

Altera Monitor Program Tutorial

For Quartus II 13.0

1 Introduction

This tutorial presents an introduction to the Altera Monitor Program, which can be used to compile, assemble, download and debug programs for Altera's Nios II processor. The tutorial gives step-by-step instructions that illustrate the features of the Monitor Program.

The Monitor Program is a software application which runs on a host PC, and communicates with a Nios II hardware system on an FPGA board. The Monitor Program is compatible with Microsoft Windows operating systems, including XP, Vista, and Windows 7. It allows the user to assemble/compile a Nios II software application, download the application to a Nios II hardware system, and then debug the running application. The Monitor Program provides features that allow a user to:

- Set up a Nios II project that specifies a desired hardware system and software program
- Download the Nios II hardware system onto an FPGA board
- Compile software programs, specified in assembly language or C, and download the resulting machine code into the Nios II hardware system
- Disassemble and display the Nios II machine code stored in memory
- Run the Nios II processor, either continuously or by single-stepping instructions
- Examine and modify the contents of Nios II registers
- Examine and modify the contents of memory, as well as memory-mapped registers in I/O devices
- Set breakpoints that stop the execution of a program at a specified address, or when certain conditions are met
- Perform terminal input/output via a JTAG UART component in the Nios II hardware system
- Develop Nios II programs that make use of device driver functions provided through Altera's Hardware Abstraction Layer (HAL)

The process of downloading and debugging a Nios II program requires the presence of an FPGA board to implement the Nios II hardware system. In this tutorial it is assumed that the reader has access to the Altera DE2-115 Development and Education board, connected to a computer that has Quartus II (version 13.0) and Nios II Embedded Design Suite (EDS) software installed. Although a reader who does not have access to an FPGA board will not be able to execute the Monitor Program commands described in the tutorial, it should still be possible to follow the discussion.

The screen captures in this tutorial were obtained using version 13.0 of the Monitor Program; if other versions of the software are used, some of the images may be slightly different.

1.1 Who should use the Monitor Program

The Monitor Program is intended to be used in an educational environment by professors and students. It is not intended for commercial use.

2 Installing the Monitor Program

The Monitor Program is released as part of Altera's University Program Design Suite (UPDS). Before the UPDS can be installed on a computer, it is necessary to first install Altera's Quartus II CAD software (either the Web Edition or Subscription Edition) and the Nios II Embedded Design Suite (EDS). This release (13.0) of the Monitor Program can be used only with version 13.0 of the Quartus II software and Nios II EDS. This software can be obtained from the *Download Center* on Altera's website at *www.altera.com*. To locate version 13.0 of the software for downloading, it may be necessary to click on the item *All Design Software* in the section of the download page labeled *Archives*. Once the Quartus II software and Nios II EDS are installed, then the Altera UPDS can be installed as follows:

- 1. Install the Altera UPDS from the University Program section of Altera's website. It can be found by going to *www.altera.com* and clicking on *University Program* under *Training*. Once in the University Program section, use the navigation links on the page to select *Educational Materials > Software Tools > Altera Monitor Program*. Then click on the *EXE* item in the displayed table, which links to an installation program called *altera_upds_setup.exe*. When prompted to Run or Save this file, select Run.
- 2. The first screen of the installer is shown in Figure 1. Click on the Next button.



Figure 1. Altera UPDS Setup Program.

- 3. The installer will display the License Agreement; if you accept the terms of this agreement, then click | Agree to continue.
- 4. The installer now displays the root directory where the Altera University Program Design Suite will be installed. Click Next.
- 5. The next screen, shown in Figure 2, lists the components that will be installed, which include the Monitor Program software and University Program IP Cores. The University Program IP Cores provide a number of I/O device circuits that are used in Nios II hardware systems.

🔛 Altera University Program De	sign Suite Setup			
Choose Components Choose which features of Altera University Program Design Suite you want to install.				
Check the components you wan install. Click Install to start the ir	it to install and uncheck the components you don't want to nstallation.			
Select the type of install:	Full			
Or, select the optional components you wish to install:	Design Examples University Program IP Cores Vios II Material Altera Monitor Program Nios II Computer Systems			
Space required: 216.9MB	Description Position your mouse over a component to see its description.			
Nullsoft Install System v2,46	< Back Install Cancel			

Figure 2. The components that will be installed.

- 6. The installer is now ready to begin copying files. Click Install to proceed and then click Next after the installation has been completed. If you answered Yes when prompted about placing a shortcut on your Windows Desktop, then an icon is provided on the Desktop that can be used to start the Monitor Program.
- 7. Now, the Altera's Unveristy Program Design Suite is successfully installed on your computer, so click Finish to finish the installation.
- 8. Should an error occur during the installation procedure, a pop-up window will suggest the appropriate action. Possible errors include:

- Quartus II software is not installed or the Quartus II version is incorrect (only version 13.0 is supported by this release of the Monitor Program).
- Nios II EDS software is not installed or the version is incorrect (only version 13.0 is supported).

Note that if the Quartus II software is reinstalled at some future time, then it will be necessary to re-install the Monitor Program at that time.

3 Main Features of the Monitor Program

Each Nios II software application that is developed with the Altera Monitor Program is called a *project*. The Monitor Program works on one project at a time and keeps all information for that project in a single directory in the file system. The first step is to create a directory to hold the project's files. To store the design files for this tutorial, we will use a directory named *Monitor_Tutorial*. The running example for this tutorial is a simple assembly language program that controls some lights on a DE2-115 board.

Start the Monitor Program software, either by double-clicking its icon on the Windows Desktop or by accessing the program in the Windows Start menu under Altera > University Program > Altera Monitor Program. You should see a display similar to the one in Figure 3. This display consists of several windows that provide access to all of the features of the Monitor Program, which the user selects with the computer mouse. Most of the commands provided by the Monitor Program can be accessed by using a set of menus that are located below the title bar. For example, in Figure 3 clicking the left mouse button on the File command opens the menu shown in Figure 4. Clicking the left mouse button on the entry Exit exits from the Monitor Program. In most cases, whenever the mouse is used to select something, the left button is used. Hence we will not normally specify which button to press.

For some commands it is necessary to access two or more menus in sequence. We use the convention Menu1 > Menu2 > Item to indicate that to select the desired command the user should first click the mouse button on Menu1, then within this menu click on Menu2, and then within Menu2 click on Item. For example, File > Exit uses the mouse to exit from the system. Many commands can alternatively be invoked by clicking on an icon displayed in the Monitor Program window. To see the command associated with an icon, position the mouse over the icon and a tooltip will appear that displays the command name.

It is possible to modify the organization of the Monitor Program display in Figure 3 in many ways. Section 10 shows how to move, resize, close, and open windows within the Monitor Program display.

3.1 Creating a Project

To start working on a Nios II software application we first have to create a new project, as follows:

Select File > New Project to open the *New Project Wizard*, which leads to the screen in Figure 5. The Wizard presents a sequence of screens for defining a new project. Each screen includes a number of dialogs, as well as a message area at the bottom of the window. The message area is used to display error and information messages associated with the dialogs in the window. Double-clicking the mouse on an error message moves the cursor into the dialog box that contains the source of the error.

Altera Monitor Program [Nios II]				
Eile <u>S</u> ettings <u>A</u> ctions <u>W</u> indows <u>H</u> elp				
○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○				
Disassembly		_ ×	Registers	_ ×
Goto instruction Address (hex) or symbol name:	Go	Hide	Reg Value	
	Ŀ\$			
Terminal _ ×	Info & Errors			_ ×
	Info & Errors / GDB Server	/		

Figure 3. The main Monitor Program display.

File	<u>S</u> ettings	<u>A</u> ctions	<u>W</u> ine				
N	lew Project.						
g	Open Project						
C							
S							
E	<u>x</u> it						

Figure 4. An example of the File menu.

In Figure 5 we have specified the file system directory *D:\Monitor_Tutorial* and the project name *Monitor_Tutorial*. For simplicity, we have used a project name that matches the directory name, but this is not required.

If the file system directory specified for the project does not already exist, a message will be displayed indicating that this new directory will be created. To select an existing directory by browsing through the file system, click on the **Browse** button. Note that a given directory may contain at most one project.

2. Click Next to advance to the window shown in Figure 6, which is used to specify a Nios II hardware system. Nios II-based systems are described by a *.ptf* or *.qsys* file, which are generated by the Altera SOPC Builder

Project directory:	-	
D:\Monitor_Tutorial		Browse
Project name:		
Monitor_Tutorial		

Figure 5. Specifying the project directory and name.

tool and Qsys tool, respectively, when the system is created. More information about creating systems using SOPC Builder can be found in the tutorial called *Introduction to the Altera SOPC Builder*, while information about creating systems using Qsys can be found in the *Introduction to the Altera Qsys System Integration Tool* tutorial. Both tutorials are available in the University Program section of Altera's website. An optional *.sof* file, if specified, represents the FPGA circuit that implements the Nios II-based system; this file can be downloaded into the FPGA chip on the board that is being used.

The drop-down list on the Select a system pane can be used to choose a pre-built Nios II computer system provided with the Monitor Program, or a <Custom System> created by the user. Both the .*ptfl.qsys* and the .*sof* files are automatically filled in by the Monitor Program if a pre-built system is selected. However, if <Custom System> is selected, then the files need to be specified manually in the System details pane. Section 5 shows how to use the Monitor Program with a Custom system.

As depicted in Figure 6, select the pre-built system named *DE2-115 Basic Computer*. In the top right corner of the screen there is a Documentation button. Clicking on this button opens a user guide that provides all information needed for developing Nios II programs for the DE2-115 Basic Computer, such as the memory map for addressing all of the I/O devices in the system. This file can also be accessed at a later time by using the command Settings > System Settings and then clicking on the Documentation button.

3. Click Next to advance to the screen in Figure 7, which is used to specify the program source files that are associated with the project. The Program Type drop-down list can be used to select one of the following

lew Project Wizard	
ecify a system	
elect a system	
DE2-115 Basic Computer 🗸 👻	Documentation
This system, called the DE2-115 Basic Computer, is intended to be used as a platform fo experiments in computer organization and embedded systems. To support these beginn experiments, the system contains only a few components: a processor, memory, and so peripherals.	or introductory ing ome simple I/O
ystem details	
System description file (PTF, Qsys or SOPCInfo):	
ram\NiosII_Computer_Systems\DE2-115\DE2-115_Basic_Computer\verilog\nios_system	n.ptf Browse
Quartus II programming (SOF) file (optional):	
mputer_Systems\DE2-115\DE2-115_Basic_Computer\verilog\DE2_115_Basic_Computer	.sof Browse
The SOF file represents the FPGA programming file for the Nios II system. If it is specifi the Monitor Program can be used to download this programming file onto the board. Ot system will need to be downloaded using some other method (for example, by using Qu	ied here, then herwise, the uartus II).
Quartus II JTAG debugging information (JDI) file (optional):	
	Browse
The JDI file is required for multiprocessor systems designed in Qsys. It stores the JTAG These IDs are needed for communication between the Monitor Program and the system processors and JTAG UARTs .	Device IDs. 1's multiple
< <u>B</u> ack Next >	Einish Can

Figure 6. Specifying the Nios II hardware system.

program types:

- Assembly Program: allows the Monitor Program to be used with Nios II assembly-language code
- C Program: allows the Monitor Program to be used with C code
- Program with Device Driver Support: this is an advanced option, which can be used to build programs that make use of device driver software for the I/O devices in the Nios II hardware system. Programs that use this option can be written in either assembly, C, or C++ language (or any combination). More information about writing programs that use device drivers can be found in Section 9.
- ELF or SREC File: allows the Monitor Program to be used with a precompiled program, in ELF or SREC format
- No Program: allows the Monitor Program to connect to the Nios II hardware system without first loading a program

For this example, set the program type to Assembly Program. When a pre-built Nios II computer system has been selected for the project, as we did in Figure 6, it is possible to click on the selection Include a sample program with the project. As illustrated in Figure 7 several sample assembly language programs are available for the DE2-115 Basic Computer. For this tutorial select the program named *Getting Started*.

🖉 New Proj	ect Wizard 🛛 🔀				
Specify a p	rogram type				
Program Type: Assembly Program Lets you specify a program written in assembly language.					
Lets you specify a program written in assembly language. Include a sample program with the project Select a sample program Getting Started JTAG UART Interrupt Example Test Basic Computer It performs the following: 1. displays the SW switch values on the red LEDR 2. displays the KEY[31] pushbutton values on the green LEDG 3. displays a rotating pattern on the HEX displays 4. if KEY[31] is pressed, uses the SW switches as the pattern					
	< Back Next > Einish Cancel				

Figure 7. Selecting a program type and sample program.

Click Next to advance to the screen in Figure 8. When a sample program has been selected, the source code file(s) associated with this program are listed in the Source files box. In this case, the source file is named *getting_started.s*; this source file will be copied into the directory used for the project by the Monitor Program. If a sample program is not used, then it is necessary to click the Add button and browse to select the desired source file(s).

Figure 8 shows that it is possible to specify the label in the assembly language program that identifies the first instruction in the code. In the *getting_started.s* file, this label is called *_start*, as indicated in the figure.

4. Click Next to advance to the window in Figure 9. This dialog is used to specify the connection to the FPGA board, the Nios II processor that should be used (some hardware systems may contain multiple processors), and the terminal device. The Host connection drop-down list contains the physical connection links (such as cables) that exist between the host computer and any FPGA boards connected to it. The Nios II processors available in the system are found in the Processor drop-down list, and all terminal devices connected to the selected processor are displayed in the Terminal device drop-down list. We discuss terminal devices in section 6.

For this tutorial, accept the default values that are displayed in Figure 9.

5. Click Next to reach the final screen for creating the new project, shown in Figure 10. This screen is used

Source files —					
First source file	is used to determine t	he name of the binar	y program file.		
D:\Monitor_Tut	orial\getting_started.	s			Add Remove
					Up Down
rogram optior	15				
Start symbol:	_start	o program filos inicia	will be created in	he project directory	
ource files highligh	ited in blue are sample	e program files, which	n will be created in	the project directory	/•

Figure 8. Specifying source code files.

to specify memory settings that are needed for compiling and linking the program. Nios II programs are stored in a format that supports *sections*, which are used to divide a program into multiple parts, such as an executable code section, called *.text*, and a data section, called *.data*. The partitioning of the program into different sections is performed by the linker.

As illustrated in Figure 10, choose the SDRAM chip in the DE2-115 Basic Computer as the storage location for both the *.text* and *.data* sections, and use the value 0 for the offset into the memory for both sections. When the offsets for both sections are identical the linker automatically places the *.data* section immediately after the *.text* section.

The *getting_started.s* file shows how to include *.text* and *.data* directives in an assembly language program. These directives should be included in a program when it is desirable to separate the program text and data. For example, it may be desirable to place each section into a different memory device. Note that it is also possible to use *.org* directives in an assembly language program to specify section addresses. However, this approach can cause the machine code files generated by assembling the program to be very large if there is a wide gap in addresses between the *.text* and *.data* sections.

For the sample program selected for this tutorial it is not necessary to make use of the *.text* and *.data* sections. However, other programs, such as those that use interrupts, must utilize these sections to avoid linking errors. An example of the appropriate setting when interrupts are used in a program is given in section 8.

Click Finish to complete the creation of the new project. At this point, the Monitor Program displays the

🥔 New Project V	Vizard 🛛 🔀
Specify sys	tem parameters
_[System parame	ters
Host connection:	USB-Blaster [USB-0] Refresh
Processor:	CPU -
	Reset vector address: 0x0
	Exception vector address: 0x20
Terminal device:	JTAG_UART
	< <u>Back</u> <u>Next</u> > <u>Einish</u> <u>Cancel</u>



prompt shown in Figure 11. Clicking Yes instructs the Monitor Program to download the Nios II system associated with the project onto the FPGA board. It is also possible to download the system at a later time by using the Monitor Program command Actions > Download System.

3.1.1 Downloading a Nios II Hardware System

When downloading a Nios II hardware system onto an FPGA board, it is important to consider the type of license that is included in the hardware system for the processor. The Nios II processor uses a licensing scheme that provides two modes of operation: 1. an evaluation mode that allows the processor to be used with some restrictions when no license is present, and 2. a normal mode that allows unrestricted use when a license is present. Nios II licenses can be purchased from Altera, and are also available on a donated basis through the University Program. The prebuilt computer systems provided with the Monitor Program, such as the DE2-115 Basic Computer, include a Nios II processor that has a license. However, if other systems are being used with the Monitor Program, then it is possible that a license is not present, and the Nios II processor may be used in the evaluation mode. In this case it is necessary to use a different scheme, which is described in section 5, to download the Nios II hardware system onto the FPGA board and activate the evaluation mode.

3.2 Compiling and Loading the Program

After successfully creating a project, its software files can be assembled/compiled and downloaded onto the FPGA board using the following commands:

New Project Wizaro		×
Specify program men	nory settings	
Processor's reset and exce	ption vectors (read-only)	
Reset vector address	0	
Exception vector address (he)	(): 20	
Memory options		
Here you can specify the star directives. These addresses can be used to ensure that the .reset and .exceptions. If .te be placed right after the .tex	ting addresses of sections identified by .text and .data assembler can be in the same or in different memories (on-chip, SDRAM,). They ne .text and .data sections do not overlap with other sections, such as and .data are specified to have the same address, the .data section will t section by the linker.	
text section		
Memory device:	SDRAM/s1 (0x0 - 0x7ffffff)	
Start offset in device (hex):	0	
data section		
Memory device:	SDRAM/s1 (0x0 - 0x7ffffff) 🗸 🗸	
Start offset in device (hex):	0	
	< Back Next > Finish Can	:el

Figure 10. Specifying memory settings.

Downloa	ad SOPC Builder System - Prompt 🛛 🛛 🗙
?	Would you like to download the system associated with this project onto the board? If so, make sure that the board is connected via the correct cable and is powered up.
	Yes No

Figure 11. Download the Nios II system.

- Actions > Compile menu item or icon: compiles the source files into an ELF and SREC file. Build warnings and errors will show up in the Info & Errors window. The generated ELF and SREC files are placed in the project's directory.
- Actions > Load menu item or $\stackrel{\clubsuit}{=}$ icon: loads the compiled SREC file onto the board and begins a debugging session in the Monitor Program. Loading progress messages are displayed in the Info & Errors window.
- Actions > Compile & Load menu item or be icon: performs the operations of both compilation and loading.

Our example project has not yet been compiled, so it cannot be loaded (the Load option is disabled). Click the Actions > Compile & Load menu item or click the icon to begin the compilation and loading process. Throughout the process, messages are displayed in the Info & Errors window. The messages should resemble those shown in Figure 12.

Info & Errors _ ×						
Info: Quartus II Programmer was successful. O errors, O warnings						
Info: Peak virtual memory: 121 megabytes						
Info: Processing ended: Fri Jan 14 15:11:59 2011						
Info: Elapsed time: 00:00:02						
Info: Total CPU time (on all processors): 00:00:00						
Compiling source files						
nios2-elf-asgstabs -I C:/altera/10.1/nios2eds/components/altera_nios2/sdk/inc -I D:/Monitor_Tutorial D:/Mon						
Linking						
nios2-elf-lddefsym nasys_program_mem=0x0defsym nasys_data_mem=0x0section-start .exceptions=0x20sec						
<pre>nios2-elf-lddefsym nasys_program_mem=0x0defsym nasys_data_mem=0x0section-start .exceptions=0x20se ELF generated at D:\Monitor_Tutorial\getting_started.elf. nios2-elf-objcopy -0 srec D:/Monitor_Tutorial/getting_started.elf D:/Monitor_Tutorial/getting_started.srec SREC generated at D:\Monitor_Tutorial\getting_started.srec. Using cable "USB-Blaster [USB-0]", device 1, instance 0x00 Resetting and pausing target processor: 0K</pre>						
nios2-elf-objcopy -0 srec D:/Monitor_Tutorial/getting_started.elf D:/Monitor_Tutorial/getting_started.srec						
<pre>Info: Elapsed time: 00:00:02 Info: Total CPU time (on all processors): 00:00:00 Compiling source files nios2-elf-asgstabs -I C:/altera/10.1/nios2eds/components/altera_nios2/sdk/inc -I D:/Monitor_Tutorial D:/Mon Linking nios2-elf-lddefsym nasys_program_mem=0x0defsym nasys_data_mem=0x0section-start .exceptions=0x20sec ELF generated at D:\Monitor_Tutorial\getting_started.elf. nios2-elf-objcopy -0 srec D:/Monitor_Tutorial/getting_started.elf D:/Monitor_Tutorial/getting_started.srec SREC generated at D:\Monitor_Tutorial\getting_started.srec. Using cable "USB-Blaster [USB-0]", device 1, instance 0x00 Resetting and pausing target processor: 0K Reading System ID at address 0x10002020: verified Initializing CPU cache (if present) 0K Downloading 00000000 (0%) Verifying 00000000 (0%)</pre>						
Using cable "USB-Blaster [USB-0]", device 1, instance 0x00						
Resetting and pausing target processor: OK						
Reading System ID at address 0x10002020: verified						
Initializing CPU cache (if present)						
0K						
Downloading 00000000 (0%)						
Linking nios2-elf-lddefsym nasys_program_mem=0x0defsym nasys_data_mem=0x0section-start .exceptions=0x20sec ELF generated at D:\Monitor_Tutorial\getting_started.elf. nios2-elf-objcopy -0 srec D:/Monitor_Tutorial/getting_started.srec. SREC generated at D:\Monitor_Tutorial\getting_started.srec. Using cable "USB-Blaster [USB-0]", device 1, instance 0x00 Resetting and pausing target processor: 0K Reading System ID at address 0x10002202: verified Initializing CPU cache (if present) 0K Downloading 00000000 (0%) Downloaded 1KB in 0.0s						
Verifying 00000000 (0%)						
Verified OK						
Connection established to GDB server at localhost:2399						
Symbols loaded.						
Source code loaded.						
INFO: Program Trace not enabled, because trace requires the Nios II processor to be configured with JTAG Debu						

Figure 12. Compilation and loading messages.

After successfully completing this step, the Monitor Program display should look similar to Figure 13. At this point, the Nios II processor is halted at the first instruction of the program. The main part of the display in Figure 13 is called the *Disassembly* window. We discuss this window in detail in section 3.4. It shows the source code of the program, as well as a disassembled view of the corresponding Nios II machine code that is stored in memory. In the figure, the first line of source code is the instruction movia r15, 0x1000040. This is a *pseudo-instruction*, rather than a native Nios II instruction¹. The Disassembly window shows immediately below this pseudo-instruction the corresponding Nios II machine code, which is stored at address 0. The movia operation is implemented by using two Nios II machine instructions: orhi and addi. As illustrated in the figure, for each line of code from the project's assembly language source code files, the Monitor Program displays the source code and disassembled machine code that is stored in memory. In most cases the source code and disassembled machine code are the same, but for some operations, like pseudo-instructions, they are different.

3.2.1 Compilation Errors

During the process of developing software, it is likely that compilation errors will be encountered. Error messages from the Nios II assembler or from the C compiler are displayed in the Info & Errors window. To see an example of

¹More information about Nios II instructions and pseudo-instructions can be found in the tutorial *Introduction to the Altera Nios II Soft Processor*, available in the University Program section of Altera's website.

🔎 Altera Monit	or Program [Nios II] - Moni	tor_Tutorial.ncf :	getting_started.srec [Pause	ed]			×
<u>File S</u> ettings	<u>A</u> ctions <u>W</u> ind	ows <u>H</u> elp						
🖳 📄 🔒 🤇) 🔊 🔿 (D III 🔍 🔥	4 ¢					
Disassembly					_ ×	Registers	_	×
Coto instruction	Address (how)	or sumbol pomo			Llida	Reg	Value	
GOLD INSTRUCTION	Address (nex)	or symbol hame:		<u>a</u> o	niue	pc	0x00000000	
		.global	_start		-	zero	0x00000000	Γ
		_start:				rl	0x00000000	
						r2	0x0000000	
		/* init	ialize base addr	esses of parallel ports	*/	r3	0x00000000	
		movia	r15, 0x100	00040 /* SW slide	r switch ba	r4	0x00000000	00000
		start:				r5	0x00000000	1000
0x00000000	03c40034	orhi	r15, zero, 0x10	00		r6	0x00000000	
0x00000004	7bc01004	addi	r15, r15, 0x40			r7	0x00000000	
		movia	r16. 0x100	000000 /* red LED	base addres	r8	0x00000000	
0x00000008	04040034	orhi	rl6, zero, 0x10	00		r9	0x00000000	
0x0000000c	84000004	addi	r16, r16, 0x0			r10	0x00000000	
	0 100000 1	movia	r17 0v100	00050 /# nusbbutt	on KEV hase	r11	0x00000000	
0×00000010	04440034	orbi	rl7 zero Oylo	100 100	on the bube	r12	0x00000000	
0x00000010	994400004	addi	x17 x17 0x50			r13	0x00000000	
0X0000014	00401404	auur	×19 0×100	100010 /* meen IF	These adds	r14	0x0000000	
0-00000010	0.40.40.00.4	movia	110, UX100	000010 /" green Lt	D Dase addr	r15	0x00000000	
0x00000018	04040034	oritt	r10, zero, oxic	00	-	r16	0x00000000	
4					•	r17	0x00000000	
Disassembly (Br	reakpoints / Me	mory / Watches	/ Trace /			×10	0x00000000	
(<u></u> /		<u>.</u>	//	1		119	0x00000000	
ferminal			_ ×	Info & Errors			-	×
JTAG UART lin	k establish	ed using cab	le "USB-Blaster	Verified OK				4
[USB-0]", dev	ice l, inst	ance 0x00		Connection established	to GDB server	at local	lhost:2399	
	,			Symbols loaded.				
				Source code loaded.				
				INFO: Program Trace no	t enabled, bec	cause trac	ce requires	100
				3000000 3000000 3000000 3000000 3000000 3000000 3000000 3000000 3000000 3000000 3000000 300000 300000 300000 300000 300000 300000 30000 30000 30000 30000 30000 30000 3000			•	
				Info & Errors / GDB Server /				

Figure 13. The Monitor Program window after loading the program.

a compiler error message, edit the file *getting_started.s*, which is in the project's directory, and remove the : colon that appears at the end of the *_start* label, in line 12. Recompile the project to see the error shown in Figure 14. The error message gives the line number in the file (12) where the error was detected. Fix the error, and then compile and load the program again.



Figure 14. An example of a compiler error message.

3.3 Running the Program

As mentioned in the previous section, the Nios II processor is halted at the first instruction after the program has been loaded. To run the program, click the Actions > Continue menu item or click the \bigcirc icon. The *Getting Started* program performs the following actions on the DE2-115 board:

- Displays the DE2-115 board's SW switch settings on the red lights LEDR
- Displays the KEY₁, KEY₂, and KEY₃ pushbutton states on the green lights LEDG
- Shows a rotating pattern on the HEX displays. If KEY₁, KEY₂, or KEY₃ is pressed, the pattern is changed to correspond to the settings of the SW switches.

The Continue command runs the program indefinitely. To force the program to halt, select the Actions > Stop command, or click the \square icon. This command causes the processor to halt at the instruction to be executed next, and returns control to the Monitor Program. Another way to stop the execution of this program is to press the pushbutton KEY₀ on the DE2-115 board; this pushbutton is connected to the reset input of the Nios II processor in the DE2-115 Basic Computer. Resetting the processor causes program execution to stop and sets the processor to its reset address, which is address 0 in this system.

Figure 15 shows an example of what the display may look like when the program is halted by using the Stop command. The display highlights in yellow the next program instruction, which is at address 0×00000070 , to be executed, and highlights in red the register values in the Nios II processor that have changed since the last program stoppage. Other screens in the Monitor Program are also updated, which will be described in later parts of this tutorial.

3.4 Using the Disassembly Window

In Figure 15 the Disassembly window shows six machine instructions, at the memory addresses $0 \times 0000005c$, 0×00000064 , 0×00000068 , $0 \times 0000006c$, and 0×00000070 . The leftmost column in the window gives the memory addresses, the middle column displays the machine code at that address, and the rightmost column shows both the original source code for the instruction, in a brown color, and the disassembled view of the machine code that is stored in memory, in a green color. As shown in the figure, the program may be implemented with different instructions from those given in the source code. For example subi r7, r7, 1 is implemented in this program by using addi r7, r7, -1.

The Disassembly window can be configured to display less information on the screen, such as not showing the source code from the *.s* assembly language file or not showing the machine encoding of the instructions. These settings can be changed by right-clicking on the Disassembly window and selecting the appropriate menu item, as shown in Figure 16. The color scheme used in the Disassembly window is given in Table 1.

Different regions of memory can be disassembled and displayed by scrolling, using either the vertical scrollbar on the right side of the Disassembly window or a mouse scroll wheel. It is also possible to scroll the display to a region of memory by using the Goto instruction panel at the top of the Disassembly window, or using the command Actions > Goto instruction. The instruction address provided for the Goto command must be a multiple of four,

🥔 Altera Monit	or Program [Nios II] - Moni	tor_Tutorial.ncf : g	etting_started.srec [Paused]			X			
<u>File S</u> ettings	<u>A</u> ctions <u>W</u> ind	ows <u>H</u> elp								
👱 🗈 🔒 🤇										
Disassembly				_ >	< Registers	-	×			
Goto instruction	Address (hex)	or symbol name:		Go Hide	Reg	Value				
					pc	0x00000070	٠			
		NO_BUTTON:		La construction de la constructi	zero	0x00000000				
		stwio	r6, 0(r20)	/* store to HEX3	rl	0x00000000				
		NO_BUTTON:			r2	0x00000000				
0x0000005c	a1800035	stwio	r6, 0(r20)		r3	0x00000000				
		stwio	r6, 0(r21)	/* store to HEX7 .	r4	0x00000180				
0x00000060	a9800035	stwio	r6, 0(r21)		r5	0x00000000				
		roli	r6, r6, l	/* rotate the display	r6	0x00f00000				
0x00000064	300c107a	roli	r6, r6, 0x1		r7	0x00006b2e				
				B	r8	0x00000000				
		movia	r7, 100000	/* delay counter */	2 r9	0x00000000				
0x00000068	01c000b4	orhi	r7. zero. 0x2		r10	0x00000000				
0x0000006c	39e1a804	addi	r7, r7, -0x7960		r11	0x00000000				
	00010001		21, 21, 011500		r12	0x00000000				
		DELAY.			r13	0x00000000				
		subi	r7 r7 1		r14	0x00000000				
		DELAY.	17, 17, 1		r15	0x10000040				
0+00000070	206666674	DEBAT.	v7 v7 0v1		r17	0x10000000				
0x00000070	39111104	hno	LI, LI, FUXI	,	▼ 117 r18	0x10000030				
4			3333333	•	r10	0x10000010				
Disassembly / Br	reakpoints / Me	mory / Watches	/ Trace /		r20	0x10000020	•			
Terminal			_ ×	Info & Errors			×			
				(1-1)-1-1-4-4						
JTAG UART IIn	k establish	ed using cab.	le "USB-Blaster	Symbols loaded.						
[USB-0]", dev	ice 1, inst	ance Ux00		Source code loaded.						
INFO: Program Trace not enabled, because trace						ce requires				
				Program stopped @ 0x00000070			33			
				-			•			
				Seesees		•				
				Info & Errors / GDB Server /						

Figure 15. The Monitor Program display after the program has been stopped.

0x00001038	803ffele	han rif arrow
		✓ Show instruction words
0x0000103c	00011540	Show source code
0x00001040	18000126	Goto instruction

Figure 16. Pop-up menu to configure the display of the Disassembly window.

because Nios II instructions are word-aligned. As an example, enter the label DELAY or the address 70, and press Go. The Disassembly window scrolls to the address 0×00000070 , as depicted in Figure 17, and highlights the instruction using a pink color.

Register and memory values can be examined in the Disassembly window while the Nios II processor is *halted*. This is done by hovering the mouse over a *register* or *register* + *offset* name for an instruction in the window, as illustrated in Figure 18. If the instruction loads or stores a value from/to memory, then the Monitor Program displays the current value of the memory location in the pop-up.

The Disassembly window also produces clickable links in its display of branch and call instructions. Clicking on one of these links scrolls the display to show the target instruction of the branch or call. Figure 19 shows an

Color	Description
Brown	Source code
Green	Disassembled instruction name
Blue	Registers
Orange	Immediate & offset values
Dark blue	Address values & labels
Purple	Clickable link
Gray	Machine encoding of the instruction

Table 1. Disassembly window color scheme.

🥔 Altera Monite	or Program [[Nios II] - Mon	itor_Tutorial.ncf : g	etting_started.srec [Paused]				\mathbf{X}	
<u>File S</u> ettings	<u>A</u> ctions <u>W</u> ind	ows <u>H</u> elp							
👱 🗈 🔒 🛛									
Disassembly _ × Registers _ ×									
Goto instruction	Address (hex)	or symbol name:	DELAY	Go	Hide	Reg	Value		
		1				pc	0x00000000		
		DEL AV.			-	zero rl	0x000000000		
		DELAT:				r2	0x00000000		
		Sub1	LI, LI, I			r3	0x000000000		
0+0000020	206666674	DELAY:	*7 ×7 0×1			r4	0x00000000		
0x00000070	39111104	addi	I, I, -UXI	7		r5	0x00000000		
0.0000074	20266-1-	bne	LI, LU, DELAI			r6	0x00000000	33	
0x00000074	SOSTIFIE	bne	17, 2010, -0xo ((0X00000000; DELAI)		r7	0x00000000		
		J e er	DO DICRUAN			r8	0x0000000		
000000070	00066000	DE	DU_DISPLAT	DO DIGDIANA	888	r9	0x00000000		
0X00000078	UUSIIUU6	br	-0X40 (0X0000003	SC: DU_DISPLAY)		r10	0x0000000		
						r11	0x0000000		
		HEX_bits:				r12	0x0000000		
0x00000076	000000t	Idh	zero, U(zero)			r13	0x00000000		
0x0000080	20000226	beq	r4, zero, 0x8 (0	JXUUUUUU8C)		r14	0x00000000		
0x0000084	00000ec0	call	0x0000003b (0x00)0000ec)		r15	0x00000000		
0x0000088	00000306	br	0xc (0x00000098)			r16	0x00000000		
0x000008c	d£401215	stw	ea, 72(sp)		-	r17	0x00000000		
•	a9hfff17	Loher	*2 ((00)		•	r18	0x00000000		
Disassembly / Br	eakpoints / Me	mory / Watches	/ Trace /			r19	0x00000000		
			<u>(11460</u>)			r20	0x00000000		
Terminal			_ ×	Info & Errors			-	×	
JTAG UART link	k establish	ed using cab	le "USB-Blaster	Connection established to G	DB serve:	r at local	.host:2399	-	
[USB-0]", dev:	ice l, inst	ance 0x00		Symbols loaded.					
				Source code loaded.					
				INFO: Program Trace not ena	bled, be	cause trac	e requires	333	
							-	-	
							•		
				Info & Errors / GDB Server /					
L									

Figure 17. Goto instruction panel in the Disassembly window.

example of a clickable link for a call instruction.

The Disassembly window attempts to show disassembled code for all words in memory, even though some memory words may not correspond to Nios II executable code. For example, in Figure 17 the memory word at address 0×0000007 has the value 0×0000000 f and represents data that is used by the program. Even though the Disassembly window attempts to show a corresponding Nios II assembly language instruction for this memory word, the disassembled machine code is not meaningful because this data does not represent executable code.

0x00000030	04c00034	movia orhi	r19, HEX_bits r19, zero, 0x0	33	r8 r9	0x000013400 0x00000000 0x00000000
0X00000034	9CCUIIU4	ldw	r19, r19, 0x7c r6, 0(r19)	/* load pattern for H	r10	0x00000000
0x00000038	99800017	ldw	r6, 0(r19)		r12	0x00000000
			0x0000007c: 0x0000000f		r13 r14	0x00000000
		DO_DISPLAY:			r15	0x10000040
		ldwio	r4, 0(r15)	/* load slider swit	r16	0x10000000
		DO DISPLAY.	******		r17	0x10000050
			10000		r18	0x10000010
Disassembly / Br	reakpoints / Me	mory (Watches	(Trace)		r19	0x0000007c 💌

Figure 18. Examining a register value in the Disassembly window.

		display: call UPDATE_HEX_DISPLAY display:
0x00001028	00011b00	call 0x0000046c (MX000011b0: UPDATE_HEX_DISPLAY)
		<pre># delay loop of app1 Goto instruction label 'UPDATE_HEX_DISPLAY' (0x000011b0</pre>

Figure 19. A clickable link in the Disassembly window.

3.5 Single Stepping Program Instructions

Before discussing the single step operation, it is convenient to restart execution of the Getting Started program from

the beginning. Click the Actions > Restart menu item or click the $\frac{1}{2}$ icon to restart the program. Note that if the program is running, it must first be halted before the restart command can be performed.

The Monitor Program has the ability to perform single-step operations. Each single step consists of executing a single Nios II machine instruction and then returning control to the Monitor Program. If the source code of the program being debugged is written in C, each individual single-step will still correspond to one assembly language (machine) instruction generated from the C code.

The single-step operation is invoked by selecting the Actions > Single step menu item or by clicking on the \bigcirc icon. The instruction that is executed by the processor is the one highlighted in the Disassembly window before the single step.

Since the first step in this section was to restart the program, the first single step will execute the instruction at address 0, which will set the upper bits of the Nios II register r15 to the value 0×1000 . Subsequent single steps will continue to execute one instruction at a time, in sequential order. Single stepping at a branch instruction may jump to a non-sequential instruction address if the branch is taken. This behavior can be observed by single stepping to the address $0 \times 0000004c$, which is a beq instruction. Single stepping at this instruction will set the *pc* value to $0 \times 0000005c$, which is the location of the instruction executed at this point in the *Getting Started* program when no pushbutton KEY is being pressed on the DE2-115 board.

Another way to perform the single-step operation is to use the Step Over Subroutine command in the Actions menu. This command performs a normal single step, unless the current instruction is a call instruction. In this case the program will run until the called subroutine is completed.

3.6 Using Breakpoints

An *instruction breakpoint* provides a means of stopping a Nios II program when it reaches a specific address. A simple procedure for setting an instruction breakpoint is:

- 1. In the Disassembly window, scroll to display the instruction address that will have the breakpoint. As an example, scroll to the instruction at the label *NO_BUTTON*, which is address 0x0000005c.
- 2. Click on the gray bar to the left of the address 0000005c in the Disassembly window. As illustrated in Figure 20 the Monitor Program displays a red dot next to the address to show that an instruction breakpoint has been set. Clicking the same location again removes the breakpoint.

🗢 Altera Monite	Altera Monitor Program [Nios II] - Monitor_Tutorial.ncf : getting_started.srec [Paused]								
<u>File S</u> ettings	<u>A</u> ctions <u>W</u> ind	ows <u>H</u> elp							
👱 🗈 🔒	ې 🔈 🖪	⊫ <u>0</u> 6 8	4 of						
Disassembly				_ :	< Registers	-	×		
Goto instruction	Address (hex)	or symbol name:	5c	Go Hide	Reg	Value			
					pc	0x0000000	-		
					zero	0x00000000			
					rl	0x00000000			
		NO_BUTTON:			r2	0x00000000			
		stwio	r6, 0(r20)	/* store to HEX3	r3	0x00000000			
		NO_BUTTON:			r4	0x00000180	335		
0x0000005c	a1800035	stwio	r6, 0(r20)		r5	0x00000000			
		stwio	r6, 0(r21)	/* store to HEX7 .	r6	0x0000000f	1919		
0x00000060	a9800035	stwio	r6, 0(r21)		r7	0x000170ed			
		roli	r6, r6, 1	/* rotate the display	r8	0x00000000			
0x00000064	300c107a	roli	r6, r6, 0x1		20 r9	0x00000000			
					r10	0x00000000			
		movia	r7. 100000	/* delaw counter */	rll	0x00000000			
0×00000068	01c000b4	orhi	r7 zero 0x2	, actar counser ,	r12	0x0000000			
0x0000006a	20-1-204	addi	x7 x7 -0x7960		r13	0x0000000			
0x00000000	J9614004	auur	17, 17, -007500		r14	0x0000000			
		DELAX.			r15	0x10000040			
		DELAY:			116	0x1000000			
		Subi	r/, r/, 1		- r1/	0x10000050			
4		DEL AV.				0x10000010			
Disassembly / Br	eakpoints / Me	mory / Watches	/ Trace /		r20	0x00000070	-		
Terminal				Info & Frrors			×		
			- ^						
JTAG UART lin	k establish	ed using cab	le "USB-Blaster	Source code loaded.					
[USB-0]", dev:	ice l, inst	ance OxOO		INFO: Program Trace not enabled, h	ecause trad	ce requires	1		
				Program stopped @ 0x00000070					
				BREAK: Program break @ 0x0000005c			200		
						•	Ť		
				Info & Errors / GDB Server /					

Figure 20. Setting an instruction breakpoint.

Once the instruction breakpoint has been set, run the program. The breakpoint will trigger when the pc register value equals $0 \times 0000005c$. Control then returns to the Monitor Program, and the Disassembly window highlights in a yellow color the instruction at the breakpoint. A corresponding message is shown in the lnfo & Errors pane.

Some versions of the Nios II processor support other types of breakpoints in addition to instruction breakpoints. Other types of breakpoints are described Appendix A of this document.

3.7 Examining and Changing Register Values

The **Registers** window on the right-hand side of the Monitor Program display shows the value of each register in the Nios II processor and allows the user to edit most of the register values. The number format of the register values can be changed by right-clicking in the **Registers** window, as illustrated in Figure 21.

Registe	rs _	×
Reg	Value	
pc	0x00000000	
zero	0x00000000	
rl	0x00000000	
r2	0x00000000	
r3	0x00000000	
r4	0x00000180	333
r5	0x00000000	
Bina	ry	
Octa	al	
⊻cu		
<u>D</u> eci	imal	
<u>D</u> eci	imal adecimal	
Deci <u>D</u> eci <u>Hex</u> Sign	imal adecimal ed representation	
Deci <u>D</u> eci <u>Hex</u> Sign r13	mal adecimal ed representation 0x00000000	
Deci Deci Sign r13 r14	mal adecimal ed representation 0x00000000 0x00000000	
Deci Deci Sign r13 r14 r15	mal adecimal ed representation 0x00000000 0x00000000 0x10000040	
Deci Deci Sign r13 r14 r15 r16	adecimal ed representation 0x00000000 0x10000040 0x10000040	
<u>D</u> eci <u>D</u> eci <u>Sign</u> r13 r14 r15 r16 r17	adecimal ed representation 0x00000000 0x0000000 0x10000040 0x10000000 0x10000050	
<u>D</u> eci <u>D</u> eci <u>Sign</u> r13 r14 r15 r16 r17 r18	adecimal ox00000000 0x00000000 0x10000040 0x10000040 0x10000000 0x10000050 0x10000010	
Deci Hex Sign r13 r14 r15 r16 r17 r18 r19	adecimal ed representation 0x00000000 0x10000040 0x10000000 0x10000000 0x10000000 0x10000000 0x10000000000	

Figure 21. Setting the number format for displaying register values.

Each time program execution is halted, the Monitor Program updates the register values and highlights any changes in red. The user can also edit the register values while the program is halted. Any edits made are visible to the Nios II processor when the program's execution is resumed.

As an example of editing a register value, first scroll the Disassembly window to the label DELAY, which is at address 0×00000070 . Set a breakpoint at address 0×00000074 and then run the program. After the breakpoint triggers and control returns to the Monitor Program, notice that there is a large value in register r7. This value is used as a counter in the delay loop. As indicated in Figure 22, double-click on the contents of register r7 and edit it to the value 1. Press Enter on the computer keyboard, or click away from the register value to apply the edit. Now, single-step the program to see that it exits from the delay loop after one more iteration, when r7 becomes 0.

		DELAY: subi DELAY:	r7, r7, 1		r4 r5 r6	0x00000107 0x00000000 0x00000078	10000
0x00000070	39ffffc4	addi	r7, r7, -0x1		r7	0x00000001	
		bne	r7, r0, DELAY		r8	0x00000000	
0x00000074	383ffele	bne	r7, zero, -0x8 (0x00000070: DELAY)		r9	0x00000000	
					r10	000000000000000000000000000000000000000	
					r11	0x00000000	
		br	DU_DISPLAY		r12	0x00000000	
0x00000078	003ff006	br	-0x40 (0x000003c: D0_DISPLAY)		r13	0x0000000	

Figure 22. Editing a register value.

3.8 Examining and Changing Memory Contents

The Memory window, depicted in Figure 23, displays the contents of the system's memory space and allows the user to edit memory values. The leftmost column in the window gives a memory address, and the numbers at the top of the window represent hexadecimal address offsets from that corresponding address. For example, referring to Figure 23, the address of the last word in the second row is $0 \times 00000010 + 0 \times c = 0 \times 0000001c$.

🥔 Altera Mor	nitor Progra	m [Nios II] - M	onitor_Tuto	rial.ncf : g	etting_started.srec	[Paused]				×
<u>File S</u> ettings	<u>A</u> ctions <u>W</u>	(indows <u>H</u> elp								
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Memory	Memory _ × Registers _ ×									
Goto memory	address Add	fress (hex):			io Ouerv All Devices	Refresh Memory	Hide	Reg	Value	
						<u> </u>		pc	0x000003c	
	+0x0	+0x4	+0x8	+Uxc	_		-	zero	0x00000000	
0x00000000	03640034	7601004	04040034	84000004				<u>11</u> 2	0x00000000	
0X00000010	04440034	86401404	04840034	94800404				r3	0x00000000	
0x00000020	05040034	a5000804	05440034	ad400c04				r4	0x00000000	
0x00000030	04000034	90001104	99800017	79000037				r5	0x000000000	
0x00000040	81000035	89400037	91400035	28000326				r6	0x0000001e	
0x00000050	200d883a	89400037	283ffele	a1800035				r7	0x00000000	
0x00000060	a9800035	300c107a	01c000b4	39e1a804				r8	0x00000000	
0x00000070	39ffffc4	383ffele	003ff006	0000000f			333	r9	0x00000000	
0x00000080	20000226	00000ec0	00000306	df401215				r10	0x00000000	
0x00000090	e8bfff17	003da03a	d9401117	df401217				rll	0x00000000	
0x000000a0	dfc00017	2801707a	d8400217	d8800317				r12	0x00000000	
0х000000b0	d8c00417	d9000517	d9400617	d9800717				r13	0x00000000	
0x000000c0	d9c00817	da000917	da400a17	da800b17				r14	0x0000000	
0x000000d0	dac00c17	db000d17	db400e17	db800f17				r15	0x10000040	
0x000000e0	dbc01017	dec01304	ef80083a	defffd04	l			r16	0x10000000	
0x000000f0	dfc00215	dc000115	dc400015	0009313a	ι		-	r17	0x10000050	
0-00000100	0.40000.4.4	04400074	94624404	0002000				r18	0x10000010	
Disasaakku	Duashasiaha		haa / Turra /					r19	0x0000007c	
Disassembly								r20	0x10000020	
Terminal				_ ×	Info & Errors				-	×
JTAG UART 1	ink establi	ished using (cable "USB-D	Blaster	Program stopped	0x00000070				
[USB-0]″, d	levice l, ir	nstance OxOO			BREAK: Program b	reak 🛛 0x00000	05c			
					BREAK: Program b	reak @ 0x00000	05c			
					BREAK: Program b	reak @ 0x00000	074			335
										-
					◀ 33333335				•	
					Info & Errors GDB S	ierver /				

Figure 23. The Memory window.

If a Nios II program is running, the data values displayed in the Memory window are not updated. When the program is stopped the data can be updated by pressing the Refresh Memory button. By default, the Memory window shows only the contents of memory devices, and does not display any values from memory-mapped I/O devices. To configure the window to display memory-mapped I/O, click on the check mark beside Query All Devices, and then click Refresh Memory.

The color of a memory word displayed depends on whether that memory location corresponds to an actual memory device, a memory-mapped I/O device, or is not mapped at all in the system. A memory location that corresponds to a memory device will be colored black, memory-mapped I/O is shown in a blue color, and a non-mapped address is shown in grey. If a memory location changed value since it was previously displayed, then that memory location is shown in a red color.

Similar to the Disassembly window, it is possible to view different memory regions by scrolling using the vertical scroll bar on the right, or by using a mouse scroll wheel. There is also a Goto memory address panel, which is analogous to the Goto instruction window discussed in section 3.4. Click to turn on the check mark beside Query All Devices in the memory window. In the Goto memory address panel type the address 0×10000000 , and then press Go. The display scrolls to the requested address, which corresponds to memory-mapped I/O devices in the DE2-115 Basic Computer. Click the Refresh Memory button. The data displayed in blue at address 0×10000040 corresponds to the settings of the 18 SW switches on the DE2-115 board. Experiment with different SW switch settings and press Refresh Memory to see that the switch values are properly displayed.

As an example of editing a memory value, double-click on the memory word at address 0x10000000 and type the hexadecimal data value 15555. Press Enter on the computer keyboard, or click away from the memory word to apply the edit. This memory-mapped address in the DE2-115 Basic Computer corresponds to the red lights LEDR on the DE2-115 board. Experiment by editing this memory location to different values and observe the LEDs.

It is possible to change the appearance of the Memory window in a number of ways, such as displaying data as bytes, half-words, or words, and so on. The Memory window provides additional features that are described in more detail in the Appendix A of this document.

4 Working with Project Files

Project files store the settings for a particular project, such as the specification of a hardware system and program source files. A project file, which has the filename extension *ncf*, is stored into a project's directory when the project is created.

The Monitor Program provides the following commands, under the File menu, for working with project files:

- 1. New Project: Presents a series of screens that are used to create a new project.
- 2. Open Project: Displays a dialog to select an existing project file and loads the project.
- 3. Open Recent Project: This command displays the five most recently-used project files, and allows these projects to be reopened.
- 4. Save Project: Saves the current project's settings. This command can be used to save a project's settings after they have been modified by using the Settings command, which is described below.

4.1 Modifying the Settings of an Existing Project

After a project has been created, it is possible to modify many of its settings, if needed. This can be done by clicking on the menu item Settings > System Settings in the Monitor Program, or the icon. This action will display the existing System Settings for the project, and allow them to be changed. Similarly, the program settings for the

project can be displayed or modified by using the command Settings > Program Settings, or the \square icon. To change these settings, the Monitor Program has to first be disconnected from the system being debugged. This can

be done by using the command Actions > Disconnect, or clicking the $\frac{1}{2}$ icon.

5 Using the Monitor Program with a Nios II Evaluation License

In our discussion of Figure 11, in section 3.1, we showed how the Monitor Program can be used to download a prebuilt Nios II hardware system onto an FPGA board, when the Nios II processor has a license. It is also possible to use the Monitor Program to debug hardware systems in which the Nios II processor includes only an evaluation license. In this case it is necessary to download the hardware system onto the FPGA board by using the *Programmer* tool provided in the Quartus II software, rather than using the Monitor Program for this purpose. The Quartus II Programmer tool provides a pop-up window, shown in Figure 24, that indicates activation of the evaluation license for the Nios II processor. This pop-up window has to remain open in order to maintain the evaluation license for Nios II. As long as the pop-up window remains open, the Monitor Program can be used to compile and download software programs into the hardware system.

OpenCore Plus Status							
Click Cancel to sto	stop using OpenCore Plus IP.						
Time remai	aining: unlimited						
	Cancel						
Time remai	aining: unlimited Cancel						

Figure 24. The Quartus II Programmer pop-up window.

6 Using the Terminal Window

This section of the tutorial demonstrates the functionality of the Monitor Program's *Terminal* window, which supports text-based input and output. For this example, create a new Monitor Program project for the DE2-115 board, called *Monitor_Terminal*. Store the project in a directory of your choice.

When creating the project, follow the same steps shown for the *Monitor_Tutorial* project, which were illustrated in Figures 5 to 10. For the screen shown in Figure 7 set the program type to Assembly Program, and select the sample program named *JTAG UART*. The source code file that will be displayed in the screen of Figure 8 is called *JTAG_UART*.s. It communicates using memory-mapped I/O with the *JTAG_UART* in the DE2-115 Basic Computer that is selected as the Terminal device in the screen of Figure 9.

Compile and load the program by following the procedure in section 3.2. Then, run the program using the steps in section 3.3. The Monitor Program window should appear as shown in Figure 25. Notice that the Terminal window displays a text prompt which is sent by the *JTAG_UART.s* program. Click the mouse inside the Terminal window. Now, any characters typed on the computer keyboard are sent by the Monitor Program to the JTAG UART. These characters are shown in the Terminal window as they are typed, because the *JTAG_UART.s* program echos the characters back to the Terminal window.

The Terminal window supports a subset of the control character commands used for a de facto standard terminal, called the *VT100*. The supported commands are listed in Table 2. In this table < ESC > represents the ASCII character with the code $0 \times 1B$.

🥔 Altera Monit	or Program [Nios II] - Monit	tor_Tutorial.ncf : J	TAG_UART.srec [I	Running]			
<u>File S</u> ettings	<u>A</u> ctions <u>W</u> ind	ows <u>H</u> elp						
u 🗈 🙃	🖌 🙈 🔿 I	⊫ 00 % .⊱	1 🖑					
Disassembly _ X Registers _ X								
Goto instruction	Address (bex)	or symbol name:	DELAY	60	Hide	Reg	Value	
	1.100.000 (1.0.1)					pc	0x00000000	
		.text			/* executable cod 🔺	zero	0x00000000	
		.global	_start			rl	0x00000000	
		_start:				r2	0x00000000	
		/* set	up stack pointer	*/		r3	0x00000000	
		movia	sp, 0x007FFFF0	. /* :	starts from largest	r4	0x00000000	
		_start:				r5	0x00000000	
0x00000000	06c02034	orhi	sp, zero, 0x80			r6	0x00000000	
0x00000004	deffff04	addi	sp, sp, -0x4			r7	0x00000000	
					1333	18 	0x00000000	
		movia	r6, 0x10001	LOOO ,	/* JTAG UART base a	19	0x00000000	
0x00000008	01840034	orhi	r6, zero, 0x1000)		r10	0x00000000	
0x0000000c	31840004	addi	r6, r6, 0x1000			r11 *12	0x00000000	
						r12	0x00000000	
		/* prin	t a text string *	*/		r14	0×00000000	
		movia	r8. TEXT ST	TRING		r15	0x00000000	
0x00000010	02000034	orhi	r8. zero. 0x0			r16	0×00000000	
0x00000014	42001a04	addi	r8. r8. 0x68			r17	0x00000000	
					•	r18	0x00000000	
•		33			•	r19	0x00000000	
Disassembly Br	reakpoints / Me	mory (Watches	(_Trace_/			r20	0x00000000	
Terminal			_ ×	Info & Errors			_ ×	
JTAG HART Lin	k establish	ed using cabl	e "HSB-Blaster	Verified OK			-	
UISB-01" deu	ice l inst	ence Ov00	ie one proport	Connection esta	ablished to GDB server	at local	Lhost:2399	
[020-0] , 420	100 1, 11130	ance oxoo		Symbols loaded.				
JTAC HADT ever	mple code			Source code los	aded.		00	
N N N N N N N N N N N N N N N N N N N	mpic code			INFO: Program 7	Frace not enabled, bec	ause trad	e requires 🚽	
-				4 3333333				
				John P. Envoya	B Server			
				Inro & Errors (GD	b server			

Figure 25. Using the Terminal window.

7 Using C Programs

C programs are used with the Monitor Program in a similar way as assembly language programs. To see an example of a C program, create a new Monitor Program project for the DE2-115 board, called *Monitor_Terminal_C*. Store the project in a directory of your choice. Use the same settings as for the *Monitor_Terminal* example, but set the program type for this project to C Program. Select the C sample program called *JTAG UART*. As illustrated in Figure 26 this sample program includes a C source file named *JTAG_UART.c*; it has identical functionality to the assembly language code used in the previous example. Compile and run the program to observe its behavior.

The C code in *JTAG_UART.c* uses memory-mapped I/O to communicate with the JTAG UART. Alternatively, it is possible to use functions from the standard C library *stdio.h*, such as *putchar*, *printf*, *getchar*, and *scanf* for this purpose. Using these library functions impacts the size of the Nios II executable code that is produced when the C program is compiled, by about 30 to 64 KBytes, depending on which functions are needed. It is possible to minimize the size of the code generated for this library by checking the box labeled Use small C library in Figure 26. When this option is used the library has reduced functionality. Some limitations of the small C library include: no floating-point support in the output routines, such as *printf*, and no support for input routines, such as *scanf* and *getchar*.

In Figure 26 the option Emulate unimplemented instructions is checked. This option causes the C compiler to

Character Sequence	Description
<esc>[2J</esc>	Erases everything in the Terminal window
<esc>[7h</esc>	Enable line wrap mode
<esc>[71</esc>	Disable line wrap mode
<esc>[#A</esc>	Move cursor up by # rows or by one row if # is not specified
<esc>[#B</esc>	Move cursor down by # rows or by one row if # is not specified
<esc>[#C</esc>	Move cursor right by # columns or by one column if # is not spec-
	ified
<esc>[#D</esc>	Move cursor left by # columns or by one column if # is not speci-
	fied
<esc>[#₁;#₂f</esc>	Move the cursor to row $\#_1$ and column $\#_2$
<esc>[H</esc>	Move the cursor to the home position (row 0 and column 0)
<esc>[s</esc>	Save the current cursor position
<esc>[u</esc>	Restore the cursor to the previously saved position
<esc>[7</esc>	Same as <esc>[s</esc>
<esc>[8</esc>	Same as <esc> [u</esc>
<esc>[K</esc>	Erase from current cursor position to the end of the line
<esc>[1K</esc>	Erase from current cursor position to the start of the line
<esc>[2K</esc>	Erase entire line
<esc>[J</esc>	Erase from current line to the bottom of the screen
<esc>[2J</esc>	Erase from current cursor position to the top of the screen
<esc>[6n</esc>	Queries the cursor position. A reply is sent back in the format
	$<$ ESC> [$#_1$; $#_2$ R, corresponding to row $#_1$ and column $#_2$.

Table 2. VT100 commands supported by the Terminal window.

include code for emulating any operations that are needed to execute the C program but which are not supported by the processor. For example, the Nios II Economy version does not include a *multiply* instruction, but the C program may need to perform this operation. By checking this option, a multiply instruction will be implemented in software (by using addition and shift operations).

8 Using the Monitor Program with Interrupts

The Monitor Program supports the use of interrupts in Nios II programs. Two examples of interrupts are illustrated below, using assembly-language code and using C code.

8.1 Interrupts with Assembly-Language Programs

To see an example using interrupts with assembly-language code, create a new Monitor Program project called *Monitor_Interrupts*. When creating the new project set the program type to assembly language and select the sample program named *Interrupt Example*. Figure 27 lists the source files for this sample program. The main program for the example is the file *interrupt_example.s*, which initializes some I/O devices and enables Nios II interrupts. The other source files provide the reset and exception handling for the program, and two interrupt service routines.

ource files First source file is used to a	etermine the name of the binary program fi	le.
D:\Monitor_Terminal_C\JT.	G_UART.c	Add Remove
rogram options		Up Down
t data da contra da contra		P
Additional compiler riags:	-01 -rrunction-sections -rverbose-asm -rnc)-inline
Additional linker flags:		
Use small C library	l ✓ Emu	ulate unimplemented instructions
urce files highlighted in blue	are sample program files, which will be crea	ted in the project directory.

Figure 26. Specifying settings for a C program.

Figure 28 shows the offset values for the *text* and *data* sections that should be used for this program. These offsets cannot be 0 because the reset vector of the Nios II processor in the system being used is at address 0×0 and the exception vector is at address 0×20 . Enough space has to be left between the exception vector and the text section of the program to accommodate the exceptions processing code, which corresponds to the assembly language code in the file *exception_handler.s*. The offset value 0×400 , as shown in the figure, is large enough to accommodate the exceptions code.

Compile and load the program. Then, scroll the Disassembly window to the label *EXCEPTION_HANDLER*, which is at address 0x0000020. This address corresponds to the exception vector address for the Nios II processor in the DE2-115 Basic Computer. As illustrated in Figure 29, set a breakpoint at this address. Run the program. When the breakpoint is reached, single step the program a few more instructions to determine the cause of the interrupt. The source of the interrupt is a device in the DE2-115 Basic Computer called the *interval timer*. This device provides the ability to generate an interrupt whenever a specific time period elapses. Single step the program until the Nios II processor enters the interrupt service routine for the interval timer. This routine first clears the timer register that caused the interrupt, so that it won't immediately occur again, and then performs other functions needed for the program.

Finally, remove the breakpoint that was set earlier, at address 0×0000020 , and then select the Continue command to run the program. Observe that the program displays a rotating pattern across the HEX displays on the DE2-115 board. The direction of rotation can be changed by pressing the pushbuttons KEY₁ or KEY₂ on the DE2-115 board,

New Project N	Wizard	1
Specify pro	gram details	
Source files		
First source file	is used to determine the name of the binary program file.	_
D:\Monitor_Pro D:\Monitor_Pro D:\Monitor_Pro D:\Monitor_Pro	gram_Tutorials\Monitor_Interrupts\interrupt_example.s Add gram_Tutorials\Monitor_Interrupts\exception_handler.s gram_Tutorials\Monitor_Interrupts\interval_timer.s gram_Tutorials\Monitor_Interrupts\pushbutton_ISR.s	
Program option	Up Down	
Start symbol:	start	
	the disc bios and some first subtrial will be supplied in the supplied disc. I	
Source riles highligi	iteo in blue are sample program riles, which will be created in the project directory.	
	< Back Next > Einish Car	ncel

Figure 27. The source files for the interrupt example.

and the pattern can be changed to correspond to the values of the SW switches by pressing KEY₃. Pressing KEY₀ causes a reset of the Nios II processor and returns control to the Monitor Program at the address 0×0 .

8.2 Interrupts with C Programs

To see an example of a C program that uses interrupts, create a new project called *Monitor_Interrupts_C*. When creating this project, set the program type to C Program and select the sample program named *Interrupt Example*; this program gives C code that performs the same operations as the assembly language code in the previous example. The source files for the C code are listed in Figure 30. The main program is given in the file *interrupt_example.c*, and the other source files provide the reset and exception handling for the C program, as well as two interrupt service routines. Complete the steps for creating the project, and then compile and load it.

Set a breakpoint at the address 0×00000020 , which is the exception vector address for the Nios II processor. Also, scroll the Disassembly window to the function called *interrupt_handler*. As illustrated in Figure 31, set another breakpoint at this address. Now, run the program to reach the first breakpoint, at address 0×00000020 . The code at this address, which is found in the file *exception_handler.c*, reads the contents of a control register in the Nios II processor to determine if the interrupt is caused by an external device, then saves registers on the stack, and then calls the *interrupt_handler* function.

Press Actions > Continue in the Monitor Program to reach the second breakpoint. Single stepping the program a

ocessor's reset and exce	tion vectors (read-only)	
Reset vector address (hex):	0	
exception vector address (he): 20	
emory options		
Here you can specify the star addresses can be in the same .text and .data sections do n specified to have the same ar	ting addresses of sections identified by .text and .dat or in different memories (on-chip, SDRAM,). They t overlap with other sections, such as .reset and .ex dress, the .data section will be placed right after the	a assembler directives. These can be used to ensure that the ceptions. If .text and .data are .text section by the linker.
.text section		
Memory device:	SDRAM/s1 (0h - 7fffffh)	-
Start offset in device (hex):		400
.data section		
Memory device:	SDRAM/s1 (0h - 7fffffh)	•
Start offset in device (hex):		400

Figure 28. Memory offset settings for the interrupt example.

few more instructions shows that the interrupt is caused by the interval timer in the DE2-115 Basic Computer, as discussed in the previous example. Additional single stepping causes the Nios II processor to enter the interrupt service routine for the interval timer, as depicted in Figure 32. This routine first clears the timer register that caused the interrupt, and then performs other functions needed for the program. Finally, clear both breakpoints that were set earlier, at address 0×00000020 and *interrupt_handler*, and then run the program; it displays a rotating pattern on the HEX displays of the DE2-115 board, as discussed in the previous example.

9 Using Device Drivers (Advanced)

Altera's development environment for Nios II programs provides a facility for using device driver functions for the I/O devices in a hardware system. This facility, which is called the *hardware abstraction layer* (HAL), is supported by the Monitor Program. Using device driver functions is not recommended for beginning students, and is intended for more advanced users.

To see an example of code that uses device driver functions create a project called *Monitor_HAL*. For this project select the prebuilt system named *DE2-115 Media Computer*; this is a hardware system that provides more features than the DE2-115 Basic Computer that was used in previous examples. Set the program type to Program with Device Driver Support, check Include a sample program with the project, and select the sample program named *Media_HAL*. The source file for this sample program is called *media_HAL.c*. When creating this project, the

🥔 Altera Monito	or Program [Nios II] - Moni	itor_Interrupts.ncf	: interrupt_example.srec [Paused]			×
<u>File S</u> ettings <u>A</u>	<u>A</u> ctions <u>W</u> ind	ows <u>H</u> elp						
👱 🗈 🔒 🚸	ی 🕲 🔒	⊫ III 0 ₆ ↓	x \$					
Disassembly					_ ×	Registers	-	×
Goto instruction	Address (hex)	or symbol name:	EXCEPTION_HANDLES	R <u>G</u> o	Hide	Reg	Value	
	1	EXCEPTION F	HANDLER:			pc zero	0x00000450	
0x00000020	defffc04	addi	sp. sp0x10			rl	0x00000000	
0x00000024	de000015	stw	et. 0(sp)			r2	0x00000000	
0x00000028	0031313a	rdct1	et ipending			r3	0x00000000	
0x0000002c	c0000126	beg	et. zero. 0x4 ((0x00000034: SKIP EA DEC)		r4	0x00000000	200
0x00000030	ef7fff04	addi	ea. ea0x4			r5	0x00000000	1000
			,,			r6	0x0000000	392
		SKTP EA DEG				r7	0x00000001	
0x0000034	df400115	stw	ea. 4(sn)		1000	r8	0x00000000	
0x00000038	dfc00215	stw	ra 8(sn)		333	r9	0x00000000	
0x0000003c	dd800315	stw	r_{22} , $12(sn)$			r10	0x00000000	
0x00000040	00313139	rdct1	et inending			r11	0x00000000	
0x00000048	c000011e	hne	et zero 0v4 ()	ANDODOOOAC: CHECK LEVEL O)		r12	0x00000019	
020000044	CODODIIC	Mile	CC, 2010, 0X4 (SX0000004c: CHECK_BEVEB_0)		r13	0x00000000	-
		MOT ET.				r14	0x00000000	-
0100000048	00000706	NOT_ET.	0110 (010000000	. FWT TOTA		r15	0x10000050	-
0X0000040	00000700	DL	OXIC (0X00000000	5: END_ISR)		r10 x17	0x10002000	
		CURCH INVEL			-	r19	0x00000000	
•					•	r19	0x00000000	
Disassembly / Bri	eakpoints / Me	mory / Watches	/ Trace /			r20	0x00000000	-
Terminal				Info & Errors				~
Terminar			- ^				-	â
JTAG UART link	<pre>« establish</pre>	ed using cab	le "USB-Blaster	Symbols loaded.				
[USB-0]", dev:	ice l, inst	ance OxOO		Source code loaded.				
				INFO: Program Trace not enabl	led, bea	cause trad	ce requires	
				BREAK: Program break @ 0x0000	0020			335
				. 0000000				•
								•
				Info & Errors / GDB Server /				

Figure 29. The interrupt handler.

New Project Wizard does not display the screen for choosing memory settings, such as the one in Figure 28. This is because the HAL automatically chooses the necessary memory settings for projects that make use of device drivers.

The *media_HAL* program communicates with I/O devices by making calls to device driver functions, rather than using memory-mapped I/O as has been done in previous examples in this tutorial. To see some examples of such function-calls, examine the source code in the file *media_HAL.c.* It calls device driver functions for the audio devices in the DE2-115 Media Computer, the 16 x 2 character display, the VGA output port, the PS/2 port, and parallel ports. The device driver functions for each of these devices are defined in *include files* that are specified at the top of the *media_HAL.c.* file. The set of device driver functions provided for an IP core is specified as part of the documentation for that IP core.

Compile and load the program by using the command Actions > Compile & Load. The Monitor Program automatically compiles both the *media_HAL.c* program and all device drivers that it uses. In subsequent compilations of the program, only the *media_HAL.c* code is compiled.

Run the program. It performs the following:

• Records audio for about 10 seconds when KEY[1] is pressed. LEDG[0] is lit while recording

ource files		
First source file is used to a	etermine the name of the binary program file.	
D:\Monitor_Program_Tuto D:\Monitor_Program_Tuto D:\Monitor_Program_Tuto D:\Monitor_Program_Tuto	ials\Monitor_Interrupts_C\interrupt_example.c ials\Monitor_Interrupts_C\exception_handler.c ials\Monitor_Interrupts_C\interval_timer_ISR.c ials\Monitor_Interrupts_C\pushbutton_ISR.c	Add Remove
ogram option s		Down
Additional compiler flags:	-01 -ffunction-sections -fverbose-asm -fno-inline	
Additional linker flags		
Use small C library	Emulate unimplemented	instructions
rce files highlighted in blue	are sample program files, which will be created in the project dir	ectory.

Figure 30. The source files for the C code interrupt example.

		void interrupt_handler(void)	
		{	
		interrupt_handler:	
0 x00000698	defffe04	addi sp, sp, -0x8	
0x0000069c	dfc00115	stw ra, 4(sp)	33
0x000006a0	dc000015	stw r16, 0(sp)	
		int ipending;	
		NIOS2_READ_IPENDING(ipending);	
0x000006a4	0021313a	rdctl r16, ipending	
		if (ipending & 0xl) // interval timer is interrupt level 0	
0x000006a8	8080004c	andi r2, r16, 0x1	
0x000006ac	10000126	beg r2, zero, 0x4 (0x0000664)	
		(
		<pre>interval_timer_isr();</pre>	
0x000006b0	00006400	call 0x000001b4 (0x000006d0: interval_timer_isr)	
		}	-

Figure 31. The interrupt handler.

- Plays the recorded audio when KEY[2] is pressed. LEDG[1] is lit while playing
- Draws a blue box on the VGA display, and places a text string inside the box
- Shows a text message on the 16 x 2 character LCD display
- Displays the last three bytes of data received from the PS/2 port on the HEX displays on the DE2-115 board



Figure 32. The interrupt service routine for the interval timer.

More details about developing programs with the Monitor Program that use HAL device drivers can be found in the tutorial *Using HAL Device Drivers with the Altera Monitor Program*, which is available on the University Program section of Altera's website. More information about HAL can be found in the *Nios II Software Developer's Handbook*.

10 Working with Windows and Tabs

It is possible to rearrange the Monitor Program workspace by moving, resizing, or closing the internal windows inside the main Monitor Program window.

To move a particular window to a different location, click on the window title or the tab associated with the window, and drag the mouse to the new location. As the mouse is moved across the main window, the dragged window will snap to different locations. To detach the dragged window from the main window, drag it beyond the boundaries of the main window. To re-attach a window to the main window, drag the tab associated with the window onto the main window.

To resize a window, hover the mouse over one of its borders, and then drag the mouse. Resizing a window that is attached to the main window will cause any adjacent attached windows to also change in size accordingly.

To hide or display a particular window, use the Windows menu. To revert to the default window arrangement, simply exit and then restart the Monitor Program. Figure 33 shows an example of a rearranged workspace.



Figure 33. The Altera Monitor Program with a Rearranged Workspace.

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11 Appendix A

This appendix describes a number of Monitor Program features that are useful for advanced debugging or other purposes.

11.1 Using the Breakpoints Window

In section 3.6 we introduced instruction breakpoints and showed how they can be set using the Disassembly window. Another way to set breakpoints is to use the *Breakpoints* window, which is depicted in Figure 34. This window supports three types of breakpoints in addition to the instruction breakpoint: *read watchpoint*, *write watchpoint*, and *access watchpoint*, described below:

- 1. Read watchpoint: the Nios II processor is halted when a read operation is performed on a specific address
- 2. Write watchpoint: the Nios II processor is halted when a write operation is performed on a specific address
- 3. Access watchpoint: the Nios II processor is halted when a read or write operation is performed on a specific address

Each of the above types of breakpoints requires the use of the *Standard* or *Fast* version of the Nios II processor. These breakpoint types are not available when using the Economy version of Nios II.

In Figure 34 an instruction breakpoint is shown for the address 0×0000684 . This corresponds to an address in the program *media_HAL.c*, which we discussed in section 9. This program uses the DE2-115 Media Computer, which includes the Standard version of the Nios II processor. In section 3.6 we showed how to create such an instruction breakpoint by using the Disassembly window. But we could alternatively have created this breakpoint by right-clicking in a grey box under the label Instruction breakpoint in Figure 34 and then selecting Add. A breakpoint can be deleted by unchecking the box beside its address.

Setting a read, write, or access watchpoint is done by right-clicking on the appropriate box in Figure 34 and specifying the desired address.

The Monitor Program also supports a type of breakpoint called a *conditional* breakpoint, which triggers only when a user-specified condition is met. This type of breakpoint is specified by double-clicking in the empty box *under* the label Condition in Figure 34 to open the dialog shown in Figure 35. The condition can be associated with an instruction breakpoint, or it can be a stand-alone condition if entered in the Run until box in the Breakpoints window. In this example the condition entered is $r_2 = 5$, and is associated with the instruction breakpoint. The condition causes the breakpoint to trigger only if the Nios II register r_2 contains the value 5. Note that if a stand-alone condition is entered in the Run until box, then the Run button associated with this box must be used to run the program, rather than the normal Actions > Continue command. The processor runs much more slowly than in its normal execution mode when a conditional breakpoint is being used.

11.2 Working with the Memory Window

The Memory window was shown in Figure 23. This window is configurable in a variety of ways:

Altera Monitor Program [Nios II] - Monitor_HAL.ncf : media_H	HAL.srec [Paused]			×
<u>Eile S</u> ettings <u>A</u> ctions <u>W</u> indows <u>H</u> elp	Altera Monit	or Program [Ni	os II] - Monitor_	HAI
		n		
Breakpoints	_ ×	Registers	-	×
 Instruction breakpoint: 		Reg	Value	
Address Instruction	Condition	pc	0x0000058c	-
✓ 0x0000058ccall 0x00000234 (0x000008d0: check KEYs)		zero	0x00000000	
- Read watchpoint:		rl	0x00000000	
- Read watchpoint.		r2	Oxffffffff	
Address		r3	UXIIIIIII	
– Write watchpoint:		r4	UXUU7EEE8	
Address		r5	0x00/fffbc	33
		10 x7	0x00/11100	
 Access watchpoint: 		17 78	0x000000740	
Address		r9	0x00000000	
– Rup until:		r10	0x000000081	
Condition		r11	0x00000088	
Dun		r12	0x00000001	
		r13	0x00000000	
		r14	0x00000000	
		r15	0x00000000	
		r16	0x0000687c	
		r17	0x00006834	
		r18	0x00000000	
Disassembly Breakpoints / Memory / Watches / Trace		r19	0x007fffc0	•
Terminal _ ×	Info & Errors		-	×
Opened character LCD device	INFO: Program Trace not enabled,	because ti	ace requir	
Opened character buffer device	BREAK: Program break @ 0x0000058c	:		
Opened pixel buffer device	BREAK: Program break @ 0x0000058c	:		
Opened PS2 device	BREAK: Program break @ 0x0000058c	:		
Opened audio device	BREAK: Program break @ 0x0000058c			335
Opened pushbutton KEY device				•
Opened green LEDs device			Þ	
	Info & Errors GDB Server			

Figure 34. The Breakpoints window.

- Memory element size: the display can format the memory contents as bytes, half-words (2-bytes), or words (4-bytes). This setting can be configured by right-clicking on the Memory window, as illustrated in Figure 36.
- Number of words per line: the number of words per line can be configured to make it easier to find memory addresses, as depicted in Figure 37.
- Number format: this is similar to the number format option in the Register window, described in the previous section, and can be configured by right-clicking on the Memory window.
- Display order: the Memory window can display addresses increasing from left-to-right or right-to-left.

11.2.1 Character Display

The Memory window can also be configured to interpret memory byte values as ASCII characters. This can be done by checking the Show equivalent ASCII characters menu item, accessible by right-clicking on the Memory window, as shown in Figure 38.

The right side of Figure 38 shows a sample ASCII character display. Usually, it is more convenient to view the memory in bytes and characters simultaneously so that the characters appear in the correct sequence. This can be



Figure 35. The Conditional breakpoint dialog.

0x00000000	View as	•	Byte (1-byte)
0x00000010			E/ (/)
0x00000020	Number of words per line		Half-word (2-bytes)
0x00000030	Number format	•	 <u>W</u>ord (4-bytes)
0x00000040	Display order)⊁ Ì	da400a15
0x00000050			db400e15
0x0000060	Switch to character mode		ebffff04
0x00000070	Show equivalent ASCII characters		10000326
0x00000080			df401215
0x00000090	Goto memory address		df401217
0x000000a0	Memory fill		d8800317
0x00000b0	Load file into memory		d9800717
0x000000c0	,,,		da800b17

Figure 36. Setting the memory element size.

accomplished by clicking the Switch to character mode menu item, which can be seen in Figure 38. A sample display in the character mode is shown in Figure 39.

It is possible to return to the previous memory view mode by right-clicking and selecting the Revert to previous mode menu item.

11.2.2 Memory Fill

Memory fills can be performed in the Memory window. Click the Actions > Memory fill menu item or right-click on the Memory window and select Memory fill. A Memory fill panel will appear on the left-side of the Memory window. Simply fill in the desired values and click Fill.

0x00000000	View as	00bffd16
0x00000010	Number of months and the	
0x00000020	Mumber or words per line	Ŧ
0x0000030	Number format	2
0x00000040	Display order	• <u>4</u>
0x0000050	Switch to character mode	8
0x00000060		16
0x00000070	Show equivalent ASCII characters	32
0x00000080		<u>0</u> 2
0x00000090	Goto memory address	64
0x000000a0	Memory fill	Auto
0x000000b0	Load file into memory	13000111
0x000000c0		da800b17

Figure 37. Setting the number of words per line.

0x00000000	·····	-18	bf	10	16		: H D D				
0x00000010	View as	8	00	08	00	4000	0 V 0 0	:	h		
0x00000020	Number of words per line	12	40	d8	15					0 0	
0x00000030	Number format	6	40	d9	15					0 🗆	
0x00000040	Display order	9	00	da	15		z 0 🗆 🗆				
0x00000050		- d	00	db	15						
0x00000060	Switch to character mode	.1	40	d9	04					0 🗆	
0x00000070	. A Show equivalent ASCII characters	- 10	80	28	26		:1 0	L		Ο (
0x0000080	 Drow equivalent ASCII characters 	3	00	00	15	6 D D					
0x00000090	Goto memory address	.1	40	d9	17		: 🗆 = 🗆			0 🗆	
0x000000a0	Memory fill	12	40	d8	17		zp🗆 (0 🗆	
0х000000b0	Land file into moments	6	40	d9	17					0 🗆	
0x000000c0	Load the incomemory	_la	40	da	17		0 0 0			0 0	

Figure 38. Checking the Show equivalent ASCII characters menu item.

11.2.3 Load File Data into Memory

Data stored in a file can be loaded into the memory by using the Memory window. This feature is accessed by selecting the command Actions > Load file into memory or by right-clicking on the Memory window. The Load file panel will appear on the left side of the Memory window, as illustrated in Figure 40, to allow the user to browse and select a data file. The user provides a base address in memory where the data should be stored.

The format of these files is illustrated in Figure 41. The file consists of any number of lines, where each line comprises a comma-separated list of data values. Each data value is expressed as a hexidecimal number with an optional - sign. Two additional parameters can be specified: the value of the delimiter character (comma is the default), and size in bytes of each data value (1 is the default).

11.3 Setting a Watch Expression

Watch expressions provide a convenient means of keeping track of the value of multiple expressions of interest. These expressions are re-evaluated each time program execution is stopped. To add a watch expression:

- 1. Switch to the Watches window.
- 2. Right-click on the gray bar, as illustrated in Figure 42, and click Add.
- 3. The Edit Watch Expression window will appear, as shown in Figure 43. The desired watch expression can then

Memory																- ×
Goto memory	addres	s A	ddres	s (hex)	:							<u>G</u> o 🗌 O	Juery All Devices	Refresh M	lemory	Hide
	+0x0			+0:	κ4			+0>	(8			+0x	+0x0			
0x00020000	61 62	63	64	65	66	67	68	69	6a	6b	6c	6d	abcd	efgh	i j	k 1
0x00020010	71 72	73	74	75	76	77	78	79	7a	7b	7c	7d	qrst	uvwx	уz	(-)
0x00020020	c9 7f	fe	cf	e5	de	19	ec	a3	d9	fe	7£	bd				
0x00020030	32 75	ed	b4	7b	fd	59	69	bb	88	bb	b5	72	2 u 🛛 🖓	{ 🛛 Y i		
0x00020040	ff ac	c3	ff	£5	62	fc	fe	- 77	9e	67	72	de		□ b #: □	w 🗆	g r
0x00020050	fl f3	a3	7b	9e	8b	bЗ	74	ab	b7	b9	5£	Зf	000{	0 0 0 t		
0x00020060	ce 9d	3f	ad	ff	ed	9f	fe	7f	dd	e8	e6	le	0020			
0x00020070	3d le	£5	fd	70	£5	3b	19	96	ce	23	bf	ad	= 🗆 🗆 🗆	p 🛛 ; 🗆		# 0
0x00020080	b5 db	f8	c4	c3	4e	с9	fd	99	99	fd	fe	fa				o o <mark>***</mark>
0x00020090	ab be	bl	9c	73	7f	Зb	ff	b7	7b	bd	ff	bf		s 🛛 ; 🗆	□ {	
0x000200a0	c4 fd	72	8b	£7	dl	60	7b	£9	fb	e7	£9	Зa	00r0	00`{		
0x000200b0	3c 36	e0	71	74	2f	07	93	ff	bf	ff	72	Зf	< 6 🛛 q	t/00		🛛 r
0x000200c0	c4 7e	f6	41	fc	bd	6d	ef	a5	df	d2	a5	£5	0 ~ 0 A	#:0 m 0		
0x000200d0	3c 77	bb	db	31	bb	d6	34	fl	bl	9a	3e	fb	< ឃ 🗆 🗆	1004		□ >
0x000200e0	a7 ff	le	dd	df	9e	ed	7d	£9	de	e7	fc	ff				
0x000200f0	be 9f	fd	bf	bf	7b	33	53	bf	bb	dd	3f	73		0 { 3 5		2
0x00020100	db 4a	df	7d	58	ae	eb	af	lf	£7	ef	ff	5c	O J O }	X D D D		• • 🗸
4																
Disassembly /	Breakpo	ints	Me	mory	Wa	tche	s_(Trace	/							

Figure 39. Character mode display.

Memory							_ ×	
Goto memory addr	ess Address	s (hex):			Query All Devices	Refresh Memory	/ Hide	
1 J Cl-	Hide		+0x0	+0x4	+0x8	+0xc	-	
Load file	1100	0x000103f0	073f5fb9	bdeb6cfb	7ab699be	fffffef2		
Select a file:	Browse	0x00010400	4b2c8980	046ac2f8	a2108e20	2402c680		
		0x00010410	12210426	15816099	adc96558	205c43df		
		0x00010420	0d546fc0	840854e4	69fc4922	00b206ad		
File type:		0x00010430	346d0032	28198071	90ab009b	a8501112		
Start address (bex):		0x00010440	fe00a8bl	e28062a4	42600851	0c3a808c		
(). L		0x00010450	70032100	04b1830e	50a1870b	le698228		
	Load	0x00010460	0c0e918e	229a2cd0	4640d049	0e25091c	1000	
		0x00010470	£5340e3d	091a9500	3920c206	74642829	200	
		0x00010480	c0f09124	b1c00a82	eef90181	8e606198		
		0x00010490	98200081	0b386d10	3fb53101	4eb905b2		
		0x000104a0	0b2044c4	6b60d075	998009b9	308c2f18		
		0x000104b0	31e0322c	83052a14	323eOale	19b02b34		
		0x000104c0	40d46604	4c649cfc	2452cd24	405066e5		
		0x000104d0	d1b0271c	04840all	36983051	203119d3		
		0x000104e0	d9045924	7468949f	dce7lef8	cla656f5		
		0x000104f0	ba3c9e36	53105993	3a45aa2d	99643150	-	
4							•	
Disassembly / Breakpoints / Memory / Watches / Trace /								

Figure 40. The Load file panel.

be entered, using the syntax indicated in the window. In the figure, the expression mem32 (sp) is entered, which will display the value of the data word at the current stack pointer address.

4. Click Ok. The watch expression and its current value will appear in the table. The number format of a value displayed in the watch expression window can be changed by right-clicking on the row for that value. As the program being debugged is repeatedly run, the watch expression will be re-evaluated each time and its value will be shown in the table of watch values.



Figure 41. A Delimited hexadecimal value file.

Watches –					
Add	Expression	Value			

Figure 42. The Watches window.



Figure 43. The Edit Watch Expression window.

11.4 The GDB Server Panel (Advanced)

To see this panel, select the GDB Server panel of the Monitor Program. This window will display the low level commands being sent to the GDB Server, used to interact with the Nios II system being used. It will also show the responses that GDB sends back. The Monitor Program provides the option of typing GDB commands and sending them to the debugger. Consult online resources for the GDB program to learn what commands are available.

11.5 Running Multiple Instances of the Monitor Program (Advanced)

In some cases, it may be useful to run more than one instance of the Monitor Program on the same computer. For example, the selected system may contain more than one Nios II processor. An instance of the Monitor Program is required to run and debug programs on each available processor. As described in Section 3.1, it is possible to select a particular processor in a system via the **Processor** drop-down list in the *New Project Wizard* and *Project Settings* windows.

The Monitor Program uses *GDB Server* to interact with the Nios II hardware system, and connects to the GDB Server using TCP ports. By default, the Monitor Program uses port 2399 as the base port, and to connect to each processor in a system, the Monitor Program will attempt to use a port located at a fixed offset from this base port. For example, a single system consisting of 4 processors corresponds to ports 2399-2402.

However, the Monitor Program does not detect any ports that may already be in use by other applications. If the Monitor Program fails to connect to the GDB Server due to a port conflict, then the base port number can be changed by creating an environment variable called ALTERA_MONITOR_DEBUGGER_BASE_PORT and specifying a different number.

It is also possible to have more than one board connected to the host computer. As described in Section 3.1, a particular board can be selected via the Host connection drop-down list in the *New Project Wizard* and *Project Settings* windows. In this case, a separate instance of the Monitor Program is needed to interact with each processor on each physical board. By default, the Monitor Program assumes a maximum of 10 Nios II processors per board. This means that ports 2399-2408 are used by the Monitor Program for the first board connected to the computer, and the first processor on the second board will use port 2409.

It is possible to specify a different value for the maximum number of processors per Nios II hardware system by creating an environment variable called ALTERA_MONITOR_DEBUGGER_MAX_PORTS_PER_CABLE and specifying a different number. This is useful if a system contains more than 10 Nios II processors. It is also useful if a port conflict exists and none of the systems contain 10 or more processors. In this case, decreasing this number (in conjunction with changing the base port number) may provide a solution.

11.6 Examining the Instruction Trace (Advanced)

An instruction trace is a hardware-level mechanism to record a log of all recently executed instructions. The *Nios II JTAG Debug Module* has the instruction trace capability, but only if a Level 3 or higher debugging level is selected in the *SOPC Builder* or *Qsys* configuration of the JTAG Debug Module (See the *Nios II Processor Reference Handbook,* available from Altera, for more information about the configuration settings of the JTAG Debug Module). If the required JTAG Debug Module is not present, a message will be shown in the Info & Errors window of the Monitor Program after loading a program, to indicate that instruction trace is not available.

The *Trace* feature is automatically enabled if the required JTAG Debug Module is available. To view the instruction trace of a program, go to the *Trace* window after pausing the program during execution. As shown in Figure 44, the instructions are grouped into different colored blocks and labeled alphabetically. The number of times each instruction block is executed is shown beneath its alphabetical label.

				X
		CONTINUE		
0x000004c8	stw	r15, 0(r16)		
0x000004cc	ldw	r14, 0(r16)	E	
0x000004d0	bne	r14, r15, 0x80 (0x00000554: SHOW_ERROR)		
0x000004d4	addi	r16, r16, 0x4	F	
0x000004d8	bge	r17, r16, -0x28 (0x000004b4: MEM_L00P)	F	
	MEM_LOOP:		c	
0x000004b4	beq	et, zero, 0x4 (0x000004bc: SKIP_NOP)	G	
0x000004b8	add	zero, zero, zero	н	
0x000004bc	call	Ox0000015e (0x00000578: UPDATE_HEX_DISPLAY)	п	
	UPDATE_HEX	_DISPLAY:		
0x00000578	addi	sp, sp, -0x24		
0x0000057c	stw	ra, O(sp)		
0x00000580	stw	fp, 4(sp)		
0x00000584	stw	r15, 8(sp)		
0x00000588	stw	r16, 12(sp)		D
0x0000058c	stw	r17, 16(sp)		
0x00000590	stw	r18, 20(sp)		
0x00000594	stw	r19, 24(sp)		
0x00000598	stw	r20, 28(sp)	I	
0x0000059c	stw	r21, 32(sp)		
0x000005a0	addi	fp, sp, 0x24		
0x000005a4	orhi	r15, zero, OxO		
0x000005a8	addi	r15, r15, 0xaa4		
0x000005ac	ldw	r16, 4(r15)		
0x000005b0	orhi	rl7, zero, 0x0		
0x000005b4	addi	r17, r17, 0x7		
0x000005b8	orhi	r15, zero, 0x0		

Figure 44. The Trace window.

Right-clicking anywhere in the *Trace* window brings up several options, as shown in Figure 45. The *Trace* feature can be turned on or off by selecting the Enable trace or Disable trace options. It is also possible to toggle the *debug events* in the trace on or off by selecting Show debug events, or clear current trace sequences by selecting Clear trace sequences.

บพ	rp, ч(sp)
tw	r15, 8(sp)
tw	r16, 12(sp)
tw	r17, 16(sp)
tw	r18, 20(sp)
tw	r19, 24(an)
tw	r20, ✓ Show debug events
tw	r21, Disable trace ^W
ddi	fp, s
rhi	r15, <u>Clear trace sequences</u>
ddi	r15, r15, 0xaa4
dw	r16, 4(r15)
rhi	r17, zero, OxO
ddi	r17, r17, 0x7

Figure 45. Right-click options in the Trace window.

Running the program using the Actions > Continue or Actions > Single Step commands will show up in the trace sequence as *debug events* after each time the program pauses execution, as shown in Figure 46.

Trace							-
	0x000006f4	andhi	r18, r17, 0xffff	р	м	в	Q
	0x000006f8 beg r18, zero, 0x24 (0x00000720: N0_CHAR)						(21
NO_CHAR:							
0x00000720 ldw ra, 0 (sp)							
	0x00000724	ldw	fp, 4(sp)				AF
	0x00000728	ldw	r15, 8(sp)				
	0x0000072c	ldw	r16, 12(sp)				
			FORCED HALT				
			SINGLE-STEP				
	0x00000730	ldw	r17, 16(sp)				AG
			SINGLE-STEP				
	0x00000734	ldw	r18, 20(sp)				AH
			SINGLE-STEP				
0x00000738 1dw r19, 24(sp)						AI	
			SINGLE-STEP				
	0x0000073c	addi	sp, sp, Oxlc				AJ
			SINGLE-STEP				
	0x00000740	ret					AK
			CONTINUE				
	0x000004c8	stw	r15, 0(r16)				
	0x000004cc	ldw	r14, 0(r16)		D		
	0x000004d0	bne	r14, r15, 0x80 (0x00000554: SHOW_ERROR)				
	0x000004d4	addi	r16, r16, 0x4		F		
	0x000004d8 bge r17, r16, -0x28 (0x000004b4: MEM_L00P)			£			
		MEM_LOOP:			F	С	в
	0x000004b4 beg et, zero, 0x4 (0x000004bc: SKIP_NOP)			г			
	0x000004b8 add zero, zero				c i		
0x000004bc call 0x0000015e (0x00000578: UPDATE_HEX_DISPLAY)					G		
	UPDATE_HEX_DISPLAY:						
	0x00000578	ibbe	sn = nv24				

Figure 46. The *Trace* window with various debug events.

If the pc value is changed before the program continues to run, the Monitor Program will insert a gap sequence in the trace, as shown in Figure 47. The Actions > Restart command will set the pc value back to the initial starting address. The pc value can also be arbitrarily set by double clicking its value in the Registers window and editing its hexadecimal value.

Í.	0X00000500	SUW	L1/, 10(SP)						
	0x00000590	stw	r18, 20(sp)						
	FORCED HALT								
\otimes									
				CONTINUE					
	0x000004c8	stw	r15, 0(r16)						
	0x000004cc	ldw	r14, 0(r16)		D				
	0x000004d0	bne	r14, r15, 0x80 (0x00000554: SH	5HOW_ERROR)					
	0x000004d4	addi	r16, r16, 0x4		T				
	0v00000448	hae	r17 r16 -0v28 (0v00000464+ M	MEM LOOPI					

Figure 47. A gap sequence in the instruction trace.

Breakpoints in the program will also show up in the trace sequence as a *debug event* each time the breakpoint condition is met, as illustrated in Figure 48.

	_start:				
0x00000400	orhi	sp, zero, 0x80			BW
0x00000404	addi	sp, sp, -0x4			
			BREAKPOINT		
			SINGLE-STEP		
0x00000408	add	fp, sp, zero			BX
			CONTINUE		
0x000004c8	stw	r15, 0(r16)			
0x000004cc	ldw	r14, 0(r16)		В	
0x0000040	hne	r14, r15, 0x80	(0x00000554: SHOW ERROR)		



11.6.1 Note About Tracing Interrupt Sequences

It is possible that interrupt sequences are happening in the program, yet do not show up in the **Trace** window in the Monitor Program. This is because the instruction blocks shown in the trace sequence are actually sampled from a window of time over the entire program execution. As a result, the interrupt sequences may not be included in the sample of instruction blocks displayed in the Monitor Program. One way to deal with this problem is to trigger a breakpoint after an interrupt finishes executing.

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