

1 Introduction

This document describes a computer system that can be implemented on the Intel® DE0-Nano development and education board. This system, called the *DE0-Nano Computer*, is intended for use in experiments on computer organization and embedded systems.

To support these beginning experiments, the system contains a processor, memory, an analog-to-digital converter, an accelerometer and some simple I/O peripherals. The FPGA programming file that implements this system, as well as its design source files, can be obtained from the University Program section of Intel's web site.

2 DE0-Nano Computer Contents

A block diagram of the DE0-Nano Computer is shown in Figure 1. Its main components include the Intel Nios® II processor, memory for program and data storage, parallel ports connected to switches and lights, and a timer module. Additionally, the DE0-Nano Computer supports the onboard analog-to-digital converter and the accelerometer. As shown in the figure, the processor and its interfaces to I/O devices are implemented inside the Cyclone® IV FPGA chip on the DE0-Nano board. Each of the components shown in Figure 1 is described below.

2.1 Nios® II Processor

The Intel Nios II processor is a 32-bit CPU that can be implemented in an Intel FPGA device. Two versions of the Nios II processor are available, designated economy (/e) and fast (/f). The DE0-Nano Computer includes two instances of the Nios II/f version, configured with floating-point hardware support.

An overview of the Nios II processor can be found in the document *Introduction to the Intel Nios II Processor*, which is provided in the University Program's web site. An easy way to begin working with the DE0-Nano Computer and the Nios II processor is to make use of a utility called the *Intel® FPGA Monitor Program*. It provides an easy way to assemble/compile Nios II programs written in either assembly language or the C language. The Monitor Program, which can be downloaded from Intel's web site, is an application program that runs on the host computer connected to the DE0-Nano board. The Monitor Program can be used to control the execution of code on Nios II, list (and edit) the contents of processor registers, display/edit the contents of memory on the DE0-Nano board, and similar operations. The Monitor Program includes the DE0-Nano Computer as a predesigned system that can be downloaded onto the DE0-Nano board, as well as several sample programs in assembly language and C that show how to use the DE0-Nano Computer's peripherals. Some images that show how the DE0-Nano Computer is integrated with the Monitor Program are described in Section 7. An overview of the Monitor Program is available in the document *Intel® FPGA Monitor Program Tutorial*, which is provided in the University Program web site.

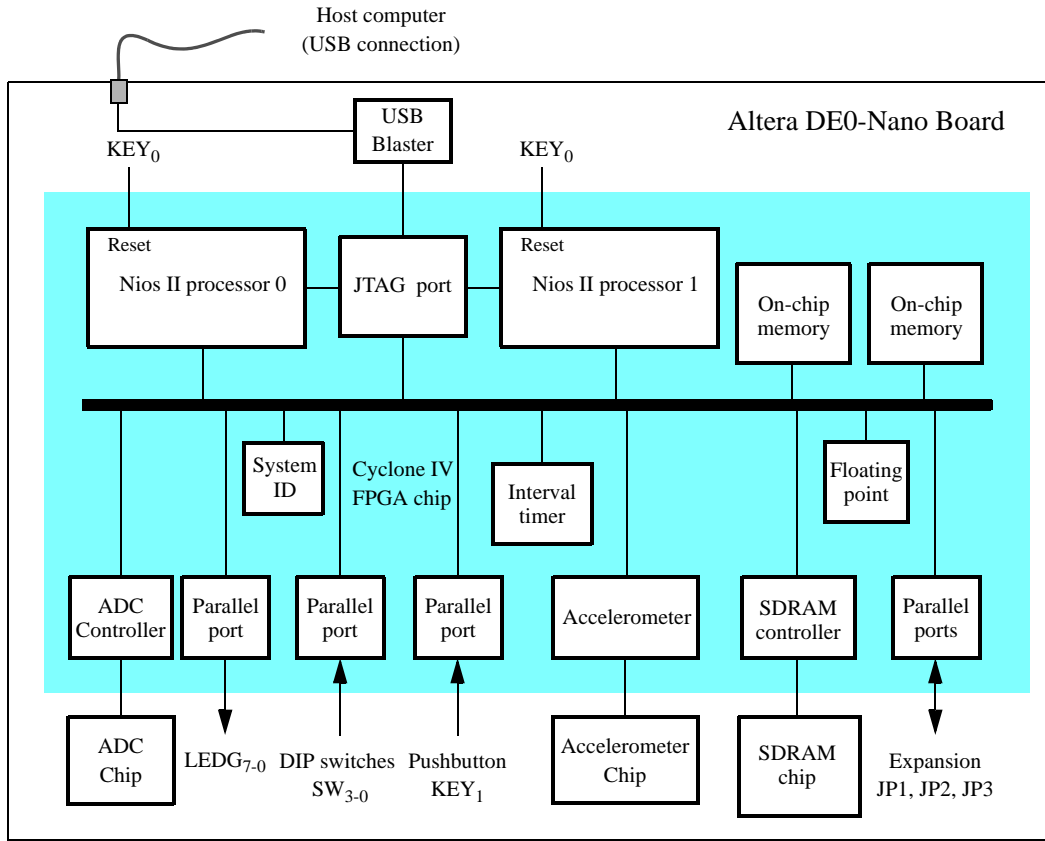


Figure 1. Block diagram of the DE0-Nano Computer.

All of the I/O peripherals in the DE0-Nano Computer are accessible by the processor as memory mapped devices, using the address ranges that are given in the following subsections.

2.2 Memory Components

The DE0-Nano Computer has two types of memory components: SDRAM and on-chip memory inside the FPGA chip. Each type of memory is described below.

2.2.1 SDRAM

An SDRAM Controller provides a 32-bit interface to the synchronous dynamic RAM (SDRAM) chip on the DE0-Nano board. This SDRAM chip is organized as 16M x 16 bits, but is accessible by the Nios II processor using word (32-bit), halfword (16-bit), or byte operations. The SDRAM memory is mapped to the address space 0x00000000 to 0x01FFFFFF.

2.2.2 On-Chip Memory

The DE0-Nano Computer includes an 8-Kbyte memory that is implemented in the Cyclone® IV FPGA chip. This memory is organized as 2K x 32 bits, and can be accessed using either word, halfword, or byte operations. The memory spans addresses in the range 0x08000000 to 0x08001FFF.

The DE0-Nano Computer includes a second 8-Kbyte memory implemented in the Cyclone® IV FPGA chip. This memory is also organized as 2K x 32 bits, and can be accessed using either word, halfword, or byte operations. It spans addresses in the range 0x09000000 to 0x09001FFF.

2.3 Parallel Ports

There are several parallel ports implemented in the FPGA that support input, output, and bidirectional transfers of data between the Nios II processor and I/O peripherals. As illustrated in Figure 2, each parallel port is assigned a *Base* address and contains up to four 32-bit registers. Ports that have output capability include a writable *Data* register, and ports with input capability have a readable *Data* register. Bidirectional parallel ports also include a *Direction* register that has the same bit-width as the *Data* register. Each bit in the *Data* register can be configured as an input by setting the corresponding bit in the *Direction* register to 0, or as an output by setting this bit position to 1. The *Direction* register is assigned the address *Base* + 4.

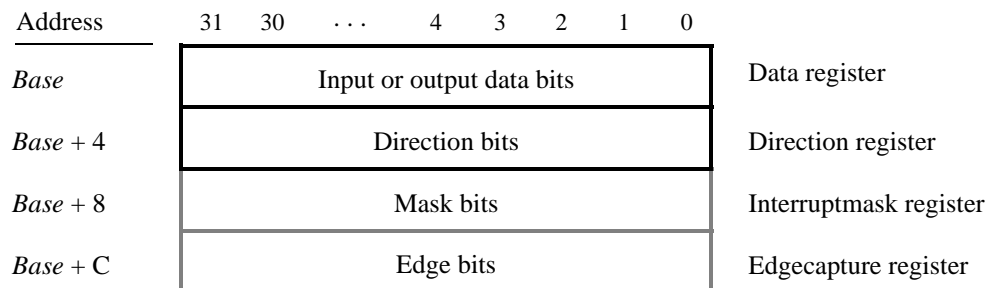


Figure 2. Parallel port registers in the DE0-Nano Computer.

Some of the parallel ports in the DE0-Nano Computer have registers at addresses *Base* + 8 and *Base* + C, as indicated in Figure 2. These registers are discussed in Section 3.

2.3.1 Green LED Parallel Port

The green lights LED_{7-0} on the DE0-Nano board are driven by an output parallel port, as illustrated in Figure 3. The port contains an 8-bit *Data* register, which has the address 0xFF200000. This register can be written or read by the processor using word accesses, and the upper bits not used in the registers are ignored.

2.3.2 DIP Switch Parallel Port

The SW_{3-0} DIP switches on the DE0-Nano board are connected to an input parallel port. As illustrated in Figure 4, this port comprises a 4-bit read-only *Data* register, which is mapped to address 0xFF200040.

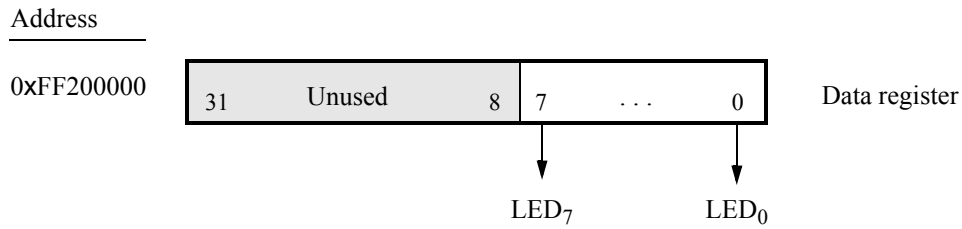


Figure 3. Output parallel port for LED.

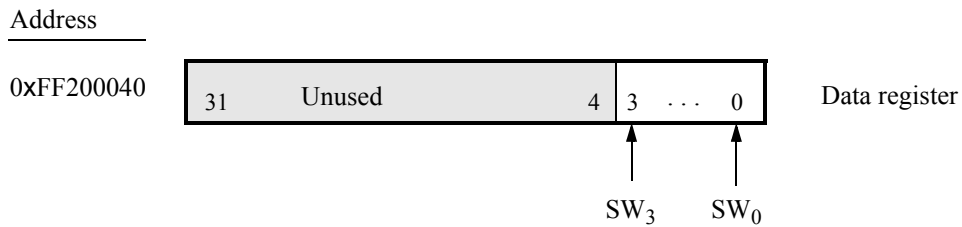


Figure 4. Data register in the DIP switch parallel port.

2.3.3 Pushbutton Key Parallel Port

The parallel port connected to the KEY_{1-0} pushbutton switches on the DE0-Nano board comprises three 2-bit registers, as shown in Figure 5. These registers have the base address 0xFF200050 and can be accessed using word operations. The read-only *Data* register provides the values of the switches KEY_{1-0} . The other two registers shown in Figure 5, at addresses 0xFF200058 and 0xFF20005C, are discussed in Section 3.

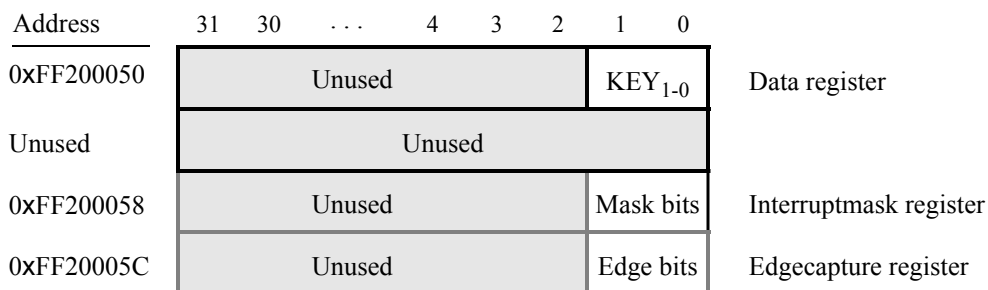


Figure 5. Registers used in the pushbutton parallel port.

2.3.4 Expansion Parallel Port

The DE0-Nano Computer includes two bidirectional parallel ports that are connected to the *JP1* and *JP2* 40-pin headers on the DE0-Nano board. These parallel ports include the four 32-bit registers that were described previously

for Figure 2. The base address of the port for JP1 is 0xFF200060, and for JP2 is 0xFF200070. Figure 6 gives a diagram of the 40-pin connectors on the DE0-Nano board, and shows how the respective parallel port *Data* register bits, D_{31-0} , are assigned to the pins on the connector. The figure shows that bit D_0 of the parallel port is assigned to the pin at the top right corner of the connector, bit D_1 is assigned below this, and so on. Note that some of the pins on the 40-pin header are not usable as input/output connections, and are therefore not used by the parallel ports. Also, only 32 of the 36 data pins that appear on each connector can be used.

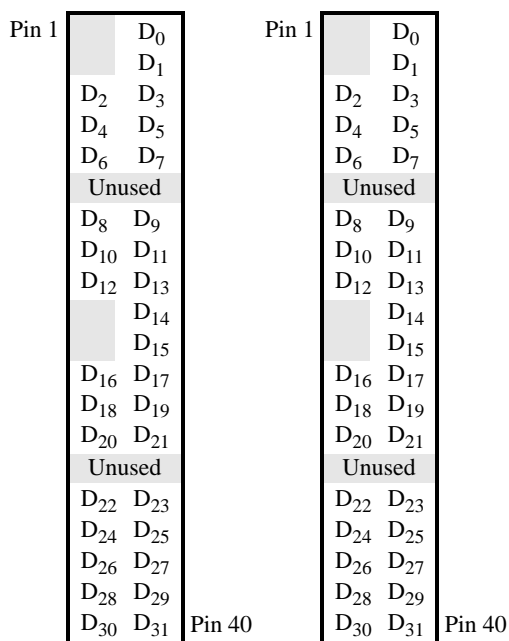


Figure 6. Assignment of parallel port bits to pins on *JP1* and *JP2*.

2.3.5 Expansion Parallel Ports JP3

The DE0-Nano Computer includes two parallel ports that are connected to the *JP3* expansion header on the DE0-Nano board. One of these parallel ports provides 13 bidirectional connections, and the other port provides three input-only connections. Each of the parallel ports includes the four 32-bit registers that were described previously for Figure 2. The base address of the 13-bit bidirectional port connected to *JP3* is 0xFF200080 and the base address of the input-only port is 0xFF200090. Figure 7 gives a diagram of the *JP3* expansion connector on the DE0-Nano board, and shows how both the bidirectional and input-only parallel ports are connected. The figure shows that bits D_0 to D_{12} of the bidirectional parallel port are assigned to pins 5 to 17 of the *JP3* connector. Bits IN_0 to IN_2 of the input-only parallel port are assigned to pins 2 to 4 of the connector.

2.3.6 Using the Parallel Ports with Assembly Language Code and C Code

The DE0-Nano Computer provides a convenient platform for experimenting with Nios II assembly language code, or C code. A simple example of such code is provided in the Appendix in Listings 1 and 2. Both programs perform the same operations, and illustrate the use of parallel ports by using either assembly language or C code.

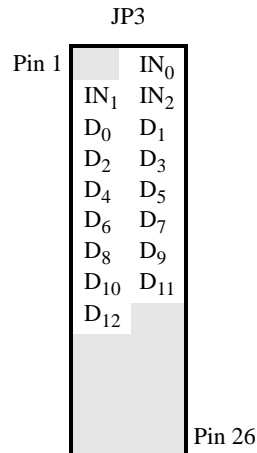


Figure 7. Assignment of parallel port bits to pins on *JP3*.

The code in the figures displays the values of the SW switches on the LED lights. A rotating pattern is displayed on the LEDs. This pattern is rotated to the left by using a Nios II *rotate* instruction, and a delay loop is used to make the shifting slow enough to observe. The pattern can be changed to the values of the SW switches by pressing a pushbutton KEY. When a pushbutton key is pressed, the program waits in a loop until the key is released.

The source code files shown in Listings 1 and 2 are distributed as part of the Intel® FPGA Monitor Program. The files can be found under the heading *sample programs*, and are identified by the name *Getting Started*.

2.4 JTAG* Port

The JTAG* port implements a communication link between the DE0-Nano board and its host computer. This link can be used by the Intel Quartus® Prime software to transfer FPGA programming files into the DE0-Nano board, and by the Intel® FPGA Monitor Program, discussed in Section 7. The JTAG port also includes a UART, which can be used to transfer character data between the host computer and programs that are executing on the Nios II processor. If the Intel® FPGA Monitor Program is used on the host computer, then this character data is sent and received through its *Terminal Window*. The programming interface of the JTAG UART consists of two 32-bit registers, as shown in Figure 8. The register mapped to address 0xFF201000 is called the *Data* register and the register mapped to address 0xFF201004 is called the *Control* register.

Address	31	...	16	15	14	...	11	10	9	8	7	...	1	0	
0xFF201000	RAVAIL			RVALID		Unused				DATA				Data register	
0xFF201004	WSPACE			Unused				AC	WI	RI	WE		RE	Control register	

Figure 8. JTAG UART registers.

When character data from the host computer is received by the JTAG UART it is stored in a 64-character FIFO. The number of characters currently stored in this FIFO is indicated in the field *RAVAIL*, which are bits 31–16 of the *Data* register. If the receive FIFO overflows, then additional data is lost. When data is present in the receive FIFO, then the value of *RAVAIL* will be greater than 0 and the value of bit 15, *RVALID*, will be 1. Reading the character at the head of the FIFO, which is provided in bits 7–0, decrements the value of *RAVAIL* by one and returns this decremented value as part of the read operation. If no data is present in the receive FIFO, then *RVALID* will be set to 0 and the data in bits 7–0 is undefined.

The JTAG UART also includes a 64-character FIFO that stores data waiting to be transmitted to the host computer. Character data is loaded into this FIFO by performing a write to bits 7–0 of the *Data* register in Figure 8. Note that writing into this register has no effect on received data. The amount of space, *WSPACE*, currently available in the transmit FIFO is provided in bits 31–16 of the *Control* register. If the transmit FIFO is full, then any characters written to the *Data* register will be lost.

Bit 10 in the *Control* register, called *AC*, has the value 1 if the JTAG UART has been accessed by the host computer. This bit can be used to check if a working connection to the host computer has been established. The *AC* bit can be cleared to 0 by writing a 1 into it.

The *Control* register bits *RE*, *WE*, *RI*, and *WI* are described in Section 3.

2.4.1 Using the JTAG* UART with Assembly Language Code and C Code

Listings 3 and 4 give simple examples of assembly language and C code, respectively, that use the JTAG UART. Both versions of the code perform the same function, which is to first send an ASCII string to the JTAG UART, and then enter an endless loop. In the loop, the code reads character data that has been received by the JTAG UART, and echoes this data back to the UART for transmission. If the program is executed by using the Intel® FPGA Monitor Program, then any keyboard character that is typed into the *Terminal Window* of the Monitor Program will be echoed back, causing the character to appear in the *Terminal Window*.

The source code files shown in Listings 3 and 4 are made available as part of the Intel® FPGA Monitor Program. The files can be found under the heading *sample programs*, and are identified by the name *JTAG UART*.

2.5 Interval Timers

The DE0-Nano Computer includes a timer module implemented in the FPGA that can be used by the Nios II processor. This timer can be loaded with a preset value, and then counts down to zero using a 100-MHz clock. The programming interface for the timer includes six 16-bit registers, as illustrated in Figure 9. The 16-bit register at address 0xFF202000 provides status information about the timer, and the register at address 0xFF202004 allows control settings to be made. The bit fields in these registers are described below:

- *TO* provides a timeout signal which is set to 1 by the timer when it has reached a count value of zero. The *TO* bit can be reset by writing a 0 into it.
- *RUN* is set to 1 by the timer whenever it is currently counting. Write operations to the status halfword do not affect the value of the *RUN* bit.

- *ITO* is used for generating interrupts, which are discussed in section 3.

Address	31	...	17	16	15	...	3	2	1	0	
0xFF202000						Unused			RUN	TO	Status register
0xFF202004						Unused	STOP	START	CONT	ITO	Control register
0xFF202008	Not present (interval timer has 16-bit registers)					Counter start value (low)					
0xFF20200C						Counter start value (high)					
0xFF202010						Counter snapshot (low)					
0xFF202014						Counter snapshot (high)					

Figure 9. Interval timer registers.

- *CONT* affects the continuous operation of the timer. When the timer reaches a count value of zero it automatically reloads the specified starting count value. If *CONT* is set to 1, then the timer will continue counting down automatically. But if *CONT* = 0, then the timer will stop after it has reached a count value of 0.
- (*START/STOP*) is used to commence/suspend the operation of the timer by writing a 1 into the respective bit.

The two 16-bit registers at addresses 0xFF202008 and 0xFF20200C allow the period of the timer to be changed by setting the starting count value. The default setting provided in the DE0-Nano Computer gives a timer period of 125 msec. To achieve this period, the starting value of the count is $100 \text{ MHz} \times 125 \text{ msec} = 12.5 \times 10^6$. It is possible to capture a snapshot of the counter value at any time by performing a write to address 0xFF202010. This write operation causes the current 32-bit counter value to be stored into the two 16-bit timer registers at addresses 0xFF202010 and 0xFF202014. These registers can then be read to obtain the count value.

A second interval timer, which has an identical interface to the one described above, is also available in the FPGA, starting at the base address 0xFF202020.

2.6 Accelerometer

The DE0-Nano Computer includes an ADXL345 3-axis digital accelerometer, which can be used to measure acceleration on the board in three directions. The Accelerometer chip is controlled by the Accelerometer SPI Mode core, which provides a memory-mapped interface at address 0xFF204020 to 0xFF204021, as shown in in Figure 10.

The ADXL345 chip contains a series of 58 internal registers, 0x00 to 0x39, which are used to control the device and store data. To access these registers, the address of the desired register should be written to the *Address* register of the Accelerometer SPI Mode core. Performing a read or write on the *Data* register will then read from or write to the requested address on the ADXL345. Commonly used registers of the accelerometer and their address are listed in Table 1. For a full list of registers, consult the ADXL345 datasheet.

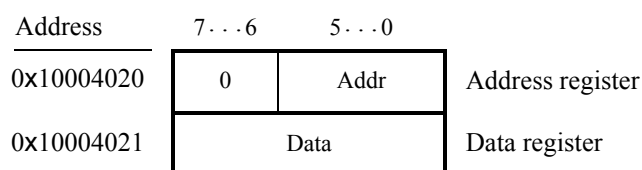


Figure 10. Accelerometer registers.

Address	Register Name	Description
0x32	<i>DATAx0</i>	Low-order byte of <i>x</i> -axis acceleration.
0x33	<i>DATAx1</i>	High-order byte of <i>x</i> -axis acceleration.
0x34	<i>DATAy0</i>	Low-order byte of <i>y</i> -axis acceleration.
0x35	<i>DATAy1</i>	High-order byte of <i>y</i> -axis acceleration.
0x36	<i>DATAz0</i>	Low-order byte of <i>z</i> -axis acceleration.
0x37	<i>DATAz1</i>	High-order byte of <i>z</i> -axis acceleration.

Table 1. Commonly used registers in the ADXL345 chip.

2.7 Floating-point Hardware

The Nios II processor in the DE0-Nano Computer includes hardware support for floating-point addition, subtraction, multiplication, and division. To use this support in a C program, variables must be declared with the type *float*. A simple example of such code is given in Listing 14. When this code is compiled, it is necessary to pass the special argument `-mcustom-fpu-cfg=60-2` to the C compiler, to instruct it to use the floating-point hardware support.

2.8 System ID

The system ID module provides a unique value that identifies the DE0-Nano Computer system. The host computer connected to the DE0-Nano board can query the system ID module by performing a read operation through the JTAG port. The host computer can then check the value of the returned identifier to confirm that the DE0-Nano Computer has been properly downloaded onto the DE0-Nano board. This process allows debugging tools on the host computer, such as the Intel® FPGA Monitor Program, to verify that the DE0-Nano board contains the required computer system before attempting to execute code that has been compiled for this system.

3 Exceptions and Interrupts

The reset address of the Nios II processor in the DE0-Nano Computer is set to 0x00000000. The address used for all other general exceptions, such as divide by zero, and hardware IRQ interrupts is 0x00000020. Since the Nios II processor uses the same address for general exceptions and hardware IRQ interrupts, the Exception Handler software must determine the source of the exception by examining the appropriate processor status register. Table 2 gives the assignment of IRQ numbers to each of the I/O peripherals in the DE0-Nano Computer. The rest of

this section describes the interrupt behavior associated with the interval timer, parallel ports, and serial ports in the DE0-Nano Computer.

I/O Peripheral	IRQ #
Interval timer	0
Pushbutton switch parallel port	1
Second interval timer	2
JTAG port	8
JP1 Expansion parallel port	11
JP2 Expansion parallel port	12
JP3 Expansion parallel port (bidirectional)	13
JP3 Expansion parallel port (input-only)	14
Accelerometer	15

Table 2. Hardware IRQ interrupt assignment for the DE0-Nano Computer.

3.1 Interrupts from Parallel Ports

Parallel ports implemented in the FPGA in the DE0-Nano Computer were illustrated in Figure 2, which is reproduced as Figure 11. As the figure shows, parallel ports that support interrupts include two related registers at the addresses $Base + 8$ and $Base + C$. The *Interruptmask* register, which has the address $Base + 8$, specifies whether or not an interrupt signal should be sent to the processor when the data present at an input port changes value. Setting a bit location in this register to 1 allows interrupts to be generated, while setting the bit to 0 prevents interrupts. Finally, the parallel port may contain an *Edgecapture* register at address $Base + C$. Each bit in this register has the value 1 if the corresponding bit location in the parallel port has changed its value from 0 to 1 since it was last read. Performing a write operation to the *Edgecapture* register sets all bits in the register to 0, and clears any associated interrupts.

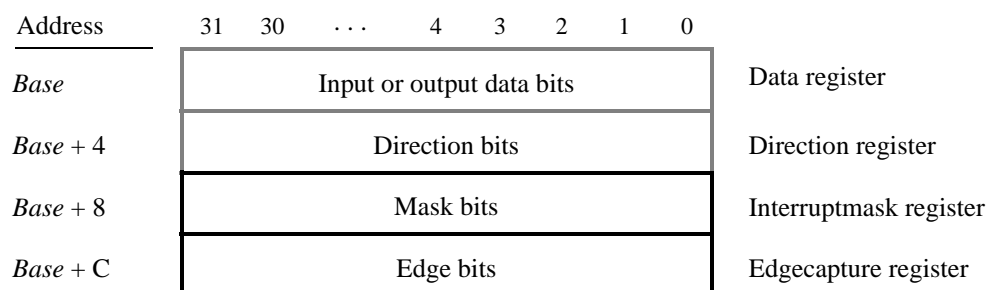


Figure 11. Registers used for interrupts from the parallel ports.

3.1.1 Interrupts from the Pushbutton Keys

Figure 5, reproduced as Figure 12, shows the registers associated with the pushbutton parallel port. The *Interruptmask* register allows processor interrupts to be generated when a key is pressed. Each bit in the *Edgecapture* register is set to 1 by the parallel port when the corresponding key is pressed. The Nios II processor can read this register to determine which key has been pressed, in addition to receiving an interrupt request if the corresponding bit in

the interrupt mask register is set to 1. Writing any value to the *Edgecapture* register deasserts the Nios II interrupt request and sets all bits of the *Edgecapture* register to zero.

Address	31	30	...	4	3	2	1	0	
0xFF200050	Unused						KEY ₁₋₀		Data register
Unused	Unused								
0xFF200058	Unused						Mask bits		Interruptmask register
0xFF20005C	Unused						Edge bits		Edgecapture register

Figure 12. Registers used for interrupts from the pushbutton parallel port.

3.2 Interrupts from the JTAG* UART

Figure 8, reproduced as Figure 13, shows the data and *Control* registers of the JTAG UART. As we said in Section 2.4, *RAVAIL* in the *Data* register gives the number of characters that are stored in the receive FIFO, and *WSPACE* gives the amount of unused space that is available in the transmit FIFO. The *RE* and *WE* bits in Figure 13 are used to enable processor interrupts associated with the receive and transmit FIFOs. When enabled, interrupts are generated when *RAVAIL* for the receive FIFO, or *WSPACE* for the transmit FIFO, exceeds 7. Pending interrupts are indicated in the Control register's *RI* and *WI* bits, and can be cleared by writing or reading data to/from the JTAG UART.

Address	31	...	16	15	14	...	11	10	9	8	7	...	1	0		
0xFF201000	RAVAIL		RVALID		Unused				DATA						Data register	
0xFF201004	WSPACE				Unused				AC	WI	RI			WE	RE	Control register

Figure 13. Interrupt bits in the JTAG UART registers.

3.3 Interrupts from the FPGA Interval Timer

Figure 9, in Section 2.5, shows six registers that are associated with the interval timer. As we said in Section 2.5, the *TO* bit in the *Status* register is set to 1 when the timer reaches a count value of 0. It is possible to generate an interrupt when this occurs, by using the *ITO* bit in the *Control* register. Setting the *ITO* bit to 1 causes an interrupt request to be sent to the processor whenever *TO* becomes 1. After an interrupt occurs, it can be cleared by writing any value into the *Status* register.

3.4 Using Interrupts with Assembly Language Code

An example of assembly language code for the DE0-Nano Computer that uses interrupts is shown in Listing 5. When this code is executed on the DE0-Nano board it displays a rotating pattern on the LEDs. The pattern's rotation can be toggled through pressing the pushbutton KEYS. Two types of interrupts are used in the code. The LEDs

are controlled by an interrupt service routine for the interval timer, and another interrupt service routine is used to handle the pushbutton keys. The speed of the rotation is set in the main program, by using a counter value in the interval timer that causes an interrupt to occur every 50 msec.

The reset and exception handlers for the main program in Listing 5 are given in Listing 6. The reset handler simply jumps to the `_start` symbol in the main program. The exception handler first checks if the exception that has occurred is an external interrupt or an internal one. In the case of an internal exception, such as an illegal instruction opcode or a trap instruction, the handler simply exits, because it does not handle these cases. For external exceptions, it calls either the interval timer interrupt service routine, for a level 0 interrupt, or the pushbutton key interrupt service routine for level 1. These routines are shown in Listings 7 and 8, respectively.

3.5 Using Interrupts with C Language Code

An example of C language code for the DE0-Nano Computer that uses interrupts is shown in Listing 9. This code performs exactly the same operations as the code described in Listing 5.

To enable interrupts the code in Listing 9 uses *macros* that provide access to the Nios II status and control registers. A collection of such macros, which can be used in any C program, are provided in Listing 10.

The reset and exception handlers for the main program in Listing 9 are given in Listing 11. The function called *the_reset* provides a simple reset mechanism by performing a branch to the main program. The function named *the_exception* represents a general exception handler that can be used with any C program. It includes assembly language code to check if the exception is caused by an external interrupt, and, if so, calls a C language routine named *interrupt_handler*. This routine can then perform whatever action is needed for the specific application. In Listing 11, the *interrupt_handler* code first determines which exception has occurred, by using a macro from Listing 10 that reads the content of the Nios II interrupt pending register. The interrupt service routine that is invoked for the interval timer is shown in 12, and the interrupt service routine for the pushbutton switches appears in Listing 13.

The source code files shown in Listing 5 to Listing 13 are distributed as part of the Intel® FPGA Monitor Program. The files can be found under the heading *sample programs*, and are identified by the name *Interrupt Example*.

4 Modifying the DE0-Nano Computer

It is possible to modify the DE0-Nano Computer by using Intel's Quartus® Prime software and Qsys tool. Tutorials that introduce this software are provided in the University Program section of Intel's web site. To modify the system it is first necessary to make an editable copy of the DE0-Nano Computer. The files for this system are installed as part of the Monitor Program installation. Locate these files, copy them to a working directory, and then use the Quartus Prime and Qsys software to make any desired changes.

Table 3 lists the names of the Qsys IP cores that are used in this system. When the DE0-Nano Computer design files are opened in the Quartus Prime software, these cores can be examined using the Qsys System Integration tool. Each core has a number of settings that are selectable in the Qsys System Integration tool, and includes a datasheet that provides detailed documentation.

The steps needed to modify the system are:

1. Install the *University Program IP Cores* from Intel's FPGA University Program web site
2. Copy the design source files for the DE0-Nano Computer from the University Program web site. These files can be found in the *Design Examples* section of the web site
3. Open the *DE0-Nano_Computer.qpf* project in the Quartus Prime software
4. Open the Qsys System Integration tool in the Quartus Prime software, and modify the system as desired
5. Generate the modified system by using the Qsys System Integration tool
6. It may be necessary to modify the Verilog or VHDL code in the top-level module, *DE0-Nano_Computer.v/vhd*, if any I/O peripherals have been added or removed from the system
7. Compile the project in the Quartus Prime software
8. Download the modified system into the DE0-Nano board

The DE0-Nano Computer includes a Nios II/f processor. When using the Quartus Prime Web Edition, compiling a design with a Nios II/s or Nios II/f processor will produce a time-limited SOF file. As a result, the board must remain connected to the host computer, and the design cannot be set as the default configuration, as discussed in Section 5. Designs using only Nios II/e processors and designs compiled using the Quartus Prime Subscription Edition do not have this restriction.

I/O Peripheral	Qsys Core
SDRAM	SDRAM Controller
On-chip Memory	On-Chip Memory (RAM or ROM)
Green LED parallel port	Parallel Port
Expansion parallel ports	Parallel Port
Slider switch parallel port	Parallel Port
Pushbutton parallel port	Parallel Port
JTAG port	JTAG UART
Interval timer	Interval timer
Accelerometer	Accelerometer SPI Mode
System ID	System ID Peripheral

Table 3. Qsys cores used in the DE0-Nano Computer.

5 Making the System the Default Configuration

The DE0-Nano Computer can be loaded into the nonvolatile FPGA configuration memory on the DE0-Nano board, so that it becomes the default system whenever the board is powered on. Instructions for configuring the DE0-Nano board in this manner can be found in the tutorial *Introduction to the Quartus Prime Software*, which is available from Intel's FPGA University Program.

6 Memory Layout

Table 4 summarizes the memory map used in the DE0-Nano Computer.

Base Address	End Address	I/O Peripheral
0x00000000	0x01FFFFFF	SDRAM
0x08000000	0x08001FFF	FPGA On-chip Memory
0x09000000	0x09001FFF	FPGA On-chip Memory
0xFF200000	0xFF20000F	Green LEDs
0xFF200040	0xFF20004F	Slider Switches
0xFF200050	0xFF20005F	Pushbutton KEYS
0xFF200060	0xFF20006F	JP1 Expansion
0xFF200070	0xFF20007F	JP2 Expansion
0xFF200080	0xFF20008F	JP3 Expansion (bidirectional)
0xFF200090	0xFF20009F	JP3 Expansion (input-only)
0xFF201000	0xFF201007	JTAG UART
0xFF2002000	0xFF30201F	Interval timer
0xFF2002020	0xFF20202F	Second Interval timer
0xFF202040	0xFF202027	System ID
0xFF204020	0xFF204021	Accelerometer

Table 4. Memory layout used in the DE0-Nano Computer.

7 Intel® FPGA Monitor Program Integration

As we mentioned earlier, the DE0-Nano Computer system, and the sample programs described in this document, are made available as part of the Intel® FPGA Monitor Program. Figures 14 to 17 show a series of windows that are used in the Monitor Program to create a new project. In the first screen, shown in Figure 14, the user specifies a file system folder where the project will be stored, gives the project a name, and specifies the type of processor that is being used. Pressing Next opens the window in Figure 15. Here, the user can select the DE0-Nano Computer as a pre-designed system. The Monitor Program then fills in the relevant information in the *System details* box, which includes the appropriate system info and fpga configuration files, and preloader. The first of these files specifies to the Monitor Program information about the components that are available in the DE0-Nano Computer, such as the type of processor and memory components, and the address map. The second file is an FPGA programming bitstream for the DE0-Nano Computer, which can be downloaded by the Monitor Program into the DE0-Nano board. Any system which contains a Hard Processor System (HPS) component must also specify the preloader to be run immediately following the circuit being downloaded. This preloader is used to configure the components within the HPS with the setting required for the specific board.

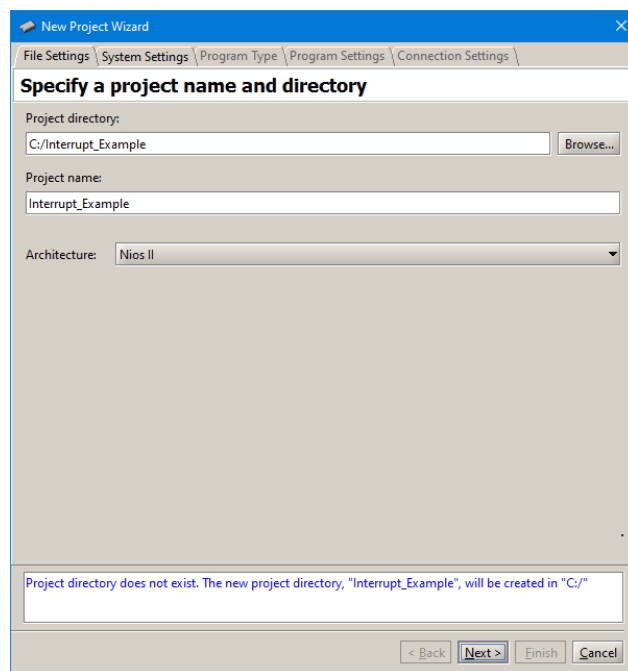


Figure 14. Specifying the project folder and project name.

Pressing **Next** again opens the window in Figure 16. Here the user selects the type of program that will be used, such as Assembly language, or C. Then, the check box shown in the figure can be used to display the list of sample programs for the DE0-Nano Computer that are described in this document. When a sample program is selected in this list, its source files, and other settings, can be copied into the project folder in subsequent screens of the Monitor Program.

Figure 17 gives the final screen that is used to create a new project in the Monitor Program. This screen shows the default addresses of compiler and linker sections that will be used for the assembly language or C program associated with the Monitor Program project. In the figure, the drop-down menu called *Linker Section Presets* has been set to **Exceptions**. With this setting the Monitor Program uses specific compiler and linker sections for the selected processor. For the Nios II processor, these sections are for reset and exceptions code, and another section for the main program, called *.text*. For the A9 processor, it has a section for the exception table, called *.vectors*, and another section for the main program, called *.text*. It also shows the initial value used to set the main stack pointer for C programs, which is the starting address of the *.stack* section.

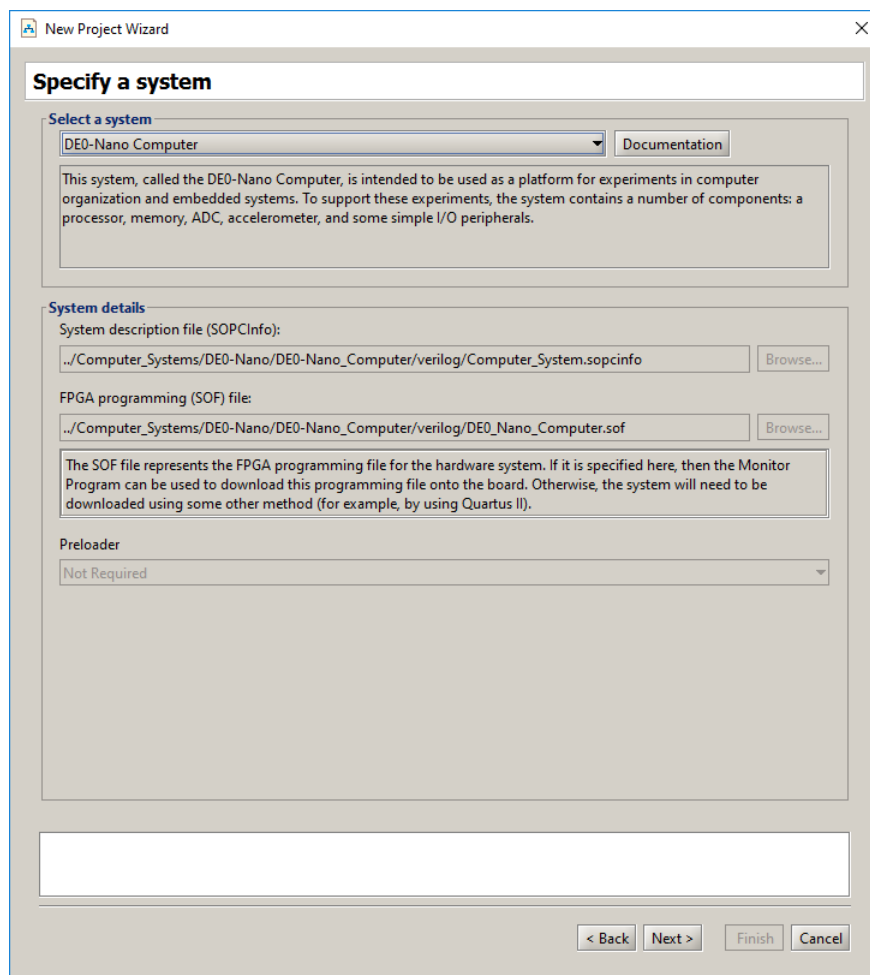


Figure 15. Specifying the DE0-Nano Computer system.

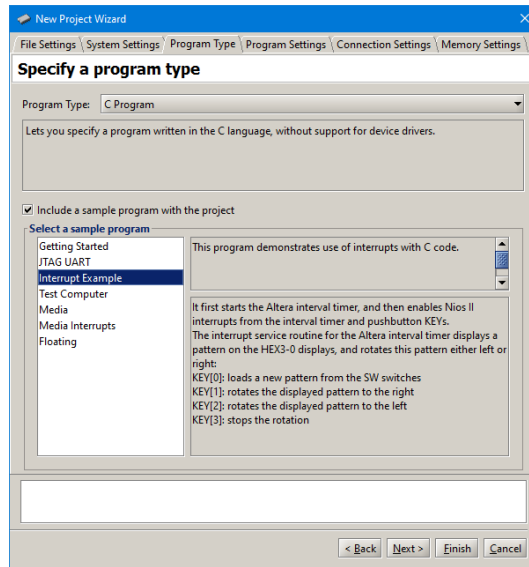


Figure 16. Selecting sample programs.

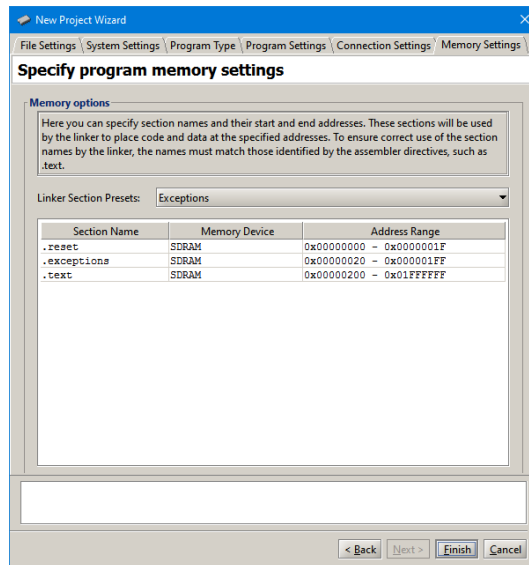


Figure 17. Setting offsets for .text and .data.

8 Appendix

This section contains all of the source code files mentioned in the document.

8.1 Parallel Ports

```
.include      "address_map_nios2.s"

/*****
 * This program demonstrates use of parallel ports
 *
 * It performs the following:
 * 1. displays a rotating pattern on the LEDs
 * 2. if any KEY is pressed, the SW switches are used as the rotating pattern
 *****/

.text                # executable code follows
.global      _start
_start:

/* initialize base addresses of parallel ports */
    movia    r15, SW_BASE      # SW slider switch base address
    movia    r16, LED_BASE     # LED base address
    movia    r17, KEY_BASE     # pushbutton KEY base address
    movia    r18, LED_bits     # LED bits
    ldwio    r6, 0(r18)        # load pattern for LED lights

DO_DISPLAY:
    ldwio    r4, 0(r15)        # load slider switches

    ldwio    r5, 0(r17)        # load pushbuttons
    beq      r5, r0, NO_BUTTON
    mov      r6, r4            # copy SW switch values onto LEDs
    roli     r4, r4, 8         # the SW values are copied into the upper three
                                # bytes of the pattern register
    or       r6, r6, r4        # needed to make pattern consistent as all
                                # 32-bits of a register are rotated
    roli     r4, r4, 8         # but only the lowest 8-bits are displayed on
                                # LEDs

    or       r6, r6, r4
    roli     r4, r4, 8
    or       r6, r6, r4

WAIT:
    ldwio    r5, 0(r17)        # load pushbuttons
    bne      r5, r0, WAIT      # wait for button release

NO_BUTTON:
    stwio    r6, 0(r16)        # store to LED
    roli     r6, r6, 1         # rotate the displayed pattern
```

```
        movia    r7, 1500000          # delay counter
DELAY:
        subi    r7, r7, 1
        bne     r7, r0, DELAY

        br      DO_DISPLAY

/*****
.data          # data follows

LED_bits:
.word         0x0F0F0F0F

.end
```

Listing 1. An example of Nios II assembly language code that uses parallel ports.

```

#include "address_map_nios2.h"
/* This program demonstrates use of parallel ports in the Computer System
 *
 * It performs the following:
 * 1. displays a rotating pattern on the LEDs
 * 2. if a KEY is pressed, uses the SW switches as the pattern
 */
int main(void) {
    /* Declare volatile pointers to I/O registers (volatile means that IO load
     * and store instructions will be used to access these pointer locations,
     * instead of regular memory loads and stores)
     */
    volatile int * LED_ptr      = (int *)LED_BASE; // LED address
    volatile int * SW_switch_ptr = (int *)SW_BASE;  // SW slider switch address
    volatile int * KEY_ptr      = (int *)KEY_BASE;  // pushbutton KEY address

    int LED_bits = 0x0F0F0F0F; // pattern for LED lights
    int SW_value, KEY_value;
    volatile int
        delay_count; // volatile so the C compiler doesn't remove the loop

    while (1) {
        SW_value = *(SW_switch_ptr); // read the SW slider (DIP) switch values

        KEY_value = *(KEY_ptr); // read the pushbutton KEY values
        if (KEY_value != 0) // check if any KEY was pressed
        {
            /* set pattern using SW values */
            LED_bits = SW_value | (SW_value << 8) | (SW_value << 16) |
                (SW_value << 24);
            while (*KEY_ptr)
                ; // wait for pushbutton KEY release
        }
        *(LED_ptr) = LED_bits; // light up the LEDs

        /* rotate the pattern shown on the LEDs */
        if (LED_bits & 0x80000000)
            LED_bits = (LED_bits << 1) | 1;
        else
            LED_bits = LED_bits << 1;

        for (delay_count = 350000; delay_count != 0; --delay_count)
            ; // delay loop
    }
}

```

Listing 2. An example of C code that uses parallel ports.

8.2 JTAG* UART

```
.include      "address_map_nios2.s"

/*****
 * This program demonstrates use of the JTAG UART port
 *
 * It performs the following:
 * 1. sends a text string to the JTAG UART
 * 2. reads character data from the JTAG UART
 * 3. echos the character data back to the JTAG UART
 *****/

.text        # executable code follows
.global     _start
_start:
/* set up stack pointer */
    movia   sp, SDRAM_END - 3    # starts from largest memory address

    movia   r6, JTAG_UART_BASE  # JTAG UART base address

/* print a text string */
    movia   r8, TEXT_STRING
LOOP:
    ldb     r5, 0(r8)
    beq     r5, zero, GET_JTAG   # string is null-terminated
    call    PUT_JTAG
    addi    r8, r8, 1
    br     LOOP

/* read and echo characters */
GET_JTAG:
    ldwio   r4, 0(r6)           # read the JTAG UART data register
    andi    r8, r4, 0x8000      # check if there is new data
    beq     r8, r0, GET_JTAG    # if no data, wait
    andi    r5, r4, 0x00ff      # the data is in the least significant byte

    call    PUT_JTAG           # echo character
    br     GET_JTAG

/*****
 * Subroutine to send a character to the JTAG UART
 *
 * r5 = character to send
 * r6 = JTAG UART base address
 *****/
.global     PUT_JTAG
PUT_JTAG:
/* save any modified registers */
```

Listing 3. An example of assembly language code that uses the JTAG UART (Part a).

```
subi    sp, sp, 4           # reserve space on the stack
stw     r4, 0(sp)          # save register

ldwio   r4, 4(r6)          # read the JTAG UART control register
andhi   r4, r4, 0xffff     # check for write space
beq     r4, r0, END_PUT    # if no space, ignore the character
stwio   r5, 0(r6)          # send the character

END_PUT:
/* restore registers */
ldw     r4, 0(sp)
addi   sp, sp, 4

ret

/*****/
.data
```

Listing 3. An example of assembly language code that uses the JTAG UART (Part b).

```
#include "JTAG_UART.h"
#include "address_map_nios2.h"

/*****
 * Subroutine to send a character to the JTAG UART
 *****/
void put_jtag(volatile int * JTAG_UART_ptr, char c)
{
    int control;
    control = *(JTAG_UART_ptr + 1); // read the JTAG_UART control register
    if (control & 0xFFFF0000) // if space, echo character, else ignore
        *(JTAG_UART_ptr) = c;
}

/*****
 * Subroutine to read a character from the JTAG UART
 * Returns \0 if no character, otherwise returns the character
 *****/
char get_jtag(volatile int * JTAG_UART_ptr)
{
    int data;
    data = *(JTAG_UART_ptr); // read the JTAG_UART data register
    if (data & 0x00008000) // check RVALID to see if there is new data
        return ((char)data & 0xFF);
    else
        return ('\0');
}
```

Listing 4. An example of C code that uses the JTAG UART (Part a).

```
#include "JTAG_UART.h"
#include "address_map_nios2.h"

/*****
 * This program demonstrates use of the JTAG UART port
 *
 * It performs the following:
 * 1. sends a text string to the JTAG UART
 * 2. reads character data from the JTAG UART
 * 3. echos the character data back to the JTAG UART
 *****/
int main(void)
{
    /* Declare volatile pointers to I/O registers (volatile means that IO load
       and store instructions will be used to access these pointer locations,
       instead of regular memory loads and stores) */
    volatile int * JTAG_UART_ptr = (int *)JTAG_UART_BASE; // JTAG UART address

    char text_string[] = "\nJTAG UART example code\n> \0";
    char *str, c;

    /* print a text string */
    for (str = text_string; *str != 0; ++str)
        put_jtag(JTAG_UART_ptr, *str);

    /* read and echo characters */
    while (1)
    {
        c = get_jtag(JTAG_UART_ptr);
        if (c != '\0')
            put_jtag(JTAG_UART_ptr, c);
    }
}
```

Listing 4. An example of C code that uses the JTAG UART (Part b).

8.3 Interrupts

```
.include    "address_map_nios2.s"
.include    "globals.s"

/*****
 * This program demonstrates use of interrupts. It
 * first starts an interval timer with 50 msec timeouts, and then enables
 * Nios II interrupts from the interval timer and pushbutton KEYS
 *
 * The interrupt service routine for the interval timer displays a pattern
 * on the LEDs, and shifts this pattern either left or right:
 *     KEY[0]: loads a new pattern from the SW switches
 *     KEY[1]: toggles the shift direction the displayed pattern
 *****/

.text      # executable code follows
.global    _start
_start:
/* set up the stack */
    movia   sp, SDRAM_END - 3    # stack starts from largest memory
                                   # address

    movia   r16, TIMER_BASE      # interval timer base address
/* set the interval timer period for scrolling the LED lights */
    movia   r12, 5000000         # 1/(100 MHz) x (5 x 10^6) = 50 msec
    sthio   r12, 8(r16)          # store the low half word of counter
                                   # start value

    srli    r12, r12, 16
    sthio   r12, 0xC(r16)        # high half word of counter start value

/* start interval timer, enable its interrupts */
    movi    r15, 0b0111          # START = 1, CONT = 1, ITO = 1
    sthio   r15, 4(r16)

/* write to the pushbutton port interrupt mask register */
    movia   r15, KEY_BASE        # pushbutton key base address
    movi    r7, 0b11             # set interrupt mask bits
    stwio   r7, 8(r15)          # interrupt mask register is (base + 8)

/* enable Nios II processor interrupts */
    movia   r7, 0x00000001       # get interrupt mask bit for interval
                                   # timer
    movia   r8, 0x00000002       # get interrupt mask bit for pushbuttons
    or      r7, r7, r8
    wrctl   ienable, r7         # enable interrupts for the given mask
                                   # bits

    movi    r7, 1
    wrctl   status, r7          # turn on Nios II interrupt processing
```

IDLE:

```
br      IDLE          # main program simply idles

.data
/*****
 * The global variables used by the interrupt service routines for the interval
 * timer and the pushbutton keys are declared below
 *****/
.global  PATTERN
PATTERN:
.word   0x0F0F0F0F # pattern to show on the LED lights
.global  SHIFT_DIR
SHIFT_DIR:
.word   RIGHT # pattern shifting direction

.end
```

Listing 5. An example of assembly language code that uses interrupts.

```

/*****
 * RESET SECTION
 * Note: "ax" is REQUIRED to designate the section as allocatable and executable.
 * Also, the Debug Client automatically places the ".reset" section at the reset
 * location specified in the CPU settings in SOPC Builder.
 *****/
.section    .reset, "ax"

        movia    r2, _start
        jmp     r2                # branch to main program

/*****
 * EXCEPTIONS SECTION
 * Note: "ax" is REQUIRED to designate the section as allocatable and executable.
 * Also, the Monitor Program automatically places the ".exceptions" section at
 * the exception location specified in the CPU settings in SOPC Builder.
 *****/
.section    .exceptions, "ax"
.global    EXCEPTION_HANDLER

EXCEPTION_HANDLER:
        subi    sp, sp, 16        # make room on the stack
        stw    et, 0(sp)

        rdctl  et, ct14
        beq    et, r0, SKIP_EA_DEC # interrupt is not external

        subi    ea, ea, 4        # must decrement ea by one instruction
                                     # for external interrupts, so that the
                                     # interrupted instruction will be run

SKIP_EA_DEC:
        stw    ea, 4(sp)        # save all used registers on the Stack
        stw    ra, 8(sp)        # needed if call inst is used
        stw    r22, 12(sp)

        rdctl  et, ct14
        bne    et, r0, CHECK_LEVEL_0 # interrupt is an external interrupt

NOT_EI:
                                     # exception must be unimplemented
                                     # instruction or TRAP instruction. This
                                     # code does not handle those cases

        br     END_ISR

CHECK_LEVEL_0:
                                     # interval timer is interrupt level 0
        andi    r22, et, 0b1
        beq    r22, r0, CHECK_LEVEL_1

        call   INTERVAL_TIMER_ISR
        br     END_ISR

CHECK_LEVEL_1:
                                     # pushbutton port is interrupt level 1

```

```
andi    r22, et, 0b10
beq     r22, r0, END_ISR      # other interrupt levels are not handled in
                               # this code

call    PUSHBUTTON_ISR

END_ISR:
ldw     et, 0(sp)            # restore all used register to previous
                               # values
ldw     ea, 4(sp)
ldw     ra, 8(sp)           # needed if call inst is used
ldw     r22, 12(sp)
addi    sp, sp, 16

.end
```

Listing 6. Reset and exception handler assembly language code.

```

.include      "address_map_nios2.s"
.include      "globals.s"
.extern      PATTERN          # externally defined variables
.extern      SHIFT_DIR

/*****
 * Interval timer - Interrupt Service Routine
 *
 * Shifts a PATTERN being displayed. The shift direction is determined by the
 * external variable SHIFT_DIR.
 *****/
.global      INTERVAL_TIMER_ISR
INTERVAL_TIMER_ISR:
    subi     sp, sp, 40        # reserve space on the stack
    stw     ra, 0(sp)
    stw     r4, 4(sp)
    stw     r5, 8(sp)
    stw     r6, 12(sp)
    stw     r8, 16(sp)
    stw     r10, 20(sp)
    stw     r20, 24(sp)
    stw     r21, 28(sp)
    stw     r22, 32(sp)
    stw     r23, 36(sp)

    movia   r10, TIMER_BASE   # interval timer base address
    sthio   r0, 0(r10)        # clear the interrupt

    movia   r20, LED_BASE     # LED base address
    movia   r21, PATTERN      # set up a pointer to the display pattern
    movia   r22, SHIFT_DIR    # set up a pointer to the shift direction variable

    ldw     r6, 0(r21)        # load the pattern
    stwio   r6, 0(r20)        # store to LEDs

CHECK_SHIFT:
    ldw     r5, 0(r22)        # get shift direction
    movi    r8, RIGHT
    bne     r5, r8, SHIFT_L

SHIFT_R:
    movi    r5, 1              # set r5 to the constant value 1
    ror     r6, r6, r5        # rotate the displayed pattern right
    br      STORE_PATTERN

SHIFT_L:
    movi    r5, 1              # set r5 to the constant value 1
    rol     r6, r6, r5        # shift left

STORE_PATTERN:
    stw     r6, 0(r21)        # store display pattern

```

```
END_INTERVAL_TIMER_ISR:
    ldw    ra, 0(sp)      # restore registers
    ldw    r4, 4(sp)
    ldw    r5, 8(sp)
    ldw    r6, 12(sp)
    ldw    r8, 16(sp)
    ldw    r10, 20(sp)
    ldw    r20, 24(sp)
    ldw    r21, 28(sp)
    ldw    r22, 32(sp)
    ldw    r23, 36(sp)
    addi   sp, sp, 40    # release the reserved space on the stack
```

```
.end
```

Listing 7. Interrupt service routine for the interval timer.

```

.include      "address_map_nios2.s"
.include      "globals.s"
.extern      PATTERN                               # externally defined variables
.extern      SHIFT_DIR

/*****
 * Pushbutton - Interrupt Service Routine
 *
 * This routine checks which KEY has been pressed and updates the global
 * variables as required.
 *****/
.global      PUSHBUTTON_ISR
PUSHBUTTON_ISR:
    subi     sp, sp, 20                          # reserve space on the stack
    stw     ra, 0(sp)
    stw     r10, 4(sp)
    stw     r11, 8(sp)
    stw     r12, 12(sp)
    stw     r13, 16(sp)

    movia   r10, KEY_BASE                        # base address of pushbutton KEY
                                                # parallel port
    ldwio   r11, 0xC(r10)                        # read edge capture register
    stwio   r11, 0xC(r10)                        # clear the interrupt

CHECK_KEY0:
    andi    r13, r11, 0b0001                    # check KEY0
    beq     r13, zero, CHECK_KEY1

    movia   r10, SW_BASE                          # base address of SW slider
                                                # switches parallel port
    ldwio   r12, 0(r10)                          # load a new pattern from the SW
                                                # switches
    movia   r10, PATTERN                          # set up a pointer to the pattern
                                                # variable
    stw     r12, 0(r10)                          # store the new pattern to the
                                                # global variable

CHECK_KEY1:
    andi    r13, r11, 0b0010                    # check KEY1
    beq     r13, zero, END_PUSHBUTTON_ISR

    movia   r10, SHIFT_DIR                        # set up a pointer to the shift
                                                # direction variable
    ldw     r12, 0(r10)                          # load the current shift direction
    xori    r12, r12, 1                          # toggle the direction
    stw     r12, 0(r10)                          # store the new shift direction

END_PUSHBUTTON_ISR:
    ldw     ra, 0(sp)                            # Restore all used register to
                                                # previous
    ldw     r10, 4(sp)

```

```
ldw    r11, 8(sp)
ldw    r12, 12(sp)
ldw    r13, 16(sp)
addi   sp, sp, 20
```

```
.end
```

Listing 8. Interrupt service routine for the pushbutton KEYS.


```

#include "address_map_nios2.h"
#include "globals.h" // defines global values
#include "nios2_ctrl_reg_macros.h"

/* the global variables are written by interrupt service routines; we have to
 * declare
 * these as volatile to avoid the compiler caching their values in registers */
volatile int pattern      = 0x0000000F; // pattern for shifting
volatile int shift_dir    = LEFT;      // direction to shift the pattern
volatile int shift_enable = ENABLE;    // enable/disable shifting of the pattern

/*****
 * This program demonstrates use of interrupts. It
 * first starts the interval timer with 50 msec timeouts, and then enables
 * Nios II interrupts from the interval timer and pushbutton KEYS
 *
 * The interrupt service routine for the interval timer displays a pattern on
 * the LED lights, and shifts this pattern either left or right. The shifting
 * direction is reversed when KEY[1] is pressed
 *****/
int main(void) {
    /* Declare volatile pointers to I/O registers (volatile means that IO load
     * and store instructions will be used to access these pointer locations,
     * instead of regular memory loads and stores)
     */
    volatile int * interval_timer_ptr =
        (int *)TIMER_BASE;           // interval timer base address
    volatile int * KEY_ptr = (int *)KEY_BASE; // pushbutton KEY address

    /* set the interval timer period for scrolling the LED lights */
    int counter = 2500000; // 1/(50 MHz) x (2500000) = 50 msec
    *(interval_timer_ptr + 0x2) = (counter & 0xFFFF);
    *(interval_timer_ptr + 0x3) = (counter >> 16) & 0xFFFF;

    /* start interval timer, enable its interrupts */
    *(interval_timer_ptr + 1) = 0x7; // STOP = 0, START = 1, CONT = 1, ITO = 1

    *(KEY_ptr + 2) = 0x3; // enable interrupts for all pushbuttons

    /* set interrupt mask bits for levels 0 (interval timer) and level 1
     * (pushbuttons) */
    NIOS2_WRITE_IENABLE(0x3);

    NIOS2_WRITE_STATUS(1); // enable Nios II interrupts

    while (1)
        ; // main program simply idles
}

```

Listing 9. An example of C code that uses interrupts.

```
#ifndef __NIOS2_CTRL_REG_MACROS__
#define __NIOS2_CTRL_REG_MACROS__

/*****
/* Macros for accessing the control registers. */
*****/

#define NIOS2_READ_STATUS(dest) \
    do { dest = __builtin_rdctl(0); } while (0)

#define NIOS2_WRITE_STATUS(src) \
    do { __builtin_wrctl(0, src); } while (0)

#define NIOS2_READ_ESTATUS(dest) \
    do { dest = __builtin_rdctl(1); } while (0)

#define NIOS2_READ_BSTATUS(dest) \
    do { dest = __builtin_rdctl(2); } while (0)

#define NIOS2_READ_IENABLE(dest) \
    do { dest = __builtin_rdctl(3); } while (0)

#define NIOS2_WRITE_IENABLE(src) \
    do { __builtin_wrctl(3, src); } while (0)

#define NIOS2_READ_IPENDING(dest) \
    do { dest = __builtin_rdctl(4); } while (0)

#define NIOS2_READ_CPUID(dest) \
    do { dest = __builtin_rdctl(5); } while (0)

#endif
```

Listing 10. Macros for accessing Nios II status and control registers.

```

#include "nios2_ctrl_reg_macros.h"

/* function prototypes */
void main(void);
void interrupt_handler(void);
void interval_timer_ISR(void);
void pushbutton_ISR(void);

/* The assembly language code below handles CPU reset processing */
void the_reset(void) __attribute__((section(".reset")));
void the_reset(void)
/*****
 * Reset code. By giving the code a section attribute with the name ".reset" we
 * allow the linker program to locate this code at the proper reset vector
 * address. This code just calls the main program.
 *****/
{
    asm(".set      noat"); /* Instruct the assembler NOT to use reg at (r1) as
                          * a temp register for performing optimizations */
    asm(".set      nobreak"); /* Suppresses a warning message that says that
                              * some debuggers corrupt regs bt (r25) and ba
                              * (r30)
                              */
    asm("movia    r2, main"); // Call the C language main program
    asm("jmp      r2");
}

/* The assembly language code below handles CPU exception processing. This
 * code should not be modified; instead, the C language code in the function
 * interrupt_handler() can be modified as needed for a given application.
 */
void the_exception(void) __attribute__((section(".exceptions")));
void the_exception(void)
/*****
 * Exceptions code. By giving the code a section attribute with the name
 * ".exceptions" we allow the linker program to locate this code at the proper
 * exceptions vector address.
 * This code calls the interrupt handler and later returns from the exception.
 *****/
{
    asm("subi    sp, sp, 128");
    asm("stw     et, 96(sp)");
    asm("rdctl   et, ct14");
    asm("beq     et, r0, SKIP_EA_DEC"); // Interrupt is not external
    asm("subi    ea, ea, 4");          /* Must decrement ea by one instruction
                                      * for external interrupts, so that the
                                      * interrupted instruction will be run */

    asm("SKIP_EA_DEC:");
    asm("stw     r1, 4(sp)"); // Save all registers
    asm("stw     r2, 8(sp)");
}

```

```
asm("stw    r3, 12(sp)");
asm("stw    r4, 16(sp)");
asm("stw    r5, 20(sp)");
asm("stw    r6, 24(sp)");
asm("stw    r7, 28(sp)");
asm("stw    r8, 32(sp)");
asm("stw    r9, 36(sp)");
asm("stw    r10, 40(sp)");
asm("stw    r11, 44(sp)");
asm("stw    r12, 48(sp)");
asm("stw    r13, 52(sp)");
asm("stw    r14, 56(sp)");
asm("stw    r15, 60(sp)");
asm("stw    r16, 64(sp)");
asm("stw    r17, 68(sp)");
asm("stw    r18, 72(sp)");
asm("stw    r19, 76(sp)");
asm("stw    r20, 80(sp)");
asm("stw    r21, 84(sp)");
asm("stw    r22, 88(sp)");
asm("stw    r23, 92(sp)");
asm("stw    r25, 100(sp)"); // r25 = bt (skip r24 = et, because it is saved
                          // above)
asm("stw    r26, 104(sp)"); // r26 = gp
// skip r27 because it is sp, and there is no point in saving this
asm("stw    r28, 112(sp)"); // r28 = fp
asm("stw    r29, 116(sp)"); // r29 = ea
asm("stw    r30, 120(sp)"); // r30 = ba
asm("stw    r31, 124(sp)"); // r31 = ra
asm("addi   fp, sp, 128");

asm("call   interrupt_handler"); // Call the C language interrupt handler

asm("ldw    r1, 4(sp)"); // Restore all registers
asm("ldw    r2, 8(sp)");
asm("ldw    r3, 12(sp)");
asm("ldw    r4, 16(sp)");
asm("ldw    r5, 20(sp)");
asm("ldw    r6, 24(sp)");
asm("ldw    r7, 28(sp)");
asm("ldw    r8, 32(sp)");
asm("ldw    r9, 36(sp)");
asm("ldw    r10, 40(sp)");
asm("ldw    r11, 44(sp)");
asm("ldw    r12, 48(sp)");
asm("ldw    r13, 52(sp)");
asm("ldw    r14, 56(sp)");
asm("ldw    r15, 60(sp)");
asm("ldw    r16, 64(sp)");
asm("ldw    r17, 68(sp)");
asm("ldw    r18, 72(sp)");
```

```

asm("ldw    r19, 76(sp)");
asm("ldw    r20, 80(sp)");
asm("ldw    r21, 84(sp)");
asm("ldw    r22, 88(sp)");
asm("ldw    r23, 92(sp)");
asm("ldw    r24, 96(sp)");
asm("ldw    r25, 100(sp)"); // r25 = bt
asm("ldw    r26, 104(sp)"); // r26 = gp
// skip r27 because it is sp, and we did not save this on the stack
asm("ldw    r28, 112(sp)"); // r28 = fp
asm("ldw    r29, 116(sp)"); // r29 = ea
asm("ldw    r30, 120(sp)"); // r30 = ba
asm("ldw    r31, 124(sp)"); // r31 = ra

asm("addi   sp,  sp, 128");

asm("eret");
}

/*****
 * Interrupt Service Routine
 * Determines what caused the interrupt and calls the appropriate
 * subroutine.
 *
 * ipending - Control register 4 which has the pending external interrupts
 *****/
void interrupt_handler(void) {
    int ipending;
    NIOS2_READ_IPENDING(ipending);
    if (ipending & 0x1) // interval timer is interrupt level 0
    {
        interval_timer_ISR();
    }
    if (ipending & 0x2) // pushbuttons are interrupt level 1
    {
        pushbutton_ISR();
    }
    // else, ignore the interrupt
    return;
}

```

Listing 11. Reset and exception handler C code.

```

#include "address_map_nios2.h"
#include "globals.h" // defines global values

extern volatile int pattern, shift_dir, shift_enable;
/*****
 * Interval timer interrupt service routine
 *
 * Shifts a PATTERN being displayed on the LED lights. The shift direction
 * is determined by the external variable key_dir.
 *****/
void interval_timer_ISR() {
    volatile int * interval_timer_ptr = (int *)TIMER_BASE;
    volatile int * LEDG_ptr           = (int *)LED_BASE; // LED address

    *(interval_timer_ptr) = 0; // clear the interrupt

    *(LEDG_ptr) = pattern; // display pattern on LED

    if (shift_enable == DISABLE) // check if shifting is disabled
        return;

    /* rotate the pattern shown on the LEDG lights */
    if (shift_dir == LEFT) // rotate left
        if (pattern & 0x80000000)
            pattern = (pattern << 1) | 1;
        else
            pattern = pattern << 1;
    else // rotate right
        if (pattern & 0x00000001)
            pattern = (pattern >> 1) | 0x80000000;
        else
            pattern = (pattern >> 1) & 0x7FFFFFFF;

    return;
}

```

Listing 12. Interrupt service routine for the interval timer.

```

#include "address_map_nios2.h"
#include "globals.h" // defines global values

extern volatile int pattern, shift_dir, shift_enable;
/*****
 * Pushbutton - Interrupt Service Routine
 *
 * This routine checks which KEY has been pressed and updates the global
 * variables as required.
 *****/
void pushbutton_ISR(void) {
    volatile int * KEY_ptr          = (int *)KEY_BASE;
    volatile int * slider_switch_ptr = (int *)SW_BASE;
    int          press;

    press          = *(KEY_ptr + 3); // read the pushbutton interrupt register
    *(KEY_ptr + 3) = press;         // Clear the interrupt

    if (press & 0x1) // KEY0
        pattern = *slider_switch_ptr;

    if (press & 0x2) // KEY1
        shift_dir = shift_dir ^ 1;

    return;
}

```

Listing 13. Interrupt service routine for the pushbutton KEYS.

8.4 Floating Point

```

/*****
 * This program demonstrates use of floating-point numbers
 *
 * It performs the following:
 *   1. reads two FP numbers from the Terminal window
 *   2. performs +, -, *, and / on the numbers
 *   3. prints the results on the Terminal window
 *   Note: Please enable "Echo input" in the terminal window
 *****/
#include <stdio.h>

int flush()
{
    while (getchar() != '\n')
        ;
    return 1;
}

int main(void)
{
    float x, y, add, sub, mult, div;

    while (1)
    {
        printf("Enter FP values X: ");

        while ((scanf("%f", &x) != 1) && flush())
            ; // get valid floating point value and flush the invalid input
        printf("%f\n", x); // echo the typed data to the Terminal window

        printf("Enter FP values Y: ");

        while ((scanf("%f", &y) != 1) && flush())
            ; // get valid floating point value and flush the invalid input
        printf("%f\n", y); // echo the typed data to the Terminal window

        add = x + y;
        sub = x - y;
        mult = x * y;
        div = x / y;
        printf("X + Y = %f\n", add);
        printf("X - Y = %f\n", sub);
        printf("X * Y = %f\n", mult);
        printf("X / Y = %f\n", div);
    }
}

```

Listing 14. An example of code that uses floating-point variables.

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