The ARMSim# User Guide[1]

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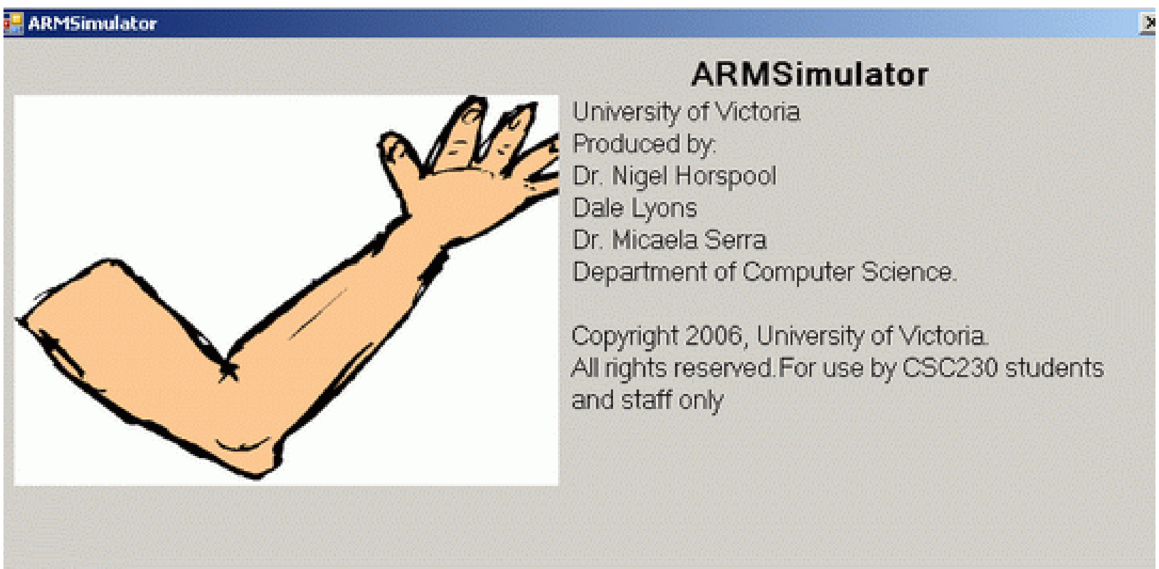
1. Overview

ARMSim# is a desktop application running in a Windows environment. It allows users to simulate the execution of ARM assembly language programs on a system based on the ARM7TDMI processor. ARMSim# includes both an assembler and a linker; when a file is loaded, the simulator automatically assembles and links the program. ARMSim# also provides features not often found in similar applications. They enable users both to debug ARM assembly programs and to monitor the state of the system while a program executes. The monitoring information includes both cache states and clock cycles consumed.

The purpose of this user guide is to explain how to use the tools and views provided by ARMSim#. In this document, a view is a window displayed by the ARMSim# simulator that shows the state of some aspect of the program being run. The scope of the document has been limited to the features of the simulator. It does not cover ARM assembly programming or computer architecture. Users who are unfamiliar with these topics should consult other material, some of which is listed in the references.



The topics in this document have been organized to provide a step-by-step introduction to ARMSim#, including the extra features regarding I/O instructions, based on custom SWI codes, and plug-ins. The table of contents below summarizes the items described.

1. Last updated July 2010 for ARMSim#.191

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2. Features

The ARMSim# toolbar and views give the user access to a variety of tools to debug and monitor ARM assembly language programs. The following sections describe the controls provided by the toolbar and the information displayed in the views.

2.1 Toolbar

The ARMSim# toolbar provides easy access to many of the debugging features of the simulator, especially those features that allow the user to control the execution of a program. The functions of the buttons on the toolbar are summarized in Table 1.

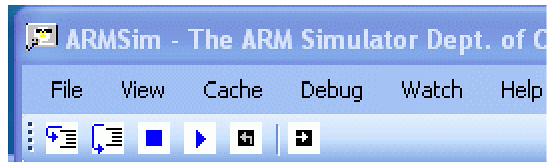
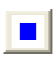
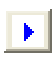


Table 1. Toolbar Buttons.

	The **Step Into** button causes the simulator to execute the highlighted instruction and move to the next instruction in the program. If the highlighted instruction is a subroutine call (BL or BX instruction) then the next highlighted instruction will be the first instruction of the subroutine.
	The **Step Over** button causes the simulator to execute the highlighted instruction and move to the next instruction in the current subroutine. If the highlighted instruction is a subroutine call (BL or BX instruction) then the program is run until the subroutine returns. Thus, unless a breakpoint is encountered, the next highlighted instruction will be at the return point from the subroutine call.
	The **Stop** button causes the simulator to stop the execution of the program.
	The **Continue** button causes the simulator to run the program until it encounters a breakpoint, an SWI 0x11 instruction (end of execution), or a run-time error.
	The **Restart** button causes the simulator to start the execution of the program from the beginning.
	The **Reload** button causes the simulator to load a new version of the program file from the hard drive and start the execution of the program from the beginning.

2.2 Views

The ARMSim# views display the simulator's output and the contents of the system's storage. ARMSim# provides several views, as shown in Figure 1 and summarized in Table 2.

All views are enabled by selecting the appropriate item from **View menu** above the toolbar. All views, except the **Code View**, appear in docking windows (see Figure 2). Their placement and movement is described below.

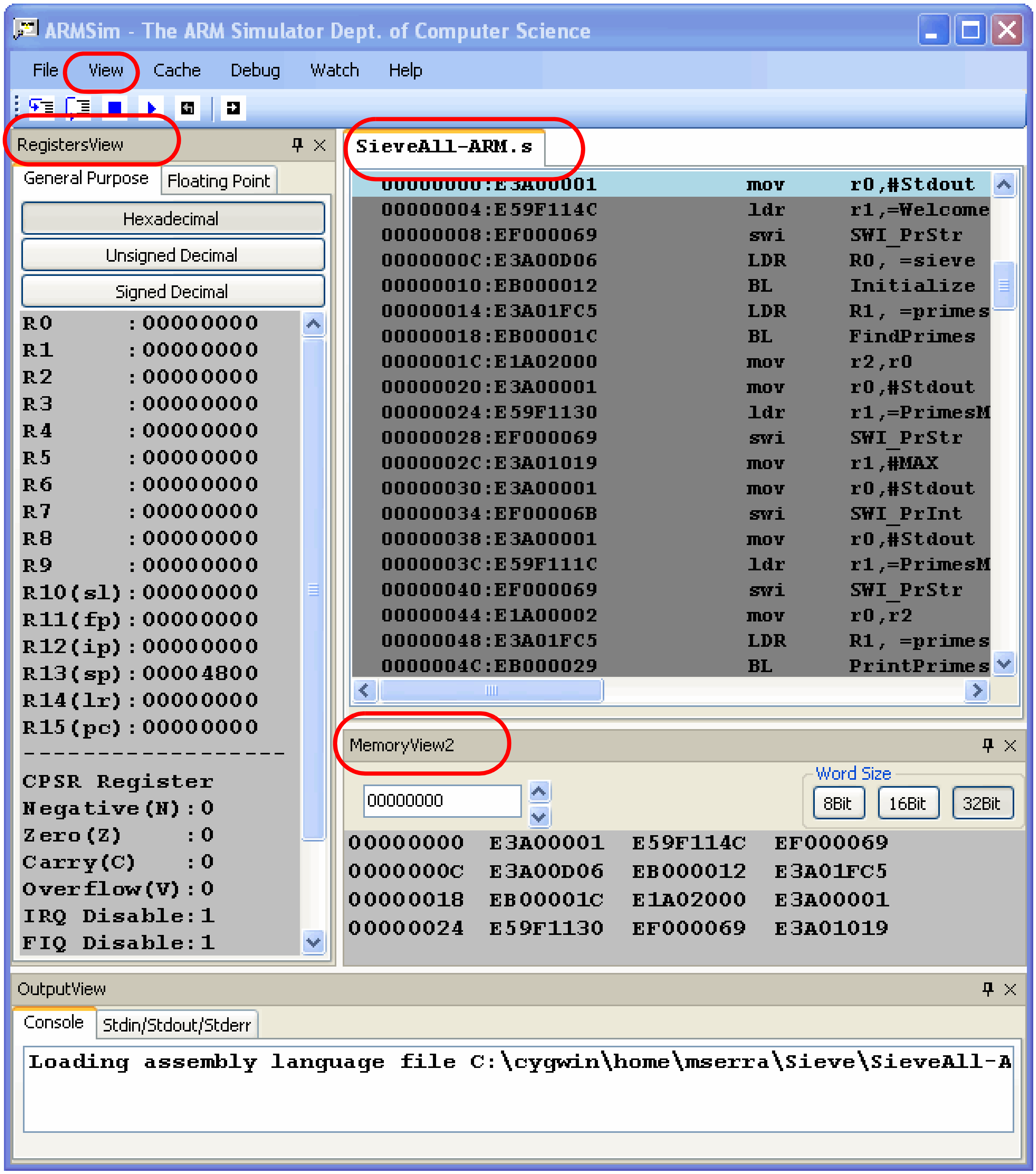


Figure 1. Views

Table 2. ARMSim# Views

Code View	It displays the assembly language instructions of the program that is currently open. This view is always visible and cannot be closed.
Registers View	It displays the contents of the 16 general-purpose user registers available in the ARM processor, as well as the status of the Current Program Status Register (CPSR) and the condition code flags. The contents of the registers can be displayed in hexadecimal, unsigned decimal, or signed decimal formats. Additionally the contents of the Vector Floating Point Coprocessor (VFP) registers can be displayed. They include the overlapped Single Precision Registers (s0-s31) and the Double Precision Floating Point Registers (d0-d15).
Output View: Console	It displays any automatic success and error messages produced by the simulator.
Output View: Stdin/Stdout/Stderr	It displays any text printed to standard output, Stdout.
Stack View	It displays the contents of the system stack. In this view, the top word in the stack is highlighted.
Watch View	It displays the values of variables that the user has added to the watch list, that is, the list of variables that the user wishes to monitor during the execution of a program.
Cache Views	They display the contents of the L1 cache. This cache can consist of either a unified data and instruction cache, displayed in the **Unified Cache View**, or separate data and instruction caches, displayed in the **Data Cache** and **Instruction Cache Views**, respectively, depending on the cache properties selected by the user.
Board Controls View	It displays the user interfaces of any loaded plug-ins. If no plug-ins were loaded at application start, this view is disabled.
Memory View	It displays the contents of main memory, as 8-bit, 16-bit, or 32-bit words. There can be multiple memory views, each displaying a different region of memory.

3. Setting up the Simulator

The appearance of ARMSim#, including the location, font, and colour of the views, can be customized to suit the user's preferences. When the simulator is closed, the settings are remembered for next time the user starts up ARMSim#. The following sections describe how to customize ARMSim#'s appearance.

3.1 Docking Windows

All views, except the **Code View**, appear in docking windows (see Figure 2). Each window can be docked along any side of the application window, or it can float above the application window. In addition, each docking window can be displayed or hidden, and each displayed window has an auto-hide option.

To move a docking window, click the title bar of the window, and drag the window to the desired location. If multiple views have been stacked within a single docking window, select the tab with the desired view name from the tabs along the bottom of the docking window, click this tab, and drag it to the desired location.

To toggle a docking window between the show and hide states, select the view name from the **View** menu. Alternatively, to hide a docking window that is currently displayed, click the **X** in the top right corner of the docking window. To toggle a docking window between the show and auto-hide modes, click the pin in the top right corner.

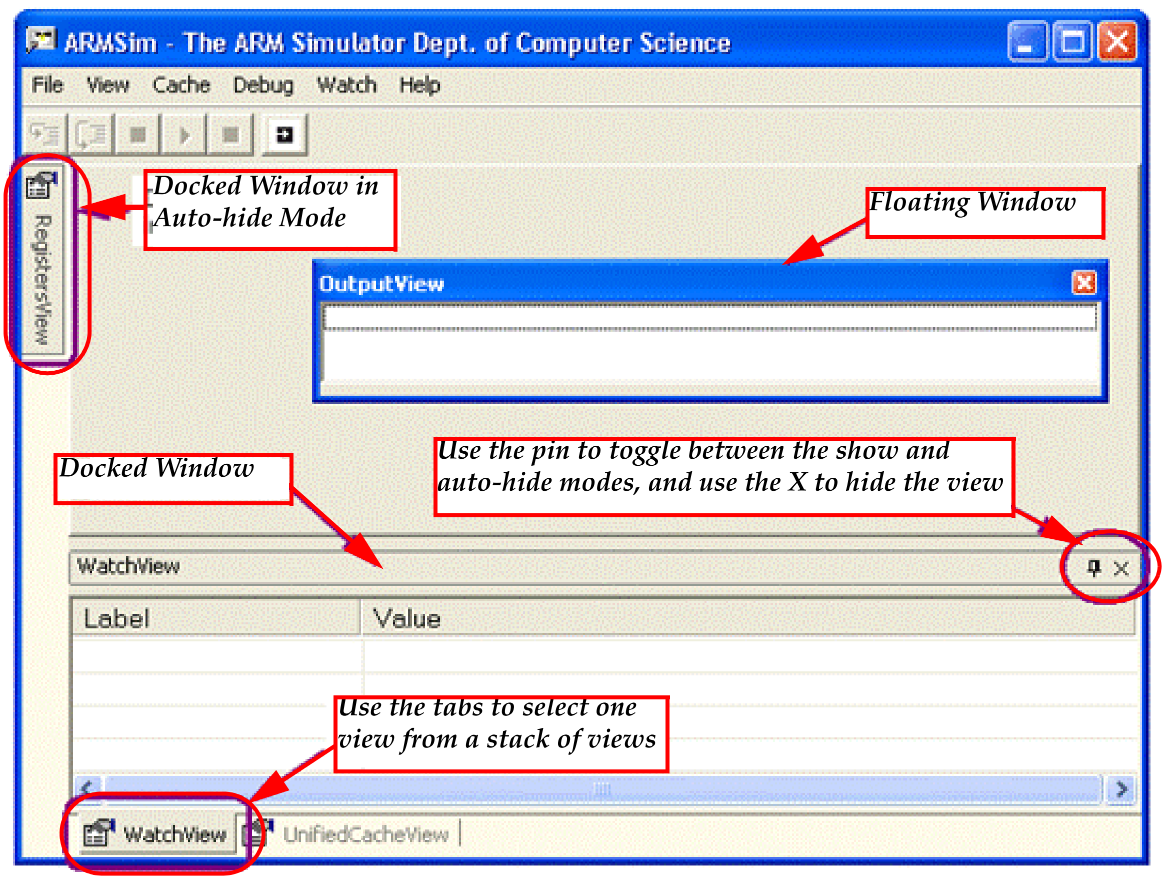


Figure 2. Docking Windows

3.2 Board Controls View: the plug-ins and the SWI instructions

While ARMSim# can be used completely on its own, the extra features of plug-ins and I/O instructions can be extremely useful. They have to be enabled explicitly even when installed at the same time. Plug-ins (see below) are seen as configurable additions to provide extra functionality, normally as a graphical view of I/O (e.g. a board with buttons and lights). One other very important extension is the use of pre-selected SWI instructions to implement I/O functionalities, such as reading and writing from standardinput or output or files (see below).

In order to enable these features, click on **File** and **Preferences** and then select the tab **Plugins**. The available modules as loaded in the ARMSim# directory are listed and need to be checked for enabling.

3.3 Fonts

To change the font, size, style, or colour of the text in a view, move the cursor into the view, click the right mouse button, and select **Font** from the context menu. Then, make changes in the **Font** dialog box, and click **OK**. To restore the original font settings, move the cursor into the view, click the right mouse button, and select **Restore Defaults** from the context menu. Note that **Restore Defaults** will also restore the default background and highlight colours.

3.4 Colours

To change the background (highlight) colour in a view, move the cursor into the view, click the right mouse button, and select **Background Colour (Highlight Colour)** from the context menu. Then, make the changes in the **Color** dialog box, and click **OK**. To restore the original background and highlight colours, move the cursor into the view, click the right mouse button, and select **Restore Defaults** from the context menu. Note that **Restore Defaults** will also restore the default font settings.

The use of the highlight colour depends on context. For example, in the **Code** and **Stack Views**, it is used as a background colour on the highlighted line, but in the **Register** and **Cache Views**, it is used as a text colour for storage locations that have been written to.

4. Getting Started

Using ARMSim# to simulate the execution of a program on an ARM processor involves two activities—actually running the program and observing the output. Sections 4.1 to 4.4 provide information on running programs with the simulator, while sections 4.5 and 4.6 describe two of the views available in the simulator.

4.1 Creating a File

ARMSim# accepts both ARM assembly source files that use the Gnu Assembler (*gas*) syntax and ARM object files generated by the Gnu tools provided with Cygwin or CodeSourcery. ARM assembly source files can be created using any text editor (e.g. TextPad) and must be saved with a .s filename extension. ARM object files can be generated from ARM assembly files or C source files and must be compiled according to the instructions in Section XX on “C and ARM”. For details on ARM assembly programming consult the references.

4.2 Opening and Loading a File

To open a file, select **File > Load**. Then navigate to the folder in which the file is stored and double-click the file to be opened. When a file is opened, it is automatically assembled (if it is a source file) and linked. If the assembly and linking processes are successful, the contents of the file appear in the

Code View with the first instruction in the _start (or main) subroutine highlighted. If the contents of the file appear in the **Code View**, but the first instruction is *not* highlighted, one must check the **Output View** for compiler errors (see section 6.3).

Notes:

- The file to be opened must be a source (.s) file or an object (.o) file.
- If the file to be opened does not appear in the directory listing in the dialog box, check to make sure that the appropriate file type has been selected.
- The source code cannot be edited in the **Code View** window, but must be changed in the original text editor and then reloaded.

4.3 Running a Program

To run the program displayed in the **Code View**, select **Debug > Run**, or click the **Continue** button on the toolbar (see Table 1). The program runs until the simulator encounters a breakpoint (see section 5.5 for an explanation of breakpoints) or an SWI 0x11 instruction (to exit the execution), or a fatal error.

4.4 Stopping a Program

To stop a program that is currently running, select **Debug > Stop**, or click the **Stop** button on the toolbar (see Table 1). When the program has stopped, any storage locations in the **Register**, **Cache**, and **Memory Views** that have been written to since the program started running are highlighted.

4.5 Code View

The **Code View** displays the assembly language instructions of the program that is currently active. Next to each instruction, the simulator shows the memory address of the instruction and the binary representation of the instruction, separated by a colon and displayed in hexadecimal format (see Figure 2).

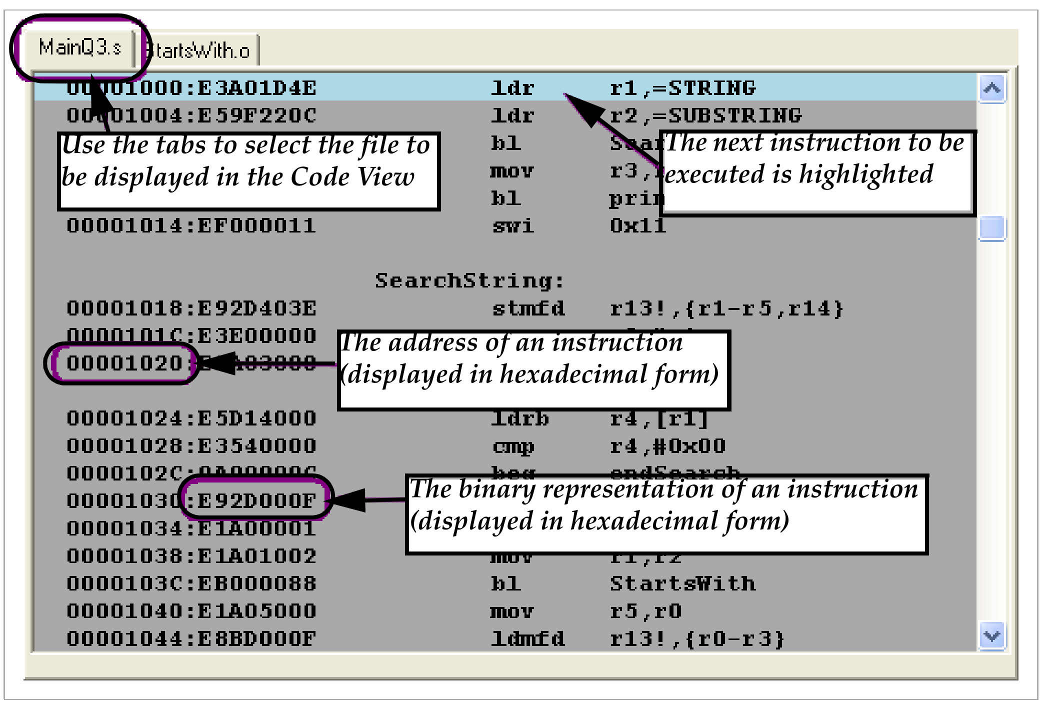


Figure 3. Code View

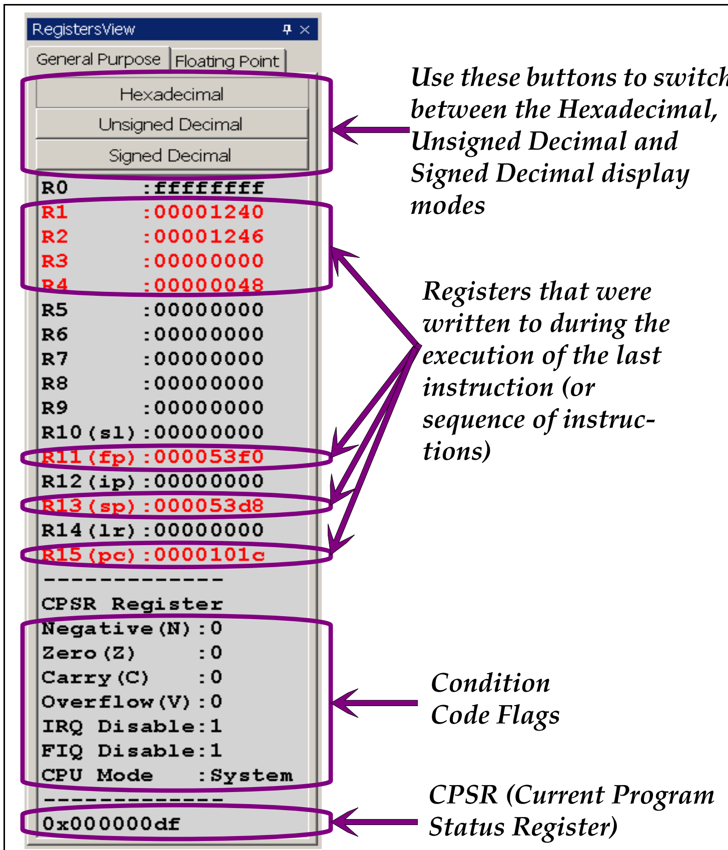
When a file is opened and successfully assembled and linked, its contents are displayed in the **Code View**, as described above, and the first instruction to be executed is highlighted. When multiple files are opened (see section 5.4), the file in which execution must start is displayed in the **Code View** with the first instruction highlighted. The other files can be viewed by clicking on the tabs at the top of the **Code View**.

4.6 Registers View

The **Registers View** displays the contents of the 16 general-purpose user registers available in the ARM processor, as well as the status of the Current Program Status Register (CPSR) and the condition code flags (the leftmost 4 bits of the CPSR, as displayed below the condition code flags in the simulator). Additionally, the Vector Floating Point (VFP) registers are available for display in the tab labelled “Floating Point”. These registers represent the 32 Single Precision registers or the 16 Double Precision Registers of the VFP. Note that these two sets of registers are overlapped.

The General Purpose Registers are selected by clicking on the “General Purpose Registers” tab in the Registers View. The contents of the general purpose registers can be displayed in hexadecimal, signed decimal, or unsigned decimal formats. Use the **Hexadecimal**, **Signed Decimal**, and **Unsigned Decimal** buttons at the top of the **Registers View** to switch between display formats (see Figure 4).

When an instruction is executed using one of the step commands (see section 5.1) or when a sequence of instructions is executed using the **Debug > Run** option or the **Continue** button (see section 4.3), any registers and condition code flags that were written to during the execution of the instruction(s) are highlighted after the execution of the instruction(s) has finished.



Registers R10-R15 are also labelled:

Table 3.

R10	sl	stack limit
R11	fp	frame pointer
R12	ip	intra-procedure-call scratch register
R13	sp	stack pointer
R14	lr	link register
R15	pc	program counter

Figure 4. General Purpose Registers View.

The Floating Point Registers are selected by clicking on the "Floating Point" tab in the Registers View. The Floating Point Registers can be viewed as Single Precision or Double Precision registers. Use the Single Precision or Double Precision tabs at the top of the Registers View to switch between the display types (see Figure 5).

5. Debugging a Program

ARMSim# provides a number of features that enable users to debug ARM assembly programs, including execution controls to step through and restart programs, **Reload** and **Open Multiple** commands, and breakpoints. Sections 5.1 and 5.2 describe the execution controls. Sections 5.3 and 5.4 describe the **Reload** and **Open Multiple** commands, respectively, and section 5.5 explains how to manage breakpoints.

5.1 Stepping Through a Program

To step through a program one instruction at a time, use either the **Step Into** button or the **Step Over** button on the toolbar, or alternatively, select **Debug > Step Into** or **Debug > Step Over**.

After an instruction has been executed using either **Step Into** or **Step Over**, both the next instruction to be executed and any memory locations in the **Registers**, **Memory**, and **Cache Views** that were written to during the execution of the instruction are highlighted.

For most instructions, the results of both **Step Into** and **Step Over** are identical; however, when an instruction is a branch to a subroutine, **Step Into** executes the branch and moves to the first instruction of the subroutine. In contrast, the **Step Over** executes the whole subroutine and moves to the instruction after the branch in the original subroutine. Therefore, if a program consists of multiple files and there is a branch from a subroutine in one file to a subroutine in another file, executing the branch using **Step Into** also changes the file displayed in the **Code View**.

5.2 Restarting a Program

To restart a program, click the **Restart** button on the toolbar, or select **Debug > Restart**. Restarting a program resets the registers, cache, and memory; it sets the program counter to the address of the first instruction in the program; and it highlights this instruction (the next instruction to be executed).

5.3 Reloading a Program

To reload a program, click the **Reload** button on the toolbar, or select **File > Reload**. Reloading a program loads a new copy of the file from the hard drive; it resets the registers, cache, memory, stack, and watches; it sets the program counter to the address of the first instruction in the program; and it highlights this instruction (the next instruction to be executed).

5.4 Opening Multiple Files

To open multiple files, select **File > Open Multiple**. Then, click the **Add** button in the **MultiFileOpen** dialog box; navigate to the folder, in which the files are stored; and double-click the file to be opened. Repeat the three steps in the previous sentence until all of the files to be opened have been added to the list in the dialog box. Then, click **OK** to open the files. When the files have been successfully opened, the contents of the file that contains the _start (or main) subroutine will appear in the **Code View** with the first instruction in this subroutine highlighted.

To remove a file from the list of files to be opened, select the filename in the dialog box, and click the **Remove** button. To remove all of the files from the list of files to be opened, click the **Clear** button.

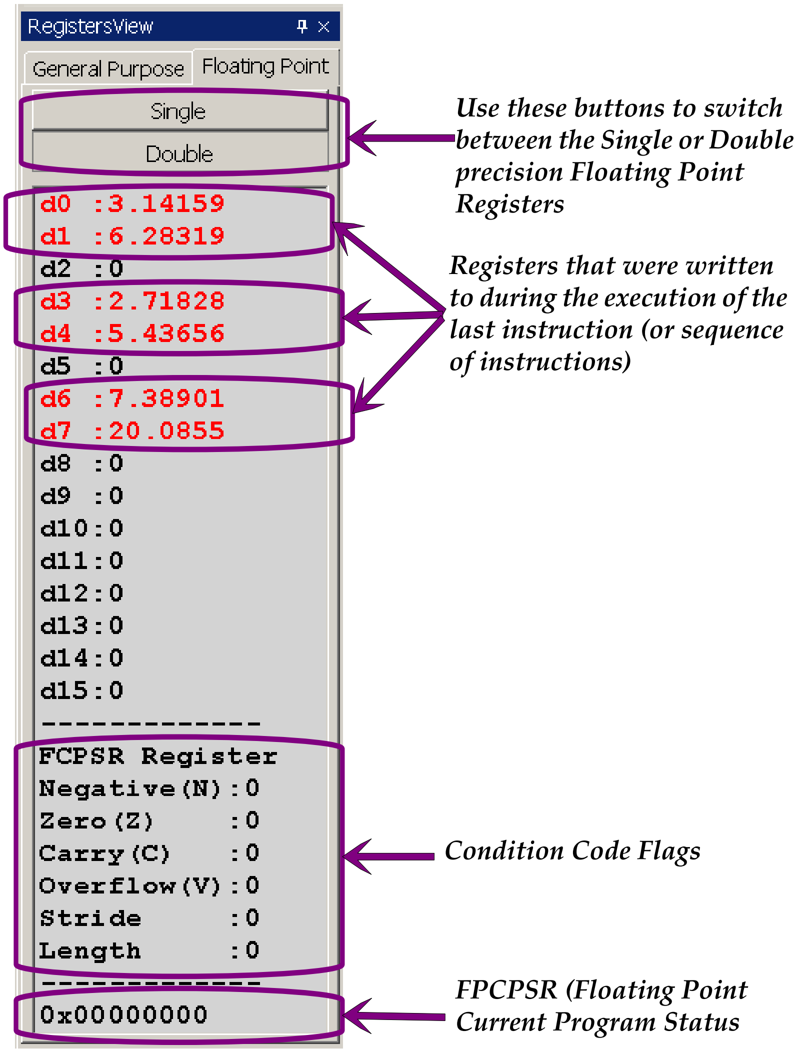


Figure 5. Floating Point Registers View.

Notes:

- The files to be opened must be ARM assembler source (.s) files, ARM object (.o) files, or a combination of source and object files.
- If a file does not appear in the directory listing in the dialog box, one must check that the appropriate file type has been selected.
- If the contents of the file appear in the **Code View**, but the first instruction is not highlighted, check the **Output View** for compiler errors (see section 6.3).
- When the file is opened, it is automatically assembled (if it is a source file) and linked.

5.5 Breakpoints

A breakpoint is a user-defined stopping point in a program (i.e. a point other than an SWI 0x11 instruction, at which execution of a program should terminate). When a program is being debugged, breakpoints are used to halt execution of the program at predefined points so that the contents of storage locations, such as registers and main memory, can be examined to ensure that the program is working correctly.

When a breakpoint is set and the program is run using either the **Debug > Run** option or the **Continue** button (see section 4.3), execution of the program stops just before execution of the instruction at which the breakpoint is set (see Figure 6).

To set a breakpoint, double-click the line of code, at which the breakpoint should be set. Alternatively, step through the code to the line, at which the breakpoint should be set, and then select **Debug > Toggle Breakpoint**. When the breakpoint is set, a large red dot appears in the **Code View** next to the address of the instruction at which the breakpoint was set.

To clear a breakpoint, double-click the line of code, at which the breakpoint is set. Alternatively, step through the code to the line, at which the breakpoint is set, and then select **Debug > Toggle Breakpoint**. To clear all of the breakpoints in a program, select **Debug > Clear All Breakpoints**.

Note:

- **Clear All Breakpoints** clears the breakpoints in *all* files that are currently open.

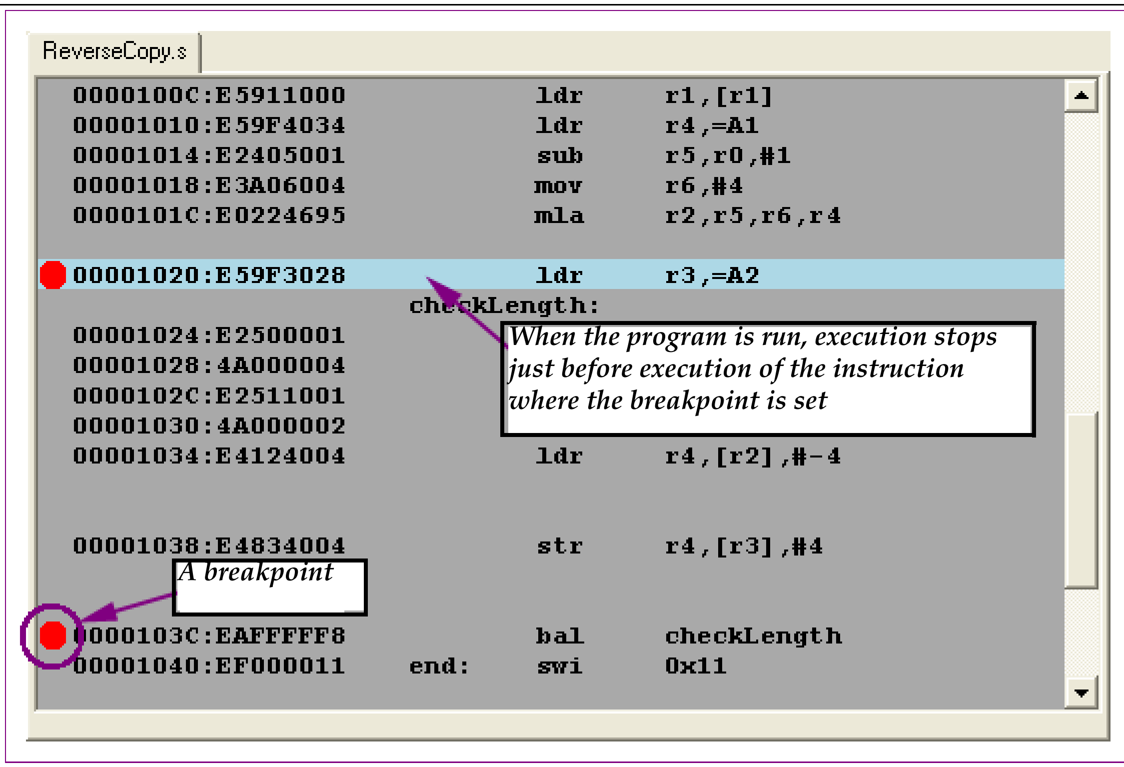


Figure 6. Breakpoints.

6. Additional Views

In addition to the **Code** and **Register Views** discussed in sections 4.5 and 4.6, respectively, ARMSim# includes **Watch**, **Memory**, **Output**, **Stack**, and **Cache Views** that enable users to observe the data transfers within the system, as well as the output of the system. The following sections describe these additional views and explain any commands and settings associated with them.

6.1 Watch View

The **Watch View** displays the values of variables that the user has added to the watch list, which is a list of variables that the user wishes to monitor during the execution of a program.

To add a variable to the watch list, select **Watch > Add Watch**. Alternatively, right-click in the **Watch View**, and select **Add Watch** from the context menu. In the **Add Watch** dialog box (see Figure 7), select the file, in which the variable appears; the label that is attached to the variable; and the display type of the variable. If applicable, specify the integer format of the variable, and select the base, in which the integer representation of the variable should be displayed. Click **OK**.

To remove a variable from the watch list, select the variable in the **Watch View**, and then select **Watch > Remove Watch**. To remove all of the variables from the watch list, select **Watch > Clear All**. Alternatively, right-click in the **Watch View**, and select **Clear All** from the context menu.

Notes:

- Although **Remove Watch** appears in the **Watch** menu, this option has not yet been implemented.
- The **Watch View** does not display arrays; however, it is possible to display the first item of an array by treating it as a scalar variable and adding it to the watch list, as described above.

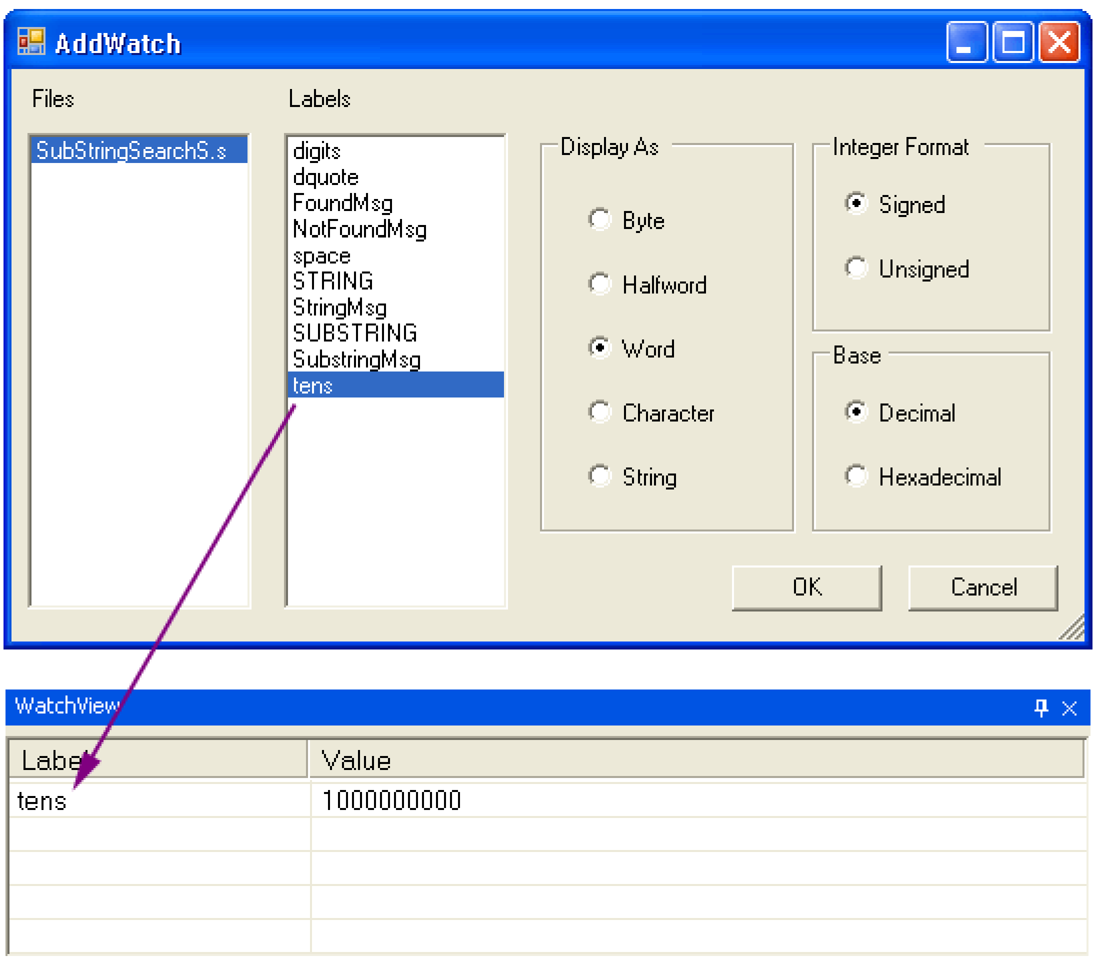


Figure 7. Adding a Watch.

6.2 Memory View

A **Memory View** displays the contents of main memory. In this view, each row contains an address followed by a series of words from memory (see Figure 8).

Since the entire main memory cannot be displayed in a single **Memory View**, each **Memory View** shows only a part of memory. The address in the top left corner of the view specifies the word, at which the part of memory displayed in the view begins, and the size of the view determines the number of words displayed.

To display a different part of memory, enter a hexadecimal address from 0 to FFFFFFFF into the text box in the top left corner of the **Memory View**. Alternatively, use the up and down arrows beside the text box to select lower and higher memory addresses, respectively. The contents of memory can be displayed as 8-bit bytes, 16-bit halfwords, or 32-bit words. Use the three buttons in the **Word Size** box in the top right corner of the **Memory View** to switch among the three display formats.

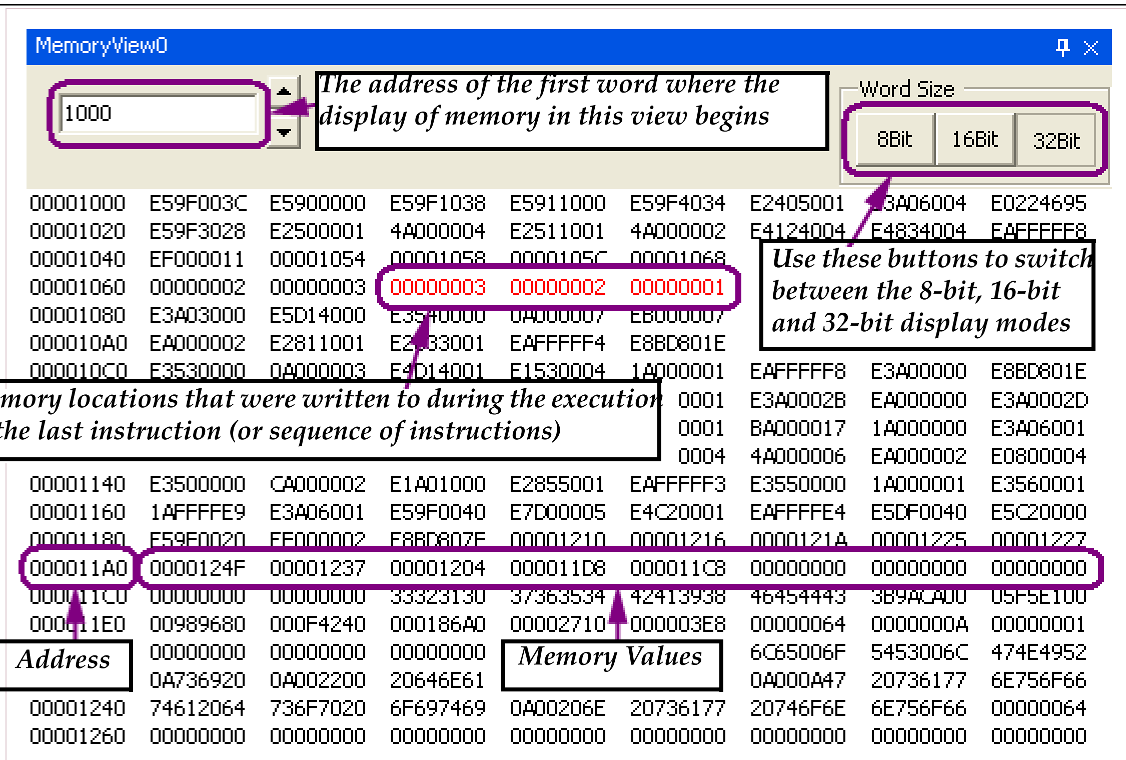


Figure 8. Memory View.

When an instruction is executed using one of the step commands (see section 5.1) or when a sequence of instructions is executed using the **Debug > Run** option or the **Continue** button (see section 4.3), any memory locations that were written to during the execution of the instruction(s) are highlighted after the execution of the instruction(s) has finished.

The properties of main memory, including its starting address, the stack area, and the heap area, can be customized to suit the user's preferences. To change these properties, select **File > Preferences**, and click the **Main Memory** tab. Type in new values for the starting address, stack area, and heap area, or use the arrow buttons beside each property to adjust the value of that property (see Figure 9). Click **OK**, and then reload the program (see section 5.3) to refresh the **Memory View(s)**.

Notes:

- If a store (STR) instruction is executed, but the value in memory does not change, check the **Cache Preferences** to make sure that the **Write Policy** is not set to **Write Back**. If it is, set it to **Write Through**. (See section 6.5 for information on setting the **Cache Preferences**.)

- The simulator can have multiple **Memory Views**, each of which displays a different region of memory. To open additional **Memory Views**, select **View > Memory**.
- When the display size is set to 8-bit, the ASCII representation of each row of bytes is displayed at the end of the row.
- When the display size is 16-bit or 32-bit, the assignment of byte addresses is little-endian.
- In the **Memory View**, all cells that are part of the memory region allocated to the program are shown in hexadecimal notation (e.g. E1A03000, 00000000); cells outside the allocated memory region are shown as question marks (e.g. ????????).

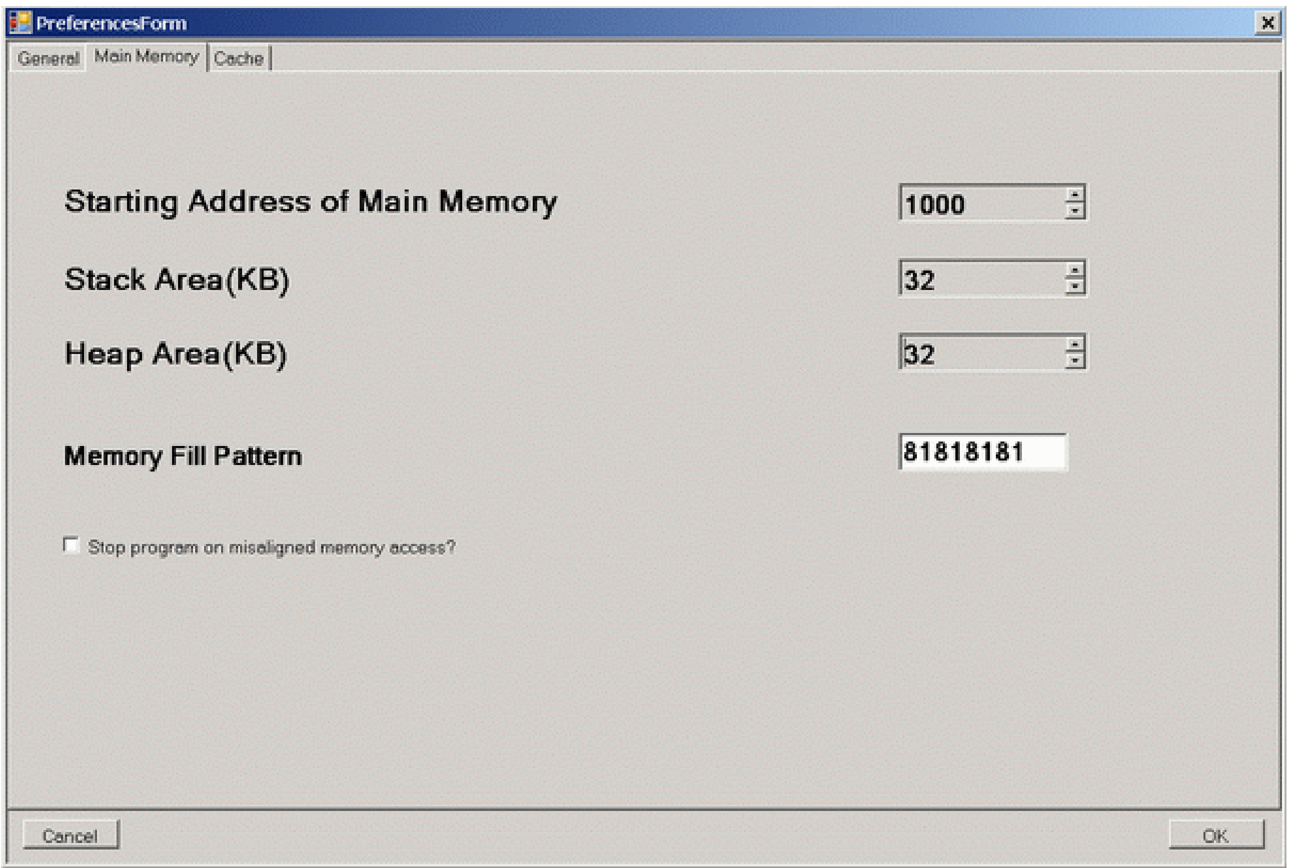


Figure 9. Main Memory Preferences Form.

6.3 Output View

The Output View contains a row of two tabs labelled “Console” and “Stdin/Stdout/Stderr”. Selecting the tab labelled “Console” brings a window to the front where the simulator outputs success and error messages. After the simulator has loaded the program, any assembler or linker errors are displayed here (see Figure 10 for an example). To find the source of an error message displayed in the **Output View** (see Figure 10), double-click the message, and scroll up one line in the **Code View**. Additional information will be displayed here such as instruction counts and runtimes.

Selecting the tab labelled “Stdin/Stdout/Stderr” brings a window to the front where output from the user program is displayed as a result of using software interrupts (SWI instructions) to perform I/O. Output directed to either the standard output or standard error (Stdin/Stdout) are displayed in this tabbed window. Any request to read from the standard input device (Stdin) causes the program to freeze until the input is provided on the keyboard; that input is echoed in this tabbed window as well.

To copy text from the one of the **Output View** tabbed windows, right-click in the view, and select **Copy to Clipboard** from the context menu. To clear the contents of the **Output View** tabbed window, right-click in the tab, and select **Clear** from the context menu.

6.4 Stack View

The **Stack View** displays the contents of the system stack. In this view, the memory address of a value and its binary representation are displayed on a single line, separated by a colon and displayed in hexadecimal format. Furthermore, the top word in the stack is highlighted (see Figure 11). Note that the system stack is a full descending stack.

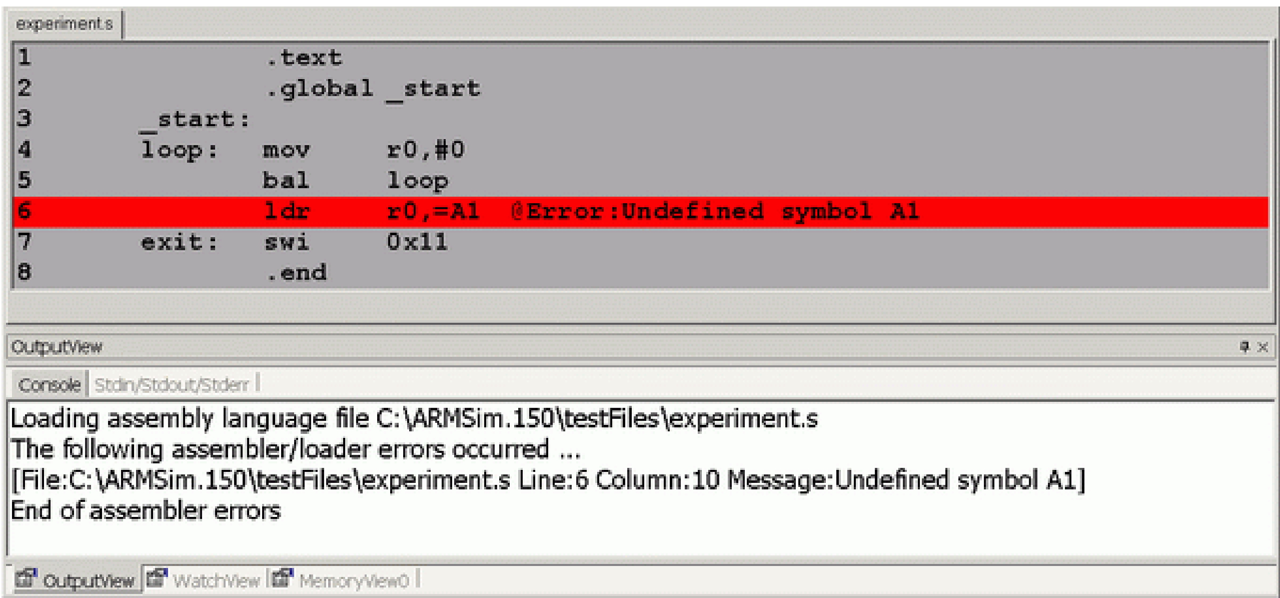


Figure 10. Error Message.

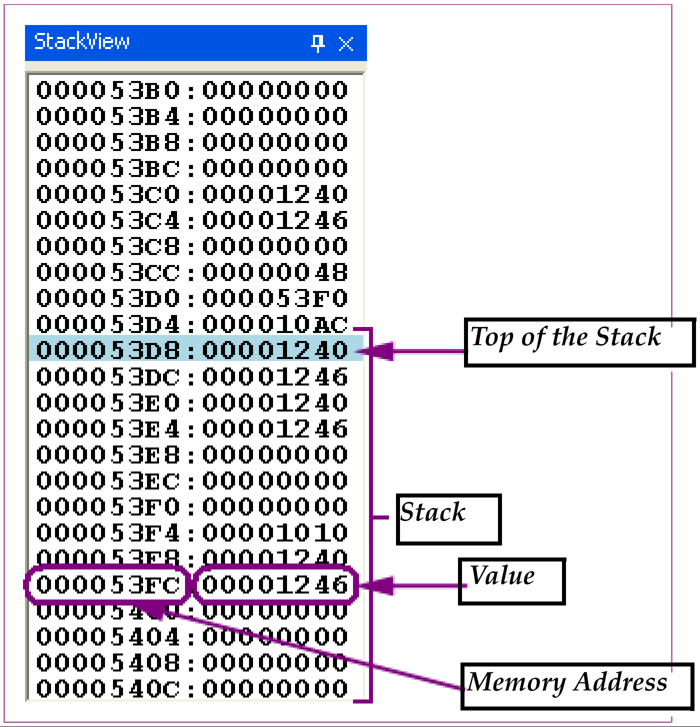


Figure 11. Stack View.

6.5 Cache Views

The **Cache Views** display the contents of the L1 cache. The cache can have different organizations. The one used by ARMSim# can be selected by the user before an ARM program is executed. The cache can consist of either a unified data and instruction cache, displayed in the **Unified Cache View**, or separate data and instruction caches, displayed in the **Data** and **Instruction Cache Views**, respectively, depending on the cache properties selected by the user.

To set the cache properties, select **File > Preferences**, and click the **Cache** tab. Then, use either the **Cache Preferences Form** (see Figure 12) or the **Cache Wizard** to change the current cache settings, and click **OK**. To restore the default cache properties, select the **Restore Defaults** button on the **Cache Preferences Form**.

When using the **Cache Preferences Form** to set the cache properties, begin by selecting the type of cache. Table 3 lists the available cache configurations. Then, set the size of the cache(s). Once the **Cache Size** has been set, selecting a value for either the **Block Size** or the **Number of Blocks** causes the remaining settings in the **Cache Size** box to assume the appropriate values, so that the three properties satisfy the following equation:

$$\textit{Cache Size (bytes)} = \textit{Block Size (bytes)} \times \textit{Number of Blocks}$$

Next, select the **Associativity** of the cache(s). If **Set Associative** is selected, set the **Blocks per Set**, and select a **Replacement Strategy**. Finally, select the **Write** and **Allocate Policies** for the **Cache** or **Data Cache**.

Table 3. Cache Configurations.

Configuration	*Settings*
Unified Data and Instruction Cache	Enable the **Unified Data and Instruction Cache**.
Separate Data and Instruction Caches	Disable the **Unified Data and Instruction Cache**, and enable the **Data Cache** and the **Instruction Cache**.
Data Cache Only	Disable the **Unified Data and Instruction Cache** and the **Instruction Cache**, and enable the **Data Cache**.
Instruction Cache Only	Disable the **Unified Data and Instruction Cache** and the **Data Cache**, and enable the **Instruction Cache**.
No Cache	Disable the **Unified Data and Instruction Cache**, the **Data Cache**, and the **Instruction Cache**.

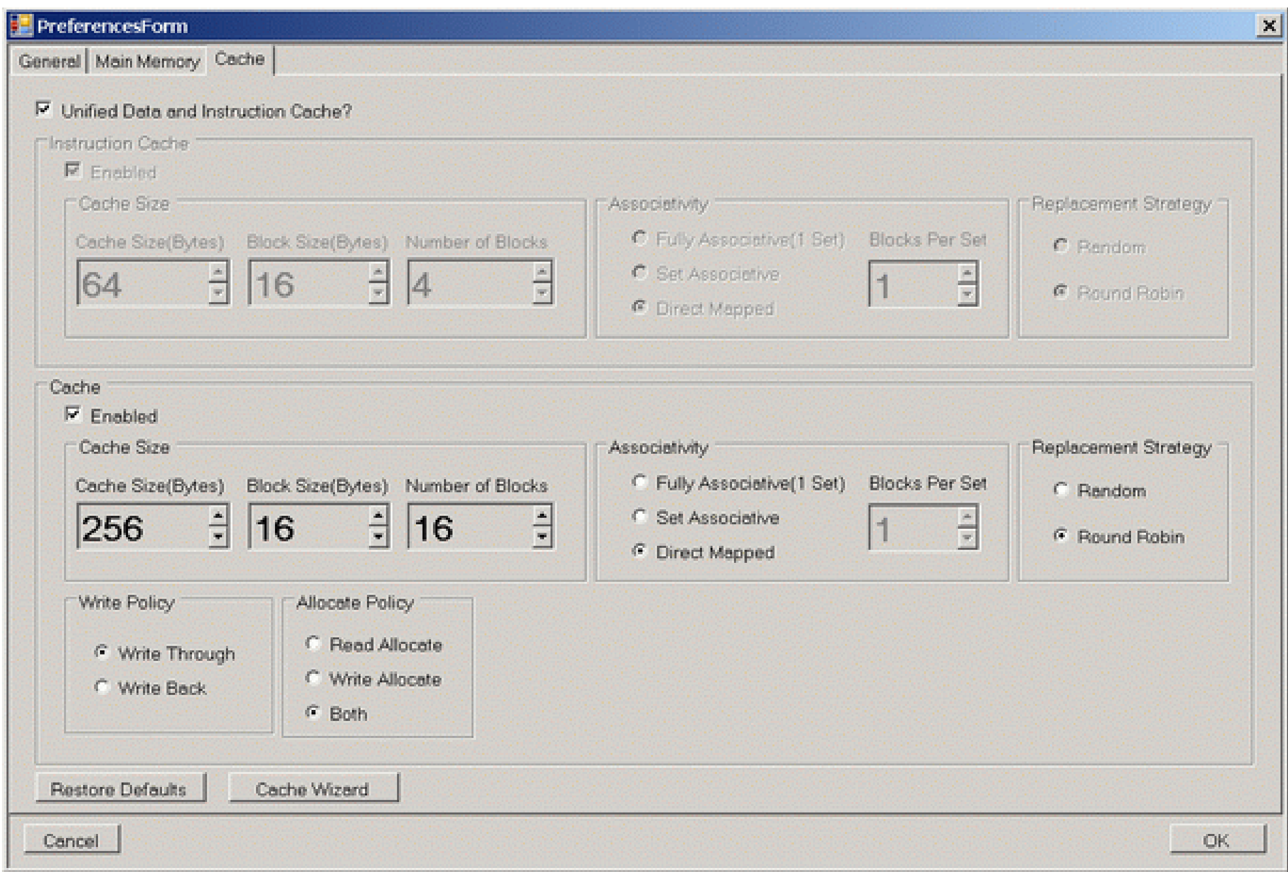


Figure 12. Cache Preferences Form.

In the **Cache Views**, the boundaries of sets are marked by the blue square brackets along the left-hand side of the view (see Figure 13). Each row consists of a memory address, followed by a cache block that shows the contents of the block at this address in memory.

When an instruction is executed using one of the step commands (see section 5.1) or when a sequence of instructions is executed using the **Debug > Run** option or the **Continue** button (see section 4.3), any cache blocks that were written to during the execution of the instruction(s) are highlighted after the execution of the instruction(s) has finished.

When the **Write Policy** is set to **Write Back**, a dirty block is marked by a red dot to the left of the row.

To clear all of the cache blocks, select **Cache > Reset**. Resetting the cache purges all of the dirty blocks, invalidates all of the cache blocks, and sets all of the cache statistics to zero. To purge all of the dirty blocks in the cache, select **Cache > Purge**. This command has no effect unless the **Write Policy** is set to **Write Back**.

To view the cache statistics, including the hit and miss rates, select **Cache > Statistics**. To clear all the cache statistics, click the **Reset** button on the **Cache Statistics** display.

Note:

- The **Instruction Cache** is sometimes referred to as the **Code Cache**.

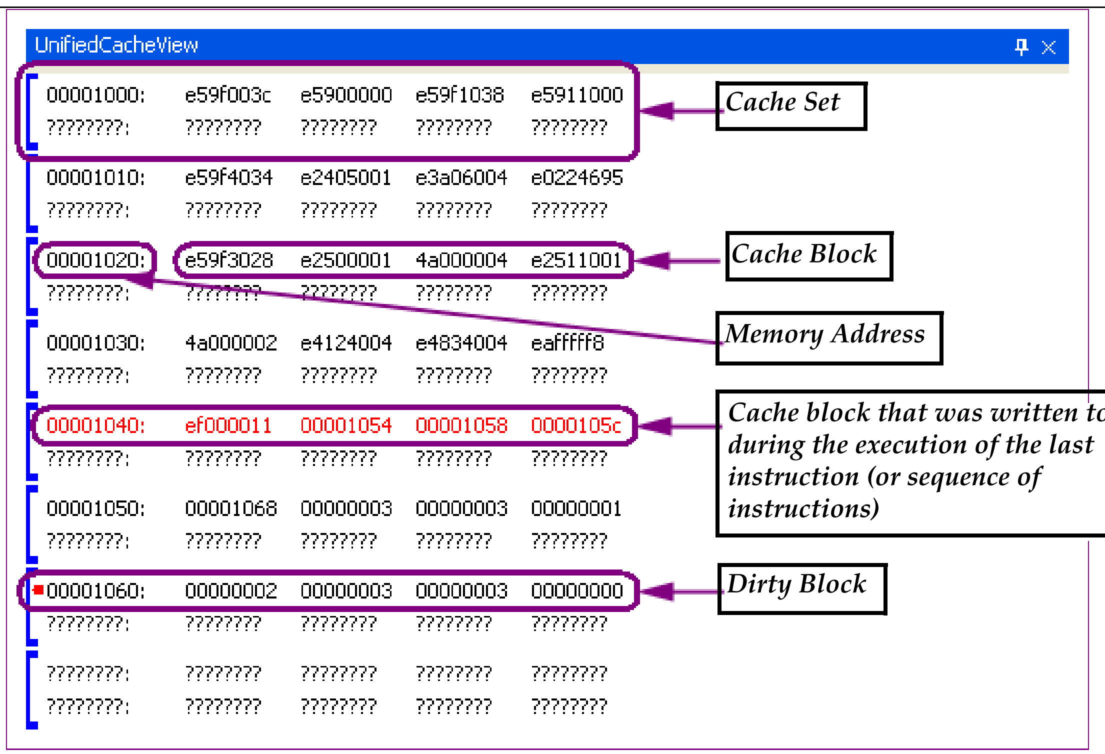


Figure 13. Cache View.

7. Some ARMSim# Limitations

The ARMSim# is an aid for learning the operation of the ARM architecture. It does not implement every feature that can be found on the ARM. Some of the more important limitations are listed below.

- The ARM architecture supports both little-endian and big-endian access to memory. The ARM-Sim# supports only the little-endian format (the same as the Intel architecture which hosts the ARMSim#).
- The ARM architecture has a special mode of execution called 'Thumb mode' which is intended for embedded system applications where memory is a scarce resource. Each thumb instruction occupies only 2 bytes. Thumb mode is not currently supported by ARMSim#.

8. SWI Codes for I/O in ARMSim#: the first Plug-in

Plug-ins have been used to extend the functionality of ARMSim# in a modular fashion. A full description of the Plug-in designs is beyond the scope of this document. The default installation of ARMSim# comes with two Plug-ins module extensions: *SWIInstructions* and *EmbestBoard*. The *SWIInstructions* plug-in implements SWI codes to extend the functionality of ARMSim# for common I/O operations and its use is detailed in this section. *Important Note: All Plug-ins have to be enabled explicitly by checking their option in the File > Preferences menu and selecting the appropriate line from within the tab labelled Plugins.*

8.1 Basic SWI Operations for I/O

The SWI codes numbered in the range 0 to 255 inclusive are reserved for basic instructions that ARM-Sim# needs for I/O and should not be altered. Their list is shown in Table 4 and examples of their use follow. The use of "`EQU`" is strongly advised to substitute the actual numerical code values. The right hand column shows the `EQU` patterns used thoughout this document in the examples.

Table 4. SWI I/O operations (0x00 - 0xFF)

Opcode	Description and Action	Inputs	Outputs	EQU
`swi 0x00`	Display Character on Stdout	r0: the character		`SWI_PrChr`
`swi 0x02`	Display String on Stdout	r0: address of a null terminated ASCII string	(see also 0x69 below)	
`swi 0x11`	Halt Execution			`SWI_Exit`
`swi 0x12`	Allocate Block of Memory on Heap	r0: block size in bytes	r0:address of block	`SWI_MeAlloc`
`swi 0x13`	Deallocate All Heap Blocks			`SWI_DAlloc`
`swi 0x66`	Open File (mode values in r1 are: 0 for input, 1 for output, 2 for appending)	r0: file name, i.e. address of a null terminated ASCII string containing the name r1: mode	r0:file handle If the file does not open, a result of -1 is returned	`SWI_Open`
`swi 0x68`	Close File	r0: file handle		`SWI_Close`
`swi 0x69`	Write String to a File or to Stdout	r0: file handleor Stdout r1: address of a null terminated ASCII string		`SWI_PrStr`

Table 4. SWI I/O operations (0x00 - 0xFF)

Opcode	Description and Action	Inputs	Outputs	EQU
swi 0x6a	Read String from a File	r0: file handle r1: destination address r2: max bytes to store	r0: number of bytes stored	SWI_RdStr
swi 0x6b	Write Integer to a File	r0: file handle r1: integer		SWI_PrInt
swi 0x6c	Read Integer from a File	r0: file handle	r0: the integer	SWI_RdInt
swi 0x6d	Get the current time (ticks)		r0: the number of ticks (milliseconds)	SWI_Timer

8.1.1 Detailed Descriptions and Examples for SWI Codes for I/O

♦ Display Character on Stdout: swi 0x00

A *character* is a 1-byte entity. The `SWI 0x00` instruction from the SWI table of the simulator (normally used with `.equ SWI_PrChr,0x00`) can print such a character to the stdout view when assigned to register r0.

The lines of code below print the character labelled "A" to the Stdout, followed by the new line character. Note that the assignment of a character to a register needs the single left quote in the syntax for the immediate operand.

Displays one character in the output window.

```
   mov  r0,#'A
   swi  PrChr
   mov  r0,#'\n
   swi  PrChr
```

♦ Display String on Stdout: swi 0x02

Displays a string in the output window. See also the more general `swi 0x69` below.

```
   ldr       r0,=MyString
   swi       0x02
   ...
MyString:  .asciz "Hello There\n"
```

♦ Halt Execution: swi 0x11

Stops the program.

```
   swi       SWI_Exit
```

♦ Allocate Block of Memory on Heap: swi 0x12

Obtain a new block of memory from the heap area of the program space. If no more memory is available, the special result -1 is returned and the C bit is set in the CPSR.

```
   mov       r0,#28   @get 28 bytes
   swi       SWI_MeAlloc
   ldr       r1,=Address
   str       r0,[r1]
   ...
Address:   .word  0
```

♦ Deallocate All Heap Blocks: swi 0x13

Causes all previously allocated blocks of memory in the heap area to be considered as deallocated (thus allowing the memory to be reused by future requests for memory blocks).

```
swi     DAlloc
```

♦ Open File: swi 0x66

Opening a file for input. Assume the following in the data section:

```
InFileName:  .asciz   "Infile1.txt"
InFileError: .asciz   "Unable to open input file\n"
    .align
InFileHandle:.word    0
```

The following lines of code open the file called “`Infile1.txt`” for input and store its file “handle”, returned in R0 by the opening call, into the appropriate memory location:.

```
    ldr  r0,=InFileName         @ set Name for input file
    mov  r1,#0                  @ mode is input
    swi  SWI_Open               @ open file for input
    bcs  InFileError            @ if error?
    ldr  r1,=InFileHandle       @ load input file handle
    str  r0,[r1]                @ save the file handle
```

Thus to open a file for input, one needs to load the address of the string containing the file name into R0, set the input mode = 0 into R1, and execute the SWI instruction with “0x66” as operand. By testing the carry bit upon return using the BCS instruction, one makes sure that the file has been opened properly, otherwise a message should be printed and the program should exit.

Opening a file for output. Assume the following in the data section:

```
OutFileName: .asciz   "Outfile1.txt"
OutFileError:.asciz   "Unable to open output file\n"
    .align
OutFileHandle:.word   0
```

The following lines of code open the file called “`Outfile1.txt`” for output and store its file “handle”, returned in R0 by the opening call, into the appropriate memory location:.

```
    ldr  r0,=OutFileName        @ set Name for output file
    mov  r1,#1                  @ mode is output
    swi  SWI_Open               @ open file for output
    bcs  OutFileError           @ if error ?
    ldr  r1,=OutFileHandle      @ load output file handle
    str  r0,[r1]                @ save the file handle
```

Thus to open a file for output, one needs to load the address of the string containing the file name into R0, set the output mode = 1 into R1, and execute the SWI instruction with “0x66” as operand. By testing the *carry bit* upon return using the `BCS` instruction, one makes sure that the file has been opened properly, or else a message should be printed and the program should exit.

Summary of the swi 0x66 file opening instruction.

Opens a text file for input or output. The file name is passed via r0. Register r1 specifies the file access mode. If r1=0, an existing text file is to be opened for input. If r1=1, a file is opened for output (if that file exists already, it will be overwritten, otherwise a new file is created). If r1=2, an existing text file is opened in append mode, so that any new text written to the file will be added at the end.
If the file is opened successfully, a positive number (the file handle) is returned in r0. Otherwise, a result of -1 is returned and the C bit is set.

```
    ldr     r0,=InFileName
    mov     r1,#0    @ input mode
    swi     SWI_Open
    bcs     NoFileFound
    ldr     r1,=InFileHandle
    str     r0,[r1]
    ...
    ldr     r0,=OutFileName
    mov     r1,#1    @ output mode
    swi     SWI_Open
    bcs     NoFileFound
    ldr     r1,=OutFileHandle
    str     r0,[r1]
    ...
OutFileHandle: .word 0
InFileHandle: .word 0
InFileName: .asciz "Infile1.txt"
OutFileName: .asciz "Outfile1.txt"
```

Note: The default location for the file is the same folder as the assembler source code file. If another location is desired, a full path to the file location can be used. For example, the code shown below opens (or creates) a text file in the Windows Temporary directory.

```
    ldrr0,PathName
    movr1,#1 @ output mode
    swiSWI_Open
    ...
PathName:
    .asciz "C:\\TEMP\\MyFile.txt"
```

♦ Close File: swi 0x68

At the end of execution a file should be properly closed, or else it may be inaccessible to other applications. The following lines of code show how to close both the input and output files used as examples above.

Closes a previously opened file. Unless a file is closed, it often cannot be inspected or edited by another program(e.g.TextPad).

```
@ load the file handle
    ldr     r0,=InFileHandle
    ldr     r0,[r0]
    swi     SWI_Close
@ load the file handle
    ldr     r0,=OutFileHandle
    ldr     r0,[r0]
    swi     SWI_Close
```

♦ Write String to a File: swi 0x69

Assume you have the following in your data section:

```
MatMsg:  .asciz   "\nThis is the resulting matrix:\n"
```

Also assume that an output file has been opened as shown above and that its name is stored in "`OutFileName`" and its file handle is stored in "`OutFileHandle`".

Then the following lines of code print the string "`\nThis is the resulting matrix:\n`" to the output file opened as shown above. The string is preceded and followed by a new line since the character "`\n`" is embedded at the end of the string.

```
ldrr0,=OutFileHandle@ load the output file handle
ldrr0,[r0]       @ R0 = file handle
ldrr1,=MatMsg    @ R1 = address of string
swiSWI_PrStr     @ output string to file
```

Writes the supplied string to the current position in the open output file. The file handle, passed in r0, must have been obtained by an earlier call to the Open File `swi` operation.

```
  ldr  r0,=OutFileHandle
  ldr  r0,[r0]
  ldr  r1,=TextString
  swi  0x69
  bcs  WriteError
  ...
TextString: .asciz "Answer = "
```

Note: The special file handle value of 1 can be used to write a string to the Stdout output window of ARMSim# (giving the same behaviour as `swi 0x02`). A brief example appears on the right.

```
  mov  r0,#1
  ldr  r1,=Message
  swi  0x69    @ display message
  ...
Message: .asciz "Hello There\n"
```

♦ Read String from a File: swi 0x6a

Reads a string from a file. The input file is identified by a file handle passed in R0. R1 is the address of an area into which the string is to be copied. R2 is the maximum number of bytes to store into memory. One line of text is read from the file and copied into memory and a null byte terminator is stored at the end. The line is truncated if it is too long to store in memory. The result returned in r0 is the number of bytes (including the null terminator) stored in memory.

```
    ldr  r0,=InFileHandle
    ldr  r0,[r0]
    ldr  r1,=CharArray
    mov  r2,#80
    swi  0x6a
    bcs  ReadError
    ...
InFileHandle: .word 0
CharArray: .skip 80
```

♦ Write Integer to a File: swi 0x6b

Converts the signed integer value passed in r1 to a string and writes that string to the file identified by the file handle passed in r0. Assumes that an output file has been opened and that its name is stored in "`OutFileName`" and its file handle is stored in "`OutFileHandle`". The lines of code on the right print the integer 42 contained in register R1 to the opened output file.

```
  ldr  r0,=OutFileHandle
  ldr  r0,[r0]
  mov  r1,#42
  swi  SWI_PrInt
```

Note: The special file handle value of 1 can be used to write the integer to the Stdout output window. An example appears on the right.

```
   mov  r0,#1
   mov  r1,#99
   swi  0x6b ; display 99
```

♦ Read Integer from a File: swi 0x6c

Reads a signed integer from a file. The file is identified by the file handle passed in r0. The result is returned in r0.
If a properly formatted number is not found in the input, the C bit is set and r0 is unchanged. By testing the *carry bit* upon return using the `BCS` instruction, one makes sure that the integer has been read properly.

```
   ldr  r0,=InputFileHandle
   ldr  r0,[r0]
   swi  0x6c
   bcs  ReadError
@ the integer is now in r0
   ...
```

9. SWI Operations for Other Plug-Ins: the Embest Board Plug-In

The SWI codes numbered greater than 255 have special purposes. They are mainly used for interaction with Plug-in modules which can be loaded with the ARMSim# simulator. Table 5 provides a current list of these codes as they are used in the *Embest Board Plug-in View*. Examples of their use follow with illustrations of the corresponding component. The use of "EQU" is strongly advised to substitute the actual numerical code values. Examples of code is also provided at the end of the section.

A diagram representing schematically the features of the Embest board is shown in Figure 14.

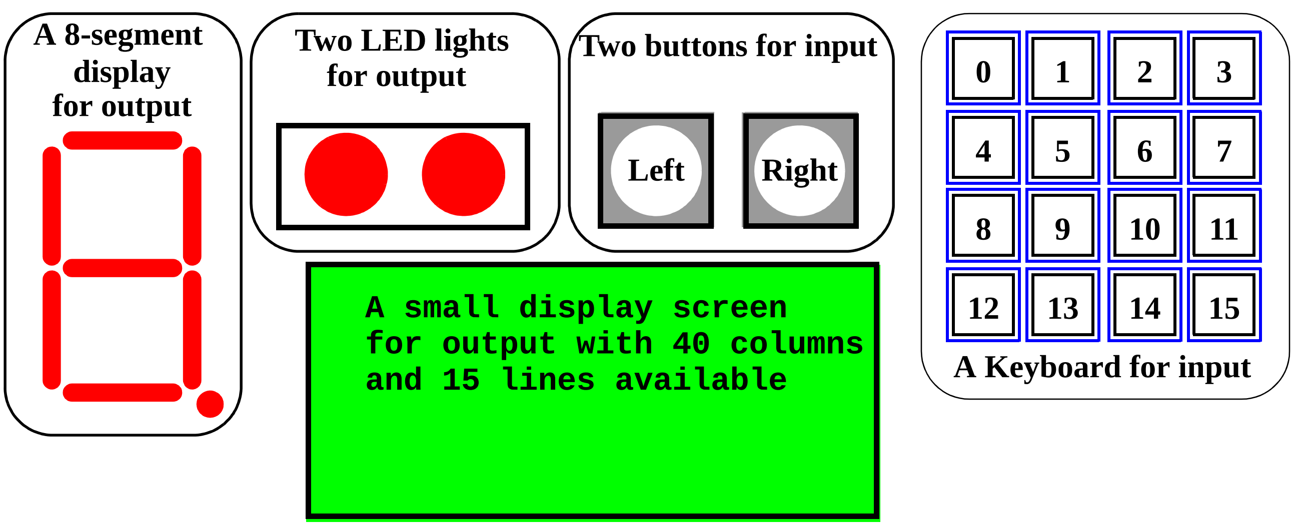


Figure 14. A diagrammatic view of the available controls and displays on the Embest Board View

There are 5 main components in this view available for programming:

1. One 8-segment display (output).
2. Two red LED lights (output).

3. Two black buttons (input).
4. Sixteen blue buttons arranged in a keyboard 4 x 4 grid (input).
5. One LCD display screen, which is a grid of 40 columns by 15 rows of individual cells. The coordinates for each LCD cell are specified by a {column, row} pair. The top-left cell has coordinates {0,0}, while the bottom-right cell has coordinates {39,14}. Each cell can contain exactly one ASCII character.

Table 5. SWI operations greater than 0xFF as currently used for the Embest board Plug-In

Opcode	Description and Action	Inputs	Outputs
`swi 0x200`	Light up the 8-Segment Display.	r0: the 8-segment Pattern (see below in Figure 15 for details)	The appropriate segments light up to display a number or a character
`swi 0x201`	Light up the two LEDs .	r0: the LED Pattern, where: Left LED on = `0x02` Right LED on = `0x01` Both LEDs on = `0x03` (i.e. the bits in position 0 and 1 of r0 must each be set to 1 appropriately)	Either the left LED is on, or the right, or both
`swi 0x202`	Check if one of the Black Buttons has been pressed.	None	r0 = the Black Button Pattern, where: Left black button pressed returns r0 = `0x02;` Right black button pressed returns r0 = `0x01;` (i.e. the bits in position 0 and 1 of r0 get assigned the appropriate values).
`swi 0x203`	Check if one of the Blue Buttons has been pressed.	None (see below in Figure 19 for details)	r0 = the Blue Button Pattern (see below in Figure 19).
`swi 0x204`	Display a string on the LCD screen	r0: x position coordinate on the LCD screen (0-39); r1: y position coordinate on the LCD screen (0-14); r2: Address of a null terminated ASCII string. Note: (x,y) = (0,0) is the top left and (0,14) is the bottom left. The display is limited to 40 characters per line.	The string is displayed starting at the given position of the LCD screen.

Table 5. SWI operations greater than 0xFF as currently used for the Embest board Plug-In

Opcode	Description and Action	Inputs	Outputs
`swi 0x205`	Display an integer on the LCD screen	r0: x position coordinate on the LCD screen (0-39); r1: y position coordinate on the LCD screen (0-14); r2: integer to print. Note: (x,y) = (0,0) is the top left and (0,14) is the bottom left. The display is limited to 40 characters per line	The string is displayed starting at the given position of the LCD screen.
`swi 0x206`	Clear the display on the LCD screen	None	Blank LCD screen.
`swi 0x207`	Display a character on the LCD screen	r0: x position coordinate on the LCD screen (0-39); r1: y position coordinate on the LCD screen (0-14); r2: the character. Note: (x,y) = (0,0) is the top left and (0,14) is the bottom left. The display is limited to 40 characters per line	The string is displayed starting at the given position of the LCD screen.
`swi 0x208`	Clear one line in the display on the LCD screen	r0: line number (y coordinate) on the LCD screen	Blank line on the LCD screen.

9.1 Details and Examples for SWI Codes for the Embest Board Plug-in

♦ Set the 8-Segment Display to light up: swi 0x200

The appropriate segments light up to display a number or a character. The pattern of segments to be lit up is assigned to register `R0` before the call to `swi 0x200`. Figure 15 shows the arrangements of segments, and an example follows. Each segment is logically labelled and its byte code is shown in the list in Table 6. For example, in Figure 15, to display the number "3", segments "*A*", "*B*", "*C*", "*D*" and "*F*" must be illuminated. The code to be assigned to `R0` is computed by the logical `OR` of the individual byte codes.

Figure 15. The Pattern for the 8-Segment Display

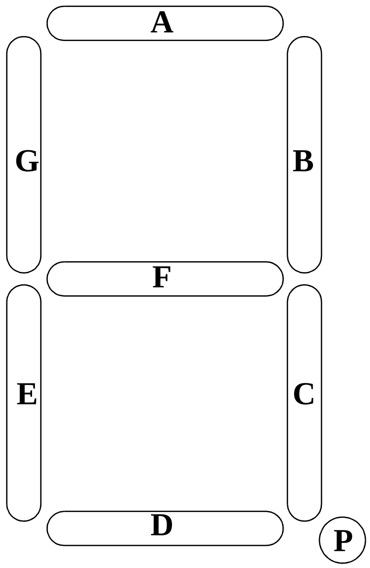
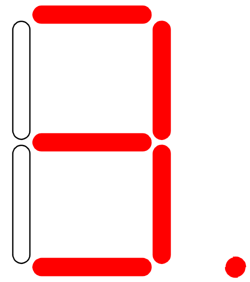


Table 6: Segmen t byte values

Display byte values	
A	0x80
B	0x40
C	0x20
P	0x10
D	0x08
E	0x04
F	0x02
G	0x01

Example: number “3” plus “dot”



As an example, the number 3 plus the right hand dot would have a pattern value computed as the logical OR of the values of the segments “A,B,C,D,F,P” to form the integer: `0x80 | 0x40 | 0x20 | 0x08 | 0x02 | 0x10 = 0xFA`, to be assigned to r0.

Below some segments of code are shown as examples for the 8-segment Display. The “`.equ`” statements are useful for accessing the byte values associated with the labels of each segment as shown in Figure 15. An example of a possible declaration of data is also given in Figure 17 for the display of integers, where the byte values representing a particular number are already “`OR`ed” together within the array data structure and can be indexed appropriately. It may be easier to use a data declaration for an array of words and then index into it. Each element can be initialized to contain the value representing a number by having the appropriate byte values “`OR`ed” together.

Use “`.equ`” statements to set up the byte value of each segment of the Display.

```
    .equ      SEG_A,0x80
    .equ      SEG_B,0x40
    .equ      SEG_C,0x20
    .equ      SEG_D,0x08
    .equ      SEG_E,0x04
    .equ      SEG_F,0x02
    .equ      SEG_G,0x01
    .equ      SEG_P,0x10
```

Figure 16. Possible data declaration for byte values for segments

A possible data declaration for an array of words which can be indexed to obtain the appropriate value for a number {0,...,9} to be displayed.

```
Digits:
  .word    SEG_A|SEG_B|SEG_C|SEG_D|SEG_E|SEG_G @0
  .word    SEG_B|SEG_C            @1
  .word    SEG_A|SEG_B|SEG_F|SEG_E|SEG_D @2
  .word    SEG_A|SEG_B|SEG_F|SEG_C|SEG_D @3
  .word    SEG_G|SEG_F|SEG_B|SEG_C @4
  .word    SEG_A|SEG_G|SEG_F|SEG_C|SEG_D @5
  .word    SEG_A|SEG_G|SEG_F|SEG_E|SEG_D|SEG_C @6
  .word    SEG_A|SEG_B|SEG_C      @7
  .word    SEG_A|SEG_B|SEG_C|SEG_D|SEG_E|SEG_F|SEG_G @8
  .word    SEG_A|SEG_B|SEG_F|SEG_G|SEG_C @9
  .word    0                     @Blank display
```

Figure 17. Possible data declaration forinteger patterns

An example of a possible routine to display a number in the 8-segment Display using the declarations given above is shown in Figure 18.

Register `R0` and `R1` are input parameters, where `R0` contains the integer to be displayed and `R1` contains "`1`" to display the "`P`" segment, or "`0`" otherwise.

```
@ *** Display8Segment (Number:R0; Point:R1) ***
@ Displays the number 0-9 in R0 on the
@ LED 8-segment display
@ If R1 = 1, the point is also shown
[1]Display8Segment:
      stmfd    sp!,{r0-r2,lr}
[2]   ldr      r2,=Digits
[3]   ldr      r0,[r2,r0,lsl#2]
[4]   tst      r1,#0x01         @if r1=1,
[5]   orrne    r0,r0,#SEG_P     @then show "P"
[6]   swi      0x200
[7]   ldmfd    sp!,{r0-r2,pc}
```

Figure 18. A possible "Display8Segment" routine

In line [3], register `r0` is assigned the byte value corresponding to the indexed element of the array digits from Figure 17. For example, to display the number "3", after execution of line [2], the input register `r0` should contain the integer value 3 and register `r2` contains the address of the array "`Digits`" . Then the computation implied by "`[r2,r0,lsl#2]`" adds 12 bytes to the address currently in `r2` (i.e. `r0` shifted left by 2 positions, which evaluates to "3" x 4 = 12) and loads the word in position 3 of the array, namely: `.word SEG_A|SEG_B|SEG_F|SEG_C|SEG_D.` In fact, this uses the segments "`A,B,C,D,F`" to display the correct number. In line [4] the content of `r1` is tested. If `r1` = 1 then the segment "`P`" is added to the display, with its value `OR`ed with the previous ones in `r0`.

♦ Set the two LEDs to light up: swi 0x201

Light up the LEDs: the left or the right or both, according to the value supplied by `r0`.

```
mov  r0,#0x02
swi  0x201          @ left LED on
mov  r0,#0x01
swi  0x201          @ right LED on
mov  r0,#0x03
swi  0x201          @ both LEDs on
```

♦ Check if one of the Black Buttons has been pressed: swi 0x202

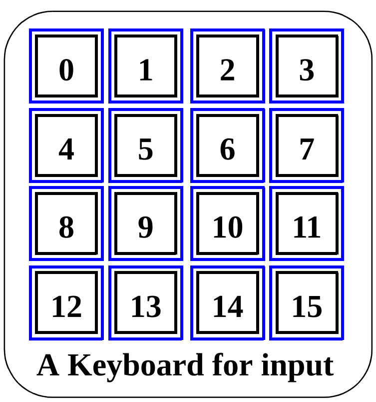
The call with `swi 0x202` sets the content of `r0` `as:r0=2` if the left black button was pressed or `r0=1`, if the right black button was pressed. Testing r0 enables follow up actions.

```
swi      0x202
cmp      r0,#0x02
beq      ActOnLeftBlack
bal      ActOnRightBlack
```

♦ Check if one of the Blue Buttons has been pressed: swi 0x203

After the call with `swi 0x203`, test the content of `r0`. The number in `r0` corresponds to the position of the blue button as depicted in Figure 19 . For example, if `r0=2` then the blue button in position 2 was pressed.

```
swi      0x203
cmp      r0,#1
cmp      r0,#2
cmp      r0,#3
. . . . .
```



The keypad with 16 blue buttons as depicted in the board view.

They are arranged such that each button has a corresponding bit position in the 16-bit lower portion of a word in register R0 after the call to swi 0x203 to poll the keypad. The "*number labels*" placed in the figure, which do not appear on the real keypad, also represent the corresponding bit position as returned in R0. When a button is pressed, the corresponding bit is set.

For example, when the button in position "1" is pressed, the `swi 0x203` instruction returns `r0 = 0x02,` that is,

`r0 = 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0`

in binary, where the bit in position "1" has been set.

Figure 19. The Pattern for the Blue Buttons

♦ Display a string on the LCD screen: swi 0x204

Display the string whose address is supplied in `r2` on the LCD screen at position (x,y), where `r0`=x and `r1`=y. In this example, `r0`=4 and `r1`=y=1 (that is, line 1 at column 4)

```
    mov  r0,#4
    mov  r1,#1
    ldr  r2,=Message
    swi  0x204    @ display message
    ...
Message: .asciz "Hello There\n"
```

♦ Display an integer on the LCD screen: swi 0x205

Display an integer on the LCD screen. The integer is in `r2`, to be shown at position (x,y), where `r0`=x and `r1`=y. In this example, r2=23, `r0`=4 and `r1`=y=1 (that is, line 1 at column 4 displays 23)

```
mov  r0,#4
mov  r1,#1
mov  r2,#23
swi  0x205    @ display integer
```

♦ Clear the display on the LCD screen: swi 0x206

Clear the whole LCD screen.

```
swi      0x206    @ clear screen
```

♦ Display a character on the LCD screen: swi 0x207

Display a character on the LCD screen. The character is in `r2`, to be shown at position (x,y), where here `r0`=x and `r1`=y. In this example, r2=’Z, `r0`=4 and `r1`=y=1 (that is, line 1 at column 4 displays Z).

```
mov  r0,#4
mov  r1,#1
mov  r2,#’Z
swi  0x207    @display char
```

♦ Clear one line in the display on the LCD screen: swi 0x208

Clear only one line on the LCD screen, where the line number is given in `r0`.

```
ldr      r0,#5
swi      0x208    @clear line 5
```

10. Combining C and ARM Code

It is useful first to review the instructions on opening and loading multiple files in Section 5.4. as combining C and ARM code requires the loading of multiple files.

10.1 Compiling a Program with C and ARM

An example program shown below in Figure 20 is constructed from two files, where the main program (in file `AddMain.s` is coded in ARM assembler and the other file (called `myAdd.c`) is coded in C and contains a function. In order to execute the program in ARMSim#, the file my`Add.c` must first be compiled to ARM assembly source file (`myAdd.s`) or to ARM object code (`myAdd.o`). This can be accomplished using a cross compiler.

```
@ File: AddMain.s
      .text
      .global _start
      .extern myAdd
_start:
      LDR   R0,=Num1
      LDR   R0,[R0]  @ first parameter passed in R0
      LDR   R1,=Num2
      LDR   R1,[R1]  @ second parameter passed in R1
      BL    myAdd    @ R0 = myAdd(Num1:R0,Num2:R1)
      LDR   R4,=Answer
      STR   R0,[R4]  @ result was returned in R0
      SWI   0x11
      .data
Num1: .word 537
Num2: .word -237
Answer:.word0
      .end
```

```
/* File: myAdd.c */

int myAdd( int arg1, int arg2 ) {
   int result = arg1 + arg2;
   return result;
}
```

Figure 20. Mixed ARM Assembler and C Program example 1

10.2 Compiling a C Program to ARM with Code Sourcery

The Code Sourcery tool chain can be used for cross compiling and a non-professional version is available for download from the site:

Code Sourcery G++ Lite Edition for ARM:
http://www.codesourcery.com/sgpp/lite/arm/portal/subscription?@template=lite

The most useful commands have also been linked into TextPad tools for easy use and both paths are shown here.

The examples assume that Code Sourcery has been installed in the directory:

```
C:\Program Files\CodeSourcery
```

All the commands below thus imply the prefix:

```
C:\Program Files\CodeSourcery\Sourcery G++ Lite\bin\
```

1. In a `cmd` window enter the command:

```
arm-none-eabi-gcc.exe –Wall –S –mcpu=arm7tdmi myAdd.c
```

Or, from TextPad use:

```
Tools | C > ARM Assembly (.s)
```

If there are no errors in the C program, the cross compiler will create an ARM assembly file named *myAdd.s*. The `-S` flag tells gcc to stop after the step of translating to assembly language.

2. To generate simpler code one should try the optimizer with:

```
arm-none-eabi-gcc.exe –Wall –S -O1 –mcpu=arm7tdmi myAdd.c
```

corresponding in TextPad to

```
Tools | C > ARM Assembly Optimize:L1(.s)
```

or with:

```
arm-none-eabi-gcc.exe –Wall –S -O2 –mcpu=arm7tdmi myAdd.c
```

corresponding in TextPad to

```
Tools | C > ARM Assembly Optimize:L2(.s)
```

3. The ARM assembly file can now be converted to an object file with:

```
arm-none-eabi-as.exe -warn -mcpu=arm7tdmi myAdd.s -o myAdd.o
```

corresponding in TextPad to

```
Tools | ARM Assembly > Binary(.o)
```

Similarly the main program in ARM can be converted from ARM assembly to an object file as in:

```
arm-none-eabi-as.exe -warn -mcpu=arm7tdmi AddMain.s -o AddMain.o
```

corresponding in TextPad to

```
Tools | ARM Assembly > Binary(.o)
```

4. Alternatively, one can compile directly from C to ARM object code using:

```
arm-none-eabi-gcc.exe -c -Wall -mcpu=arm7tdmi myAdd.c -o myAdd.o
```

corresponding in TextPad to

```
Tools | C > ARM Binary(.o)
```

10.3 Linking and Executing the Program in ARMSim#

At this point ARMSim# is able to combine the files into one program. The four acceptable choices are listed below. The **MultiFileOpen** dialog box should be used to load any of the combinations listed. ARMSim# loads and links the files, after assembling if necessary. ARMSim# is able to link and execute any of the above. During the execution the focus in the code window shifts between modules as appropriate when a `BL` instruction is invoked.

1	2	3	4
AddMain.s	AddMain.s	AddMain.o	AddMain.o
myAdd.s	myAdd.o	myAdd.s	myAdd.o

10.4 ARM Parameter Passing Conventions

The Gnu C compiler gcc can translate a function into code which conforms to the ARM procedure call standard (or APCS for short), when given the appropriate command-line options.

The APCS rules are as follows:

- The first four arguments are passed in R0, R1, R2 and R3 respectively. (If there are fewer arguments then only the first few of these registers are used.) Thus: parameter 1 always goes in R0, parameter 2 always goes in R1, parameter 3 always goes in R2, parameter 4 always goes in R3.
- Any additional arguments are pushed onto the stack.
- The return value always goes in R0.
- The function is free to destroy the contents of R0–R3 and R12 (used as "scratch"). That is, the called function can use these registers for computations and does not restore their original values when the function exits.
- The function must preserve the contents of all other registers (excluding PC of course).

Thus the C cross-compiler implements the calling conventions

Thus the version of the gcc cross-compiler from Code Sourcery implements the calling conventions and treats R0-R3 and R12 as "caller-save" registers, implying that it is the caller function responsibility to save them in the stack before the BL instruction and restore them after return.

10.5 Example 2 for combining C and ARM

Example 2 is a program with 3 files:

1. "`ARM_Main.s`" contains the main initial program in ARM which calls the function `Compute` which is in the external file "`ARM_Aux.s`". The function `Print` is called by Compute yet it is included in the main ARM file "`ARM_Main.s`".
2. "`ARM_Aux.s`" contains the function `Compute` which calls the function `Print` included in the main ARM file "`ARM_Main.s`".
3. "`Mystery.c`" contains the function `Mystery` called by `Compute`.

11. Code Examples

11.1 Example: Print Strings, Characters and Integers to Stdout using SWI Instructions for I/O

```
@@@ PRINT STRINGS, CHARACTERS, INTEGERS TO STDOUT
     .equ SWI_PrChr,0x00    @ Write an ASCII char to Stdout
     .equ SWI_PrStr, 0x69   @ Write a null-ending string
     .equ SWI_PrInt,0x6b    @ Write an Integer
     .equ Stdout,  1        @ Set output mode to be Output View
     .equ SWI_Exit, 0x11    @ Stop execution
     .global _start
     .text
_start:
@ print a string to Stdout
     mov  R0,#Stdout        @ mode is Stdout
     ldr  R1, =Message1     @ load address of Message1
     swi  SWI_PrStr         @ display message to Stdout
@ print a new line as a string to Stdout
     mov  R0,#Stdout        @ mode is Stdout
     ldr  r1, =EOL          @ end of line
     swi  SWI_PrStr
@ print a character to the screen
     mov  R0, #'A           @ R0 = char to print
     swi  SWI_PrChr
```

```
@ File: ARM_Main.s ==== Main and Print Routines
    .equ    SWI_Exit,       0x11    @ Local Constants
    .equ    SWI_PrintInt,   0x6B
    .equ    SWI_PrintChar,  0x0
    .equ    Stdout,         1
    .equ    EndInput,       -1
    .global_    start       @ Exported Symbols
    .global     Print
    .extern     Compute     @ Imported Symbols
    .text                   @ main()
_start:
    ldr     r0, =inputs
    mov     r1,#EndInput
    bl      Compute
MainEnd:
    swi     SWI_Exit
@ ==== void Print(R0:value)
Print:
    stmfd   sp!, {r0,r1,lr} @ YES, we do need this!
    mov     r1, r0          @ R1:value-to-print = R0:arg1
    mov     r0, #Stdout     @ print to console
    swi     SWI_PrintInt    @ PrintInt(R0:where, R1:value)
    mov     r0, #0x0A       @ ASCII new-line character
    swi     SWI_PrintChar   @ PrintChar(R0:value)
    ldmfd   sp!, {r0,r1,pc} @ YES, we do need this!
    .data
inputs:.word0, 1, 2, 3, 4, 5, 6, -1
    .end
```

"ARM_Main.s": main ARM routine for Example 2

```
@ print a blank character (from data)
    ldr  r0,=Blank
    ldrb r0,[r0]           @ R0 = char to print = blank
    swi  SWI_PrChr
@ print a second character to Stdout
    mov  R0, #'B           @ R0 = char to print
    swi  SWI_PrChr
@ print a new line as a character to Stdout
    ldr  r0,=NewL
    ldrb r0,[r0]           @ R0 = char to print = new line
    swi  SWI_PrChr
@ print an integer to Stdout
    mov  R0,#Stdout        @ mode is Output view
    mov  r1, #42           @ integer to print
    swi  SWI_PrInt
@ print a new line as a string to Stdout
    mov  R0,#Stdout        @ mode is Output view
    ldr  r1, =EOL          @ end of line
```

```
     swi  SWI_PrStr
     swiSWI_Exit  @ stop executing: end of program
     .data
Message1: .asciz"Hello World!"
EOL:     .asciz   "\n"
NewL:    .ascii   "\n"
Blank:   .ascii   " "
     .end
```

11.2 Example: Open and close files, read and print integers using SWI Instructions for I/O

```
@@@ OPEN INPUT FILE, READ INTEGER FROM FILE, PRINT IT, CLOSE INPUT FILE
     .equ SWI_Open, 0x66        @open a file
     .equ SWI_Close,0x68        @close a file
     .equ SWI_PrChr,0x00        @ Write an ASCII char to Stdout
     .equ SWI_PrStr, 0x69       @ Write a null-ending string
     .equ SWI_PrInt,0x6b        @ Write an Integer
     .equ SWI_RdInt,0x6c        @ Read an Integer from a file
     .equ Stdout,  1            @ Set output target to be Stdout
     .equ SWI_Exit, 0x11        @ Stop execution
     .global _start
     .text
_start:
@ print an initial message to the screen
     mov  R0,#Stdout       @print an initial message
     ldr  R1, =Message1    @ load address of Message1 label
     swi  SWI_PrStr        @ display message to Stdout
@ == Open an input file for reading =============================
@ if problems, print message to Stdout and exit
     ldr  r0,=InFileName        @ set Name for input file
     mov  r1,#0                 @ mode is input
     swi  SWI_Open              @ open file for input
     bcs  InFileError      @ Check Carry-Bit (C): if= 1 then ERROR
@ Save the file handle in memory:
     ldr  r1,=InputFileHandle   @ if OK, load input file handle
     str  r0,[r1]               @ save the file handle
@ == Read integers until end of file ==============================
RLoop:
     ldr  r0,=InputFileHandle   @ load input file handle
     ldr  r0,[r0]
     swi  SWI_RdInt             @ read the integer into R0
     bcs  EofReached       @ Check Carry-Bit (C): if= 1 then EOF reached
@ print the integer to Stdout
     mov  r1,r0                 @ R1 = integer to print
     mov  R0,#Stdout            @ target is Stdout
     swi  SWI_PrInt
     mov  R0,#Stdout            @ print new line
     ldr  r1, =NL
     swi  SWI_PrStr
     bal  RLoop                 @ keep reading till end of file
@ == End of file ===============================================
```

```
EofReached:
    mov  R0, #Stdout          @ print last message
    ldr  R1, =EndOfFileMsg
    swi  SWI_PrStr
@ == Close a file =================================================
    ldr  R0, =InFileHandle    @ get address of file handle
    ldr  R0, [R0]             @ get value at address
    swi  SWI_Close
Exit:
    swiSWI_Exit               @ stop executing
InFileError:
    mov  R0, #Stdout
    ldr  R1, =FileOpenInpErrMsg
    swi  SWI_PrStr
    bal  Exit                 @ give up, go to end
    .data
    .align
InFileHandle:    .skip    4
InFileName:      .asciz   "whatever.txt"
FileOpenInpErrMsg: .asciz "Failed to open input file \n"
EndOfFileMsg:    .asciz   "End of file reached\n"
ColonSpace:     .asciz": "
NL:          .asciz   "\n "        @ new line
Message1:    .asciz   "Hello World! \n"
    .end
```

11.3 Example: Useful patterns for using SWI Instructions for a Plug-In

This is a possible initial template to set the useful SWI codes for the Embest Board Plug-in

```
    .equ SWI_SETSEG8,      0x200        @display on 8 Segment
    .equ SWI_SETLED,       0x201        @LEDs on/off
    .equ SWI_CheckBlack,   0x202        @check Black button
    .equ SWI_CheckBlue,    0x203        @check press Blue button
    .equ SWI_DRAW_STRING,  0x204        @display a string on LCD
    .equ SWI_DRAW_INT,     0x205        @display an int on LCD
    .equ SWI_CLEAR_DISPLAY,0x206        @clear LCD
    .equ SWI_DRAW_CHAR,    0x207        @display a char on LCD
    .equ SWI_CLEAR_LINE,   0x208        @clear a line on LCD
    .equ SWI_EXIT,         0x11         @terminate program
    .equ SWI_GetTicks,     0x6d         @get current time
    .equ SEG_A,  0x80         @ patterns for 8 segment display
    .equ SEG_B,  0x40         @byte values for each segment
    .equ SEG_C,  0x20         @of the 8 segment display
    .equ SEG_D,  0x08
    .equ SEG_E,  0x04
    .equ SEG_F,  0x02
    .equ SEG_G,  0x01
    .equ SEG_P,  0x10
    .equ LEFT_LED,         0x02         @bit patterns for LED lights
    .equ RIGHT_LED,        0x01
```

```
.equ LEFT_BLACK_BUTTON,0x02        @bit patterns for black buttons
.equ RIGHT_BLACK_BUTTON,0x01       @and for blue buttons
.equ BLUE_KEY_00, 0x01    @button(0)
.equ BLUE_KEY_01, 0x02    @button(1)
.equ BLUE_KEY_02, 0x04    @button(2)
.equ BLUE_KEY_03, 0x08    @button(3)
.equ BLUE_KEY_04, 0x10    @button(4)
.equ BLUE_KEY_05, 0x20    @button(5)
.equ BLUE_KEY_06, 0x40    @button(6)
.equ BLUE_KEY_07, 0x80    @button(7)
.equ BLUE_KEY_00, 1<<8    @button(8) - different way to set
.equ BLUE_KEY_01, 1<<9    @button(9)
.equ BLUE_KEY_02, 1<<10   @button(10)
.equ BLUE_KEY_03, 1<<11   @button(11)
.equ BLUE_KEY_04, 1<<12   @button(12)
.equ BLUE_KEY_05, 1<<13   @button(13)
.equ BLUE_KEY_06, 1<<14   @button(14)
.equ BLUE_KEY_07, 1<<15   @button(15)
```

11.4 Example: Subroutine to implement a wait cycle with the 32-bit timer

```
@ Wait(Delay:r2) wait for r2 milliseconds
Wait:
    stmfd sp!, {r0-r1,lr}
    swi  SWI_GetTicks
    mov  r1, r0           @ R1: start time
WaitLoop:
    swi  SWI_GetTicks
    subs r0, r0, r1       @ R0: time since start
    rsblt r0, r0, #0      @ fix unsigned subtract
    cmp  r0, r2
    blt  WaitLoop
WaitDone:
    ldmfd sp!, {r0-r1,pc}
```

11.5 Example: Subroutine to check for an interval with a 15-bit timer (Embest Board)

The timer in ARMSim# is implemented using a 32-bit quantity and the current time (as number of ticks) is accessed by using the `SWI` instruction with operand `0x6d` (the corresponding `EQU` is set to be `SWI_GetTicks`). It returns in `R0` the number of ticks in milliseconds. On the other hand, the timer on the Embest board uses only a 15-bit quantity and this can cause a problem with rollover. Assume one checks the time at a starting point T1 and then later at point T2, and one needs to test whether a certain amount of time has passe. Ideally computing T2-T1 and comparing it to the desired interval is enough. The range in ARMSim# with a 32-bit timer is between 0 and 2^{32} -1 = 4,294,967,295. As milliseconds, this gives a range of about 71,582 minutes, which is normally enough to ensure that one can keep checking the intervals T2-T1 without T2 ever going out of range in a single program execution.

The range in the Embest board with a 15-bit timer is between 0 and 2^{15}-1 = 32,767, giving a range of only 32 seconds. When checking the interval T2-T1, there is no problem as long as T2>T1 and T2<32,767. However it can happen that T1 is obtained close to the top of the range and T1 subsequently has a value after the rollover, thus T2<T1. It is not enough to flip the sign as the following examples show.

Let T1 = 1,000 and T2 = 15,000. Then T2-T1 = 14,000 gives the correct answer for the interval. Subsequently let T1= 30,000 and the later T2 = 2,000 (afte the timer has rolled over). If one simply calculates T2-T1 = -28,000 or even tries to get its absolute value, the answer is incorrect. The value for the interval should be: (32,767 - T1) + T2 = 32,767 -30,000 + 2,000 = 4,767, which represents the correct number of ticks which passed between T1 and T2.

Two things need to be done for correct programming. First of all the timing value obtained in 32 bits in ARMSim# should be "masked" to be only a 15 bit quantity, so that the code will work both in the simulator and on the board. Secondly, the testing for the interval include a test for rollover.

```
    .equu    Sec1,             1000        @ 1 seconds interval
    .equ     Point1Sec,        100          @ 0.1 seconds interval
    .equ     EmbestTimerMask,  0x7fff       @ 15 bit mask for timer values
    .equ     Top15bitRange,    0x0000ffff   @(2^15) -1 = 32,767
    .text
_start:
    mov      r6,#0             @ counting the loops (not necessary)
    ldr      r8,=Top15bitRange
    ldr      r7,=EmbestTimerMask
    ldr      r10,=Point1Sec
    SWI      SWI_GetTicks      @Get current time T1
    mov      r1,r0             @ R1 is T1
    and      r1,r1,r7          @ T1 in 15 bits
RepeatTillTime:
    add      r6,r6,#1          @ count number of loops (not necessary)
    SWI      SWI_GetTicks      @Get current time T2
    mov      r2,r0             @ R2 is T2
    and      r2,r2,r7          @ T2 in 15 bits
    cmp      r2,r1             @ is T2>T1?
    bge      simpletime
    sub      r9,r8,r1          @ TIME= 32,676 - T1
    add      r9,r9,r2          @    + T2
    bal      CheckInt
simpletime:
    sub      r9,r2,r1          @ TIME = T2-T1
CheckInt:
    cmp      r9,r10            @is TIME < interval?
    blt      RepeatTillTime
    swi      SWI_EXIT
    .end
```

11.6 Example: Using the SWI Instructions for a Plug-In (Embest Board View)

```
@ Demonstration of Embest S3CE40 development board view
@ ===== Assume the EQU declaration from previous examples
@Clear the board, clear the LCD screen
    swi      SWI_CLEAR_DISPLAY
@Both LEDs off
    mov      r0,#0
    swi      SWI_SETLED
@8-segment blank
```

```
    mov     r0,#0
    swi     SWI_SETSEG8
@draw a message to the lcd screen on line#1, column 4
    mov     r0,#4                @ column number
    mov     r1,#1                @ row number
    ldr     r2,=Welcome          @ pointer to string
    swi     SWI_DRAW_STRING      @ draw to the LCD screen
@display the letter H in 7segment display
    ldr     r0,=SEG_B|SEG_C|SEG_G|SEG_E|SEG_F
    swi     SWI_SETSEG8
@turn on LEFT led and turn off RIGHT led
    mov     r0,#LEFT_LED
    swi     SWI_SETLED
@draw a message to the lcd screen on line#2, column 4
    mov     r0,#4        @ column number
    mov     r1,#2        @ row number
    ldr     r2,=LeftLED  @ pointer to string
    swi     SWI_DRAW_STRING  @ draw to the LCD screen
@Wait for 3 second
    ldr     r3,=3000
    BL      Wait
@turn on RIGHT led and turn off LEFT led
    mov     r0,#RIGHT_LED
    swi     SWI_SETLED
@draw a message to the lcd screen on line#2, column 4
    mov     r0,#4            @ column number
    mov     r1,#2            @ row number
    ldr     r2,=RightLED     @ pointer to string
    swi     SWI_DRAW_STRING  @ draw to the LCD screen
@Wait for 3 second
    ldr     r3,=3000
    BL      Wait
@turn on both led
    mov     r0,#(LEFT_LED|RIGHT_LED)
    swi     SWI_SETLED
@clear previous line 2
    mov     r0,#2
    swi     SWI_CLEAR_LINE
@draw a message to inform user to press a black button
    mov     r0,#6            @ column number
    mov     r1,#2            @ row number
    ldr     r2,=PressBlackL  @ pointer to string
    swi     SWI_DRAW_STRING  @ draw to the LCD screen
@wait for user to press a black button
    mov     r0,#0
LB1:
    swi     SWI_CheckBlack            @get button press into R0
    cmp     r0,#0
    beq     LB1                       @ if zero, no button pressed
    cmp     r0,#RIGHT_BLACK_BUTTON
```

```
    bne     LD1
    ldr     r0,=SEG_B|SEG_C|SEG_F     @right button, show -|
    swi     SWI_SETSEG8
    mov     r0,#RIGHT_LED             @turn on right led
    swi     SWI_SETLED
    bal     NextButtons
LD1:  @left black pressed
    ldr     r0,=SEG_G|SEG_E|SEG_F     @display |- on 8segment
    swi     SWI_SETSEG8
    mov     r0,#LEFT_LED              @turn on LEFT led
    swi     SWI_SETLED
NextButtons:
@Wait for 3 second
    ldr     r3,=3000
    BL      Wait
@Test the blue buttons 0-9 with prompting, then display
@number on 8-segment for 3 seconds. If >9, invalid.
@Draw a message to inform user to press a blue button
    mov     r0,#2               @clear previous line 2
    swi     SWI_CLEAR_LINE
    mov     r0,#6               @ column number
    mov     r1,#2               @ row number
    ldr     r2,=PressBlue       @ pointer to string
    swi     SWI_DRAW_STRING     @ draw to the LCD screen
    mov     r4,#16
BLUELOOP:
@wait for user to press blue button
    mov     r0,#0
BB1:
    swi     SWI_CheckBlue       @get button press into R0
    cmp     r0,#0
    beq     BB1                 @ if zero, no button pressed
    cmp     r0,#BLUE_KEY_15
    beq     FIFTEEN
    cmp     r0,#BLUE_KEY_14
    beq     FOURTEEN
    cmp     r0,#BLUE_KEY_13
    beq     THIRTEEN
    cmp     r0,#BLUE_KEY_12
    beq     TWELVE
    cmp     r0,#BLUE_KEY_11
    beq     ELEVEN
    cmp     r0,#BLUE_KEY_10
    beq     TEN
    cmp     r0,#BLUE_KEY_09
    beq     NINE
    cmp     r0,#BLUE_KEY_08
    beq     EIGHT
    cmp     r0,#BLUE_KEY_07
    beq     SEVEN
```

```
    cmp      r0,#BLUE_KEY_06
    beq      SIX
    cmp      r0,#BLUE_KEY_05
    beq      FIVE
    cmp      r0,#BLUE_KEY_04
    beq      FOUR
    cmp      r0,#BLUE_KEY_03
    beq      THREE
    cmp      r0,#BLUE_KEY_02
    beq      TWO
    cmp      r0,#BLUE_KEY_01
    beq      ONE
    cmp      r0,#BLUE_KEY_00
    mov      r0,#5                    @clear previous line
    swi      SWI_CLEAR_LINE
    mov      r1,#0
    mov      r0,#0
    BL   Display8Segment
    bal  CKBLUELOOP
ONE:
    mov  r0,#5               @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r1,#0
    mov  r0,#1
    BL   Display8Segment
    bal  CKBLUELOOP
TWO:
    mov  r0,#5               @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r1,#0
    mov  r0,#2
    BL   Display8Segment
    bal  CKBLUELOOP
THREE:
    mov  r0,#5               @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r1,#0
    mov  r0,#3
    BL   Display8Segment
    bal  CKBLUELOOP
FOUR:
    mov  r0,#5               @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r1,#0
    mov  r0,#4
    BL   Display8Segment
    bal  CKBLUELOOP
FIVE:
    mov  r0,#5               @clear previous line
    swi  SWI_CLEAR_LINE
```

```
    mov  r1,#0
    mov  r0,#5
    BL   Display8Segment
    bal  CKBLUELOOP
SIX:
    mov  r0,#5           @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r1,#0
    mov  r0,#6
    BL   Display8Segment
    bal  CKBLUELOOP
SEVEN:
    mov  r0,#5           @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r1,#0
    mov  r0,#7
    BL   Display8Segment
    bal  CKBLUELOOP
EIGHT:
    mov  r0,#5           @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r1,#0
    mov  r0,#8
    BL   Display8Segment
    bal  CKBLUELOOP
NINE:
    mov  r0,#5           @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r1,#0
    mov  r0,#9
    BL   Display8Segment
    bal  CKBLUELOOP
TEN:
    mov  r0,#5           @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r0,#6           @ column number
    mov r1,#5            @ row number
    ldr  r2,=InvBlue     @ pointer to string
    swi  SWI_DRAW_STRING  @ draw to the LCD screen
    mov  r1,#0
    mov  r0,#10          @ clear 8-segment
    BL   Display8Segment
    bal  CKBLUELOOP
ELEVEN:
    mov  r0,#5           @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r0,#6           @ column number
    mov r1,#5            @ row number
    ldr  r2,=InvBlue     @ pointer to string
    swi  SWI_DRAW_STRING  @ draw to the LCD screen
```

```
    mov  r1,#0
    mov  r0,#10           @ clear 8-segment
    BL   Display8Segment
    bal  CKBLUELOOP
TWELVE:
    mov  r0,#5            @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r0,#6            @ column number
    mov r1,#5             @ row number
    ldr  r2,=InvBlue      @ pointer to string
    swi  SWI_DRAW_STRING  @ draw to the LCD screen
    mov  r1,#0
    mov  r0,#10           @ clear 8-segment
    BL   Display8Segment
    bal  CKBLUELOOP
THIRTEEN:
    mov  r0,#5            @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r0,#6            @ column number
    mov r1,#5             @ row number
    ldr  r2,=InvBlue      @ pointer to string
    swi  SWI_DRAW_STRING  @ draw to the LCD screen
    mov  r1,#0
    mov  r0,#10           @ clear 8-segment
    BL   Display8Segment
    bal  CKBLUELOOP
FOURTEEN:
    mov  r0,#5            @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r0,#6            @ column number
    mov r1,#5             @ row number
    ldr  r2,=InvBlue      @ pointer to string
    swi  SWI_DRAW_STRING  @ draw to the LCD screen
    mov  r1,#0
    mov  r0,#10           @ clear 8-segment
    BL   Display8Segment
    bal  CKBLUELOOP
FIFTEEN:
    mov  r0,#5            @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r0,#6            @ column number
    mov r1,#5             @ row number
    ldr  r2,=InvBlue      @ pointer to string
    swi  SWI_DRAW_STRING  @ draw to the LCD screen
    mov  r1,#0
    mov  r0,#10           @ clear 8-segment
    BL   Display8Segment
CKBLUELOOP:
    mov  r0,#10           @clear previous line
    swi  SWI_CLEAR_LINE
```

```
    mov  r0,#4             @clear previous line
    swi  SWI_CLEAR_LINE
    mov  r0,#1             @ display number of tests
    mov r1,#4
    ldr  r2,=TestBlue
    swi  SWI_DRAW_STRING
    mov r0,#10
    mov r1,#4
    mov r2,r4
    swi  SWI_DRAW_INT
    subs r4,r4,#1
    bne  BLUELOOP          @give only 15 tests
@Prepare to exit: lst message and clear the board
@draw a message to the lcd screen on line#10, column 1
    mov  r0,#1             @ column number
    mov r1,#10             @ row number
    ldr  r2,=Bye           @ pointer to string
    swi  SWI_DRAW_STRING   @ draw to the LCD screen
@Turn off both LED's
    ldr  r0,=0
    swi  SWI_SETLED
@8-segment blank
    mov  r0,#0
    swi  SWI_SETSEG8
    ldr  r3,=2000          @delay a bit
    BL   Wait
@Clear the LCD screen
    swi  SWI_CLEAR_DISPLAY
    swi  SWI_EXIT              @all done, exit
@ ===== Display8Segment (Number:R0; Point:R1)
@ Displays the number 0-9 in R0 on the 8-segment display
@ If R1 = 1, the point is also shown
Display8Segment:
    stmfd    sp!,{r0-r2,lr}
    ldr      r2,=Digits
    ldr      r0,[r2,r0,lsl#2]
    tst      r1,#0x01 @if r1=1,
    orrne    r0,r0,#SEG_P          @then show P
    swi      SWI_SETSEG8
    ldmfd    sp!,{r0-r2,pc}
@ ===== Wait(Delay:r3) wait for r3 milliseconds
@ Delays for the amount of time stored in r3 for a 15-bit timer
Wait:
    stmfd    sp!,{r0-r5,lr}
    ldr      r4,=0x00007FFF    @mask for 15-bit timer
    SWI      SWI_GetTicks      @Get start time
    and      r1,r0,r4          @adjusted time to 15-bit
Wloop:
    SWI      SWI_GetTicks      @Get current time
    and      r2,r0,r4          @adjusted time to 15-bit
```

```
     cmp      r2,r1
     blt      Roll              @rolled above 15 bits
     sub      r5,r2,r1          @compute easy elapsed time
     bal      CmpLoop
Roll:  sub    r5,r4,r1          @compute rolled elapsed time
     add      r5,r5,r2
CmpLoop:cmp   r5,r3             @is elapsed time < delay?
     blt      Wloop        @Continue with delay
Xwait:ldmfd   sp!,{r0-r5,pc}
@ ==================================================
     .data
Welcome:      .asciz   "Welcome to Board Testing"
LeftLED:      .asciz   "LEFT light"
RightLED:     .asciz   "RIGHT light"
PressBlackL:  .asciz   "Press a BLACK button"
Bye:          .asciz   "Bye for now."
Blank:        .asciz   " "
Digits:
     .word SEG_A|SEG_B|SEG_C|SEG_D|SEG_E|SEG_G @0
     .word SEG_B|SEG_C @1
     .word SEG_A|SEG_B|SEG_F|SEG_E|SEG_D @2
     .word SEG_A|SEG_B|SEG_F|SEG_C|SEG_D @3
     .word SEG_G|SEG_F|SEG_B|SEG_C @4
     .word SEG_A|SEG_G|SEG_F|SEG_C|SEG_D @5
     .word SEG_A|SEG_G|SEG_F|SEG_E|SEG_D|SEG_C @6
     .word SEG_A|SEG_B|SEG_C @7
     .word SEG_A|SEG_B|SEG_C|SEG_D|SEG_E|SEG_F|SEG_G @8
     .word SEG_A|SEG_B|SEG_F|SEG_G|SEG_C @9
     .word 0  @Blank display
PressBlue:    .asciz   "Press a BLUE button 0-9 only - 15 tests"
InvBlue:      .asciz   "Invalid blue button - try again"
TestBlue:     .asciz   "Tests ="
     .end
```