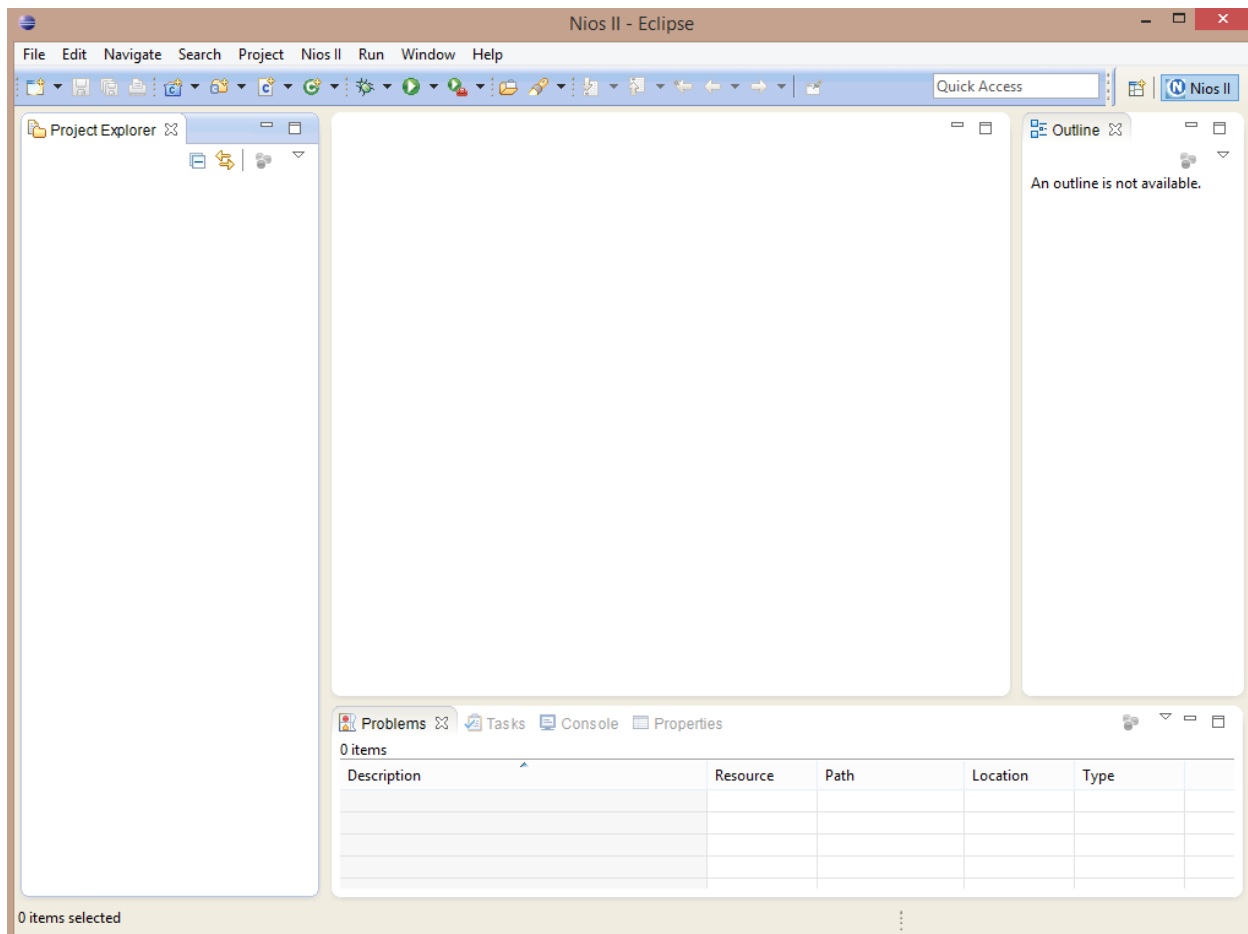


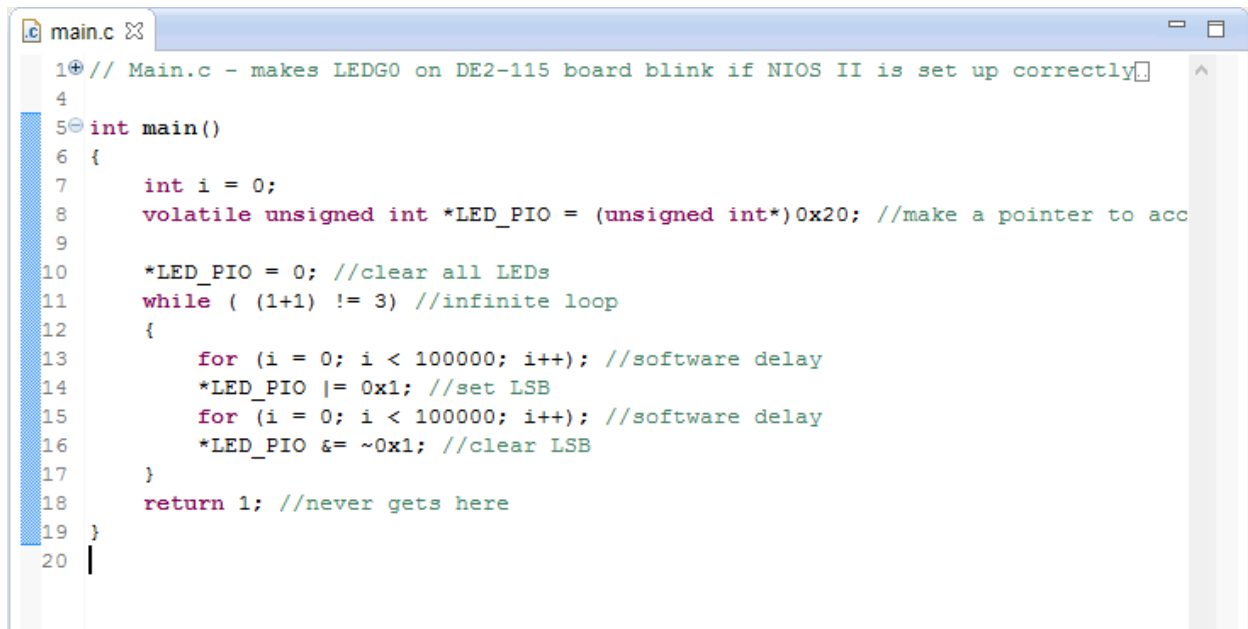
Figure 21

Eclipse works by having different “perspectives”, which represent UI layouts for different tasks common to software development. If the default perspective is not Nios II, set perspective to Nios II by going to **Menu > Window > Open Perspective > Other > Nios II**.

Create a new software program by clicking on **File > New... > Nios II Application and BST from Template**. A window should pop up, as shown in Figure 26. Set the SOPC Information File name to be lab7\nios_system.sopcinfo. The CPU name will be automatically determined. Select

“Blank Project” from the available project templates on the lower left corner. Enter Project name as lab7_app. Click **Finish**.

Two projects, *lab7_app* and *lab7_app_bsp* are generated. The bsp project contains the hardware information needed in the Makefile to compile the program. For example, the bsp contains the linker script, which tells the linker where to put various segments in memory as according to your address map. Click on the *lab7_app* project and create a new file named *main.c* and copy the contents from the *main.c* as supplied from the website, as shown in Figure 22.



```

1 // Main.c - makes LEDG0 on DE2-115 board blink if NIOS II is set up correctly
4
5 int main()
6 {
7     int i = 0;
8     volatile unsigned int *LED_PIO = (unsigned int*)0x20; //make a pointer to acc
9
10    *LED_PIO = 0; //clear all LEDs
11    while ( (1+1) != 3) //infinite loop
12    {
13        for (i = 0; i < 100000; i++); //software delay
14        *LED_PIO |= 0x1; //set LSB
15        for (i = 0; i < 100000; i++); //software delay
16        *LED_PIO &= ~0x1; //clear LSB
17    }
18    return 1; //never gets here
19 }
20

```

Figure 22

At the beginning of the program, fill in the actual address assigned by Qsys to the assignment for pointer **LED_PIO*. The address information can be found in the Qsys window. *You must be able to explain what each line of this (very short) program does to your TA. Specifically, you must be able to explain what the volatile keyword does (line 8), and how the set and clear functions work by working out an example on paper (lines 13 and 16).*

Right click on *lab7_app_bsp* project and select **Nios II > Generate BSP**. Then right click on the same project and, go to **Nios II > BSP Editor**. A window should pop up, as shown in Figure 23. Make sure your settings are the same as shown in the figure. In particular, the *exception_stack_memory_region_name* and the *interrupt_stack_memory_region_name* should be set to *sdram*.

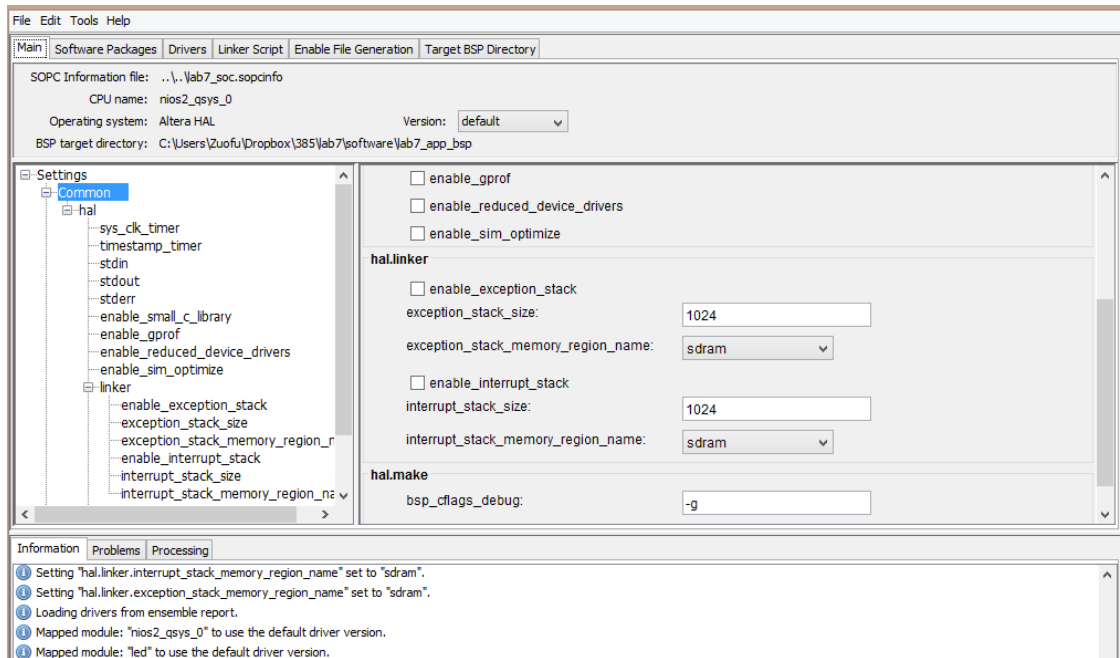


Figure 23

Finally, we have to setup the linker script. The linker script tells the linker which addresses to place the various segments of compiled code. Go to the **Linker Script** tab. Make sure all the linker regions and memory devices are set to *sdram*, as shown in Figure 24. Click **Generate**.

Look at the various segment (.bss, .heap, .rodata, .rdata, .stack, .text), what does each section mean? Give an example of C code which places data into each segment, e.g. the code:

```
const int my_constant[4] = {1, 2, 3, 4}
```

will place 1, 2, 3, 4 into the .rodata segment.

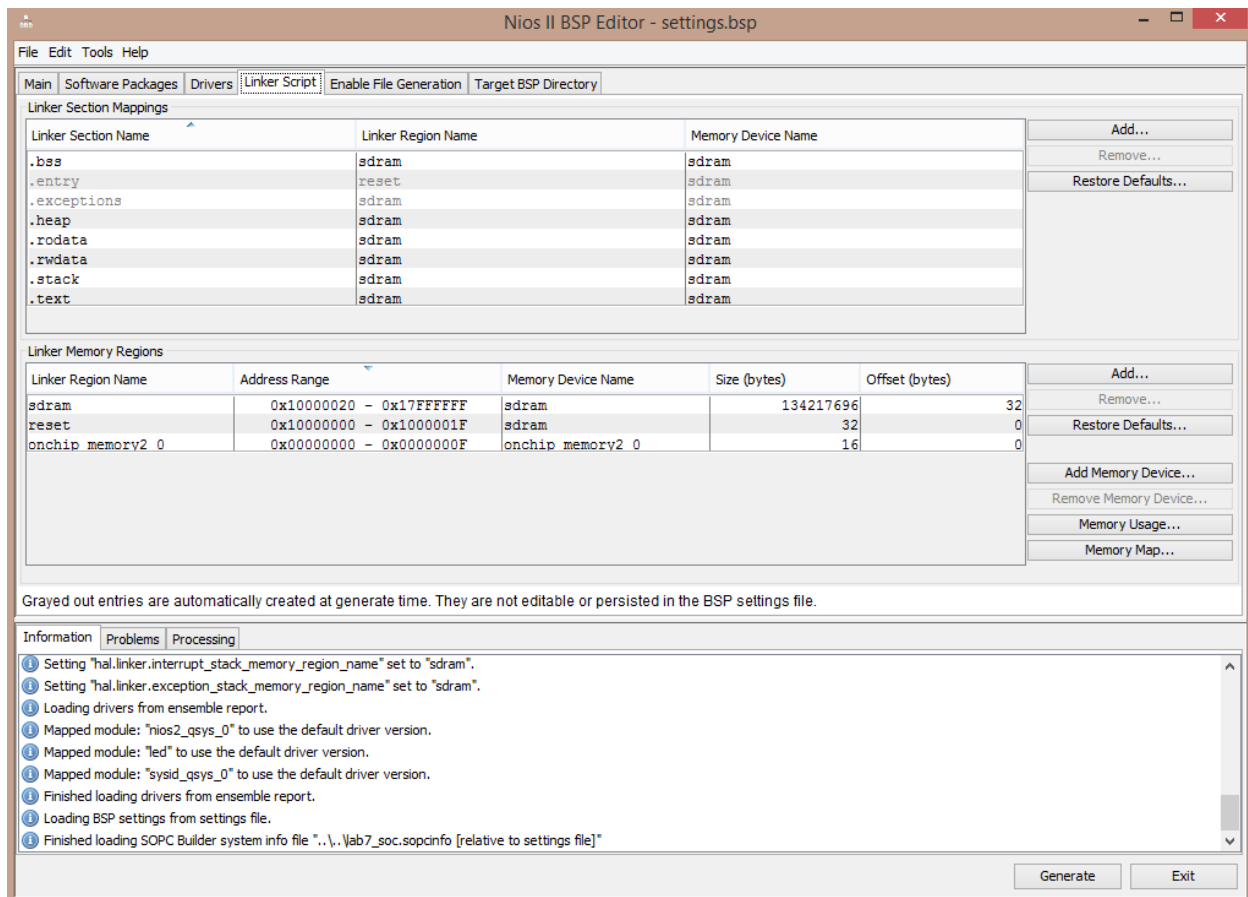


Figure 24

Now, we are ready to compile the program. Go to **Project > Build All** to compile the program.

IMPORTANT:

Whenever the hardware part is changed, it needs to be compiled in Quartus II and programmed on the FPGA. If the programmer fails to load the .sof file on the FPGA, it's likely because the software is occupying the USB Blaster port. Simply stop the program or restart the FPGA board (and reprogram the FPGA) if this is the case.

On the software side, make sure to right click on *lab7_app_bsp* and select **Nios II > Generate BSP** so the latest hardware information is included in the Makefile. Then, compile the program again (**Build All**). The System ID peripheral should report an error if you try to load software onto an incompatible hardware platform, but in either case compatibility errors occur if you fail to maintain software-hardware consistency!

Running the program Nios II:

In Eclipse, click on **Run > Run Configurations...** to open up a dialog window, as shown in Figure 25.

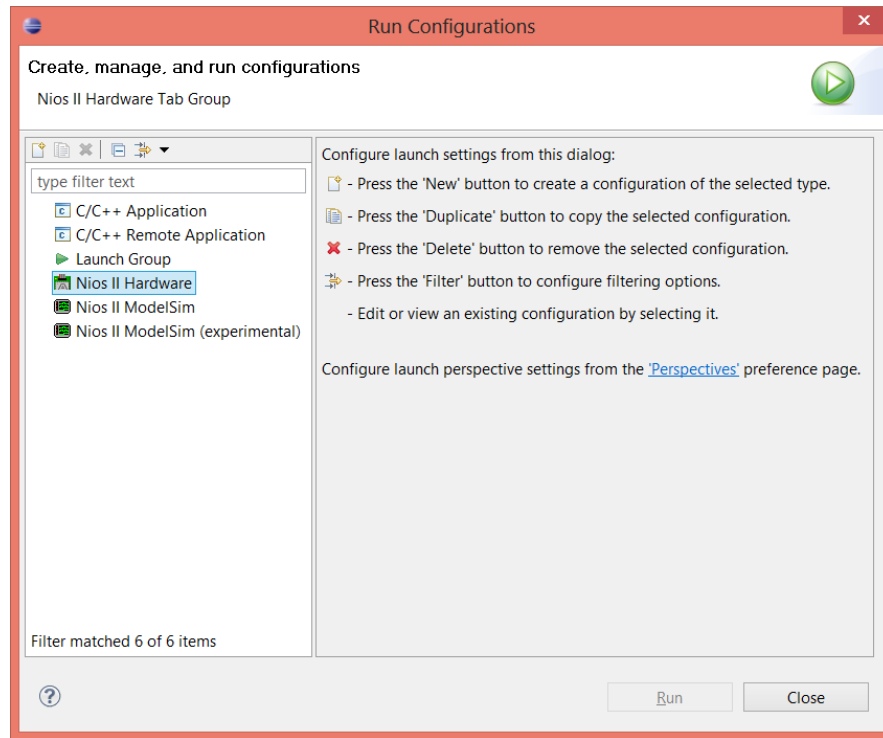


Figure 25

Right click on **Nios II Hardware** and select **New**. Type in the name of the configuration as **DE2**. In the **Project** tab, select Project name to be **lab7_app**. The corresponding ELF file should automatically be set up. See Figure 26. The ELF file is the compiled software file that is downloaded into the system memory and run on Nios II, equivalent to an “.exe” in Windows.

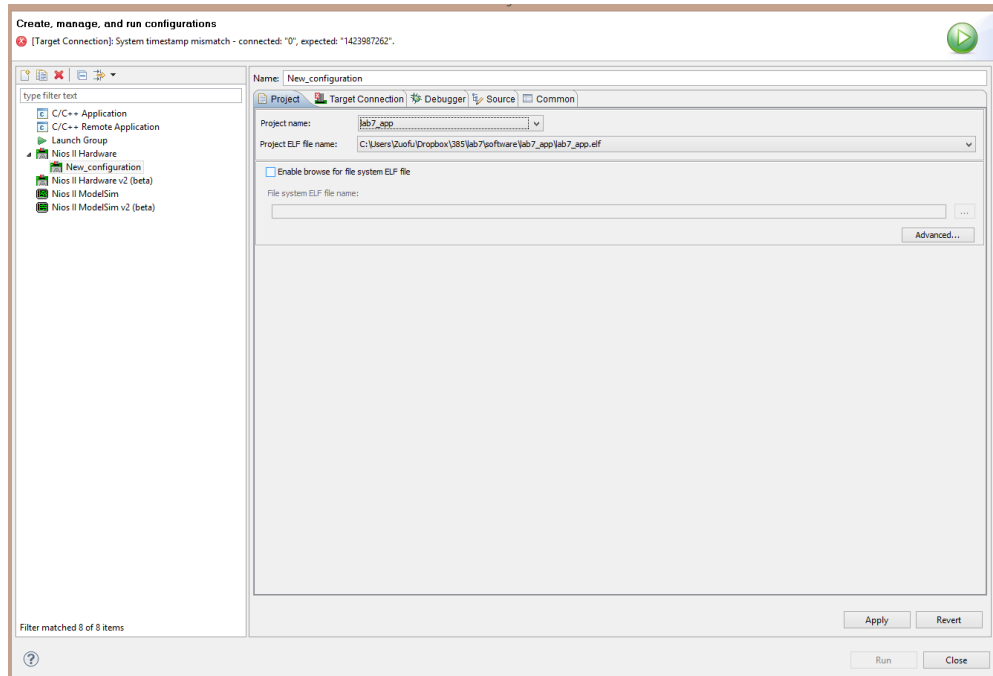


Figure 26

Go to the **Target Connection** tab. Click on Refresh Connections on the right. Make sure the **Processors** is listed as **USB-Blaster on localhost** (in Figure 27). If an error message “*Connected system ID hash not found on target at expected base address*” appears, something is wrong with your NIOS II system, your computer cannot connect to the “sysid” block that you created in Qsys. Check to make the FPGA is programmed and that all the pin assignments are correct.

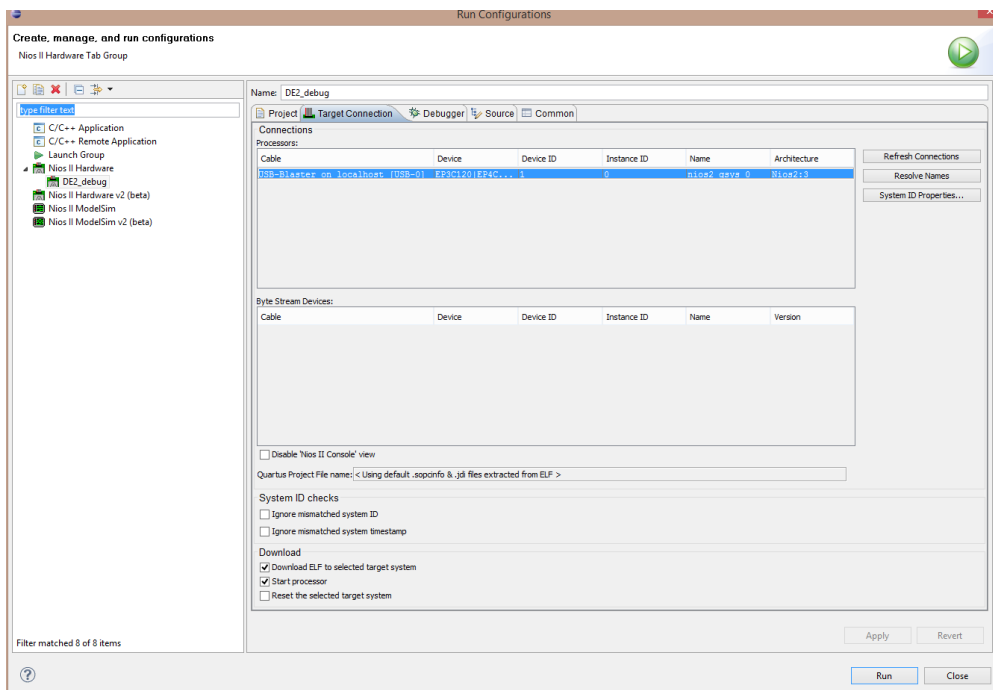


Figure 27

Click **Run** to run the program. Your LEDG0 should start blinking on your board as soon as the binary has been transmitted to the NIOS II CPU. Note that to do the actual lab assignment; you must add another PIO block as input corresponding to the switches. Do not forget you must export the PIO module from your SoC, modify the top-level SystemVerilog, re-assign memory addresses, assign the correct pins, and set the correct timing constraints. The following file will also be useful: [Altera Embedded Peripheral IP datasheet](#), specifically the chapter on PIO.