

Lecture Handouts

Computer Architecture

Appendix

Reading Material

Handouts

Summary

1. Introduction to FALSIM
2. Preparing source files for FALSIM
3. Using FALSIM
4. FALCON-A assembly language techniques

FALSIM

1. Introduction to FALSIM:

FALSIM is the name of the software application which consists of the FALCON-A assembler and the FALCON-A simulator. It runs under Windows XP.

FALCON-A Assembler:

Figure 1 shows a snapshot of the FALCON-A Assembler. This tool loads a FALCON-A assembly file with a (.asmfa) extension and parses it. It shows the parse results in an error log, lets the user view the assembled file's contents in the file listing and also provides the features of printing the machine code, an Instruction Table and a Symbol Table to a FALCON-A listing file. It also allows the user to run the FALCON-A Simulator.

The FALCON-A Assembler has two main modules, the 1st-pass and the 2nd-pass. The 1st-pass module takes an assembly file with a (.asmfa) extension and processes the file contents. It then creates a Symbol Table

which corresponds to the storage of all program variables, labels and data values in a data structure at the implementation level. If the 1st-pass completes successfully a Symbol Table is produced as an output, which is used by the 2nd-pass module. Failures of the 1st-pass are handled by the assembler using its exception handling mechanism.

The 2nd-pass module sequentially processes the .asmfa file to interpret the instruction opcodes, register opcodes and constants using the symbol table. It then produces a list file with a .lstfa extension independent of successful or failed pass. If the pass is successful a binary file with a .binfa extension is produced which contains the machine code for the program in the assembly file.

FALCON-A Simulator:

Figure 6 shows a snapshot of the FALCON-A Simulator. This tool loads a FALCON-A binary file with a (.binfa) extension and presents its contents into different areas of the simulator. It allows the user to execute the program to a specific point within a time frame or just executes it, line by line. It also allows the user to view the registers, I/O port values and memory contents as the instructions execute.

FALSIM Features:

The FALCON-A Assembler provides its user with the following features:

Select Assembly File: Labeled as “1” in Figure 1, this feature enables the user to choose a FALCON-A assembly file and open it for processing by the assembler.

Assembler Options: Labeled as “2” in Figure 1.

- *Print Symbol Table*

This feature if selected writes the Symbol Table (produced after the execution of the 1st-pass of the assembler) to a FALCON-A list file with an extension of (.lstfa). The Symbol Table includes data members, data addresses and labels with their respective values.

- *Print Instruction Table*

This feature if selected writes the Instruction Table to a FALCON-A list file with an extension of (.lstfa).

List File: Labeled as “3”, in Figure 1, the List File feature gives a detailed insight of the FALCON-A listing file, which is produced as a result of the execution of the 1st and 2nd-pass. It shows the Program Counter value in hexadecimal and decimal formats along with the machine code generated for every line of assembly code. These values are printed when the 2nd-pass is completed.

Error Log: The Error Log is labeled as “4” in Figure 1. It informs the user about the errors and their respective details, which occurs in any of the passes of the assembler.

Search: Search is labeled as “5” in Figure 1 and helps the user to search for a certain input with the options of searching with “**match whole**” and “**match any**” parts of the string. The search also has the option of checking with/without considering “**case-sensitivity**”. It searches the List File area and highlights the search results using the yellow color. It also indicates the total number of matches found.

Start Simulator: This feature is labeled as “6” in Figure 1. The FALCON-A Simulator is run using the FALCON-A Assembler’s Start Simulator option. The FALCON-A Simulator is invoked by the user from the FALCON-A Assembler. Its features are detailed as follows:

Load Binary File: The button labeled as “11” in Figure 6, allows the user to choose and open a FALCON-A binary file with a (.binfa) extension. When a file is being loaded into the simulator all the register, constants (if any) and memory values are set.

Registers: The area labeled as “12” in Figure 6. enables, the user to see values present in different registers before during and after execution.

Instruction: This area is labeled as “13” in Figure 6 and contains the value of PC, address of an instruction, its representation in Assembly, the Register Transfer Language, the op-code and the instruction type.

I/O Ports: I/O ports are labeled as “14” in Figure 6. These ports are available for the user to enter input operation values and visualize output operation values whenever an I/O operation takes place in the program. The input value for an input operation is given by the user before an instruction executes. The output values are visible in the I/O port area once the instruction has successfully executed.

Memory: The memory is divided into 2 areas and is labeled as “15” in Figure 6, to facilitate the view of data stored at different memory locations before, during and after program execution.

Processor’s State: Labeled as “16” in Figure 6, this area shows the current values of the Instruction register and the Program Counter while the program executes.

Search: The search option for the FALCON-A simulator is labeled as “17” in Figure 6. This feature is similar to the way the search feature of the FALCON-A Assembler works. It offers to highlight the search string which goes as an input, with the “All “ and “ Part “ option. The results of the search are highlighted in the color yellow. It also indicates the total number of matches.

The following is a description of the options available on the button panel labeled as “18” in Figure 6.

Single Step: “Single Step” lets the user execute the program, one instruction at a time. The next instruction is not executed unless the user does a “single step” again. By default, the instruction to be executed will be the one next in the sequence. It changes if the user specifies a different PC value using the Change PC option (explained below).

Change PC: This option lets the user change the value of PC (Program Counter). By changing the PC the user can execute the instruction to which the specified PC points.

Execute: By choosing this button the user is able to execute the instructions with the options of execution with/without breakpoint insertion (refer to Fig. 5). In case of breakpoint insertion, the user has the option to choose from a list of valid breakpoint values. It also has the option to set a limit on the time for execution. This “Max Execution Time” option restricts the program execution to a time frame specified by the user, and helps the simulator in exception handling.

Change Register: Using the Change Register feature, the user can change the value present in a particular register.

Change Memory Word: This feature enables the user to change values present at a particular memory location.

Display Memory: Display Memory shows an updated memory area, after a particular memory location other than the pre-existing ones is specified by the user.

Change I/O: Allows the user to give an I/O port value if the instruction to be executed requires an I/O operation. Giving in the input in any one of the I/O ports areas before instruction execution, indicates that a particular I/O operation will be a part of the program and it will have an input from some source. The value given by the user indicates the input type and source.

Display I/O: Display I/O works in a manner similar to Display Memory. Here the user specifies the starting index of an I/O port. This features displays the I/O ports stating from the index specified.

2. Preparing source files for FALSIM:

In order to use the FALCON-A assembler and simulator, FALSIM, the source file containing assembly language statements and directives should be prepared according to the following guidelines:

- The source file should contain ASCII text only. Each line should be terminated by a carriage return. The extension **.asmfa** should be used with each file name. After assembly, a list file with the original filename and an extension **.lstfa**, and a binary file with an extension **.binfa** will be generated by FALSIM.
- Comments are indicated by a semicolon (;) and can be placed anywhere in the source file. The FALSIM assembler ignores any text after the semicolon.
- Names in the source file can be of one of the following types:
 - Variables: These are defined using the **.equ** directive. A value must also be assigned to variables when they are defined.
 - Addresses in the “data and pointer area” within the memory: These can be defined using the **.dw** or the **.sw** directive. The difference between these two directives is that when **.dw** is used, it is not possible to store any value in the memory. The integer after **.dw** identifies the number of memory words to be reserved starting at the current address. (The directive **.db** can be used to reserve bytes in

- memory.) Using the **.sw** directive, it is possible to store a constant or the value of a name in the memory. It is also possible to use pointers with this directive to specify addresses larger than 127. Data tables and jump tables can also be set up in the memory using this directive.
- Labels: An assembly language statement can have a unique label associated with it. Two assembly language statements cannot have the same name. Every label should have a colon (:) after it.
 - Use the **.org 0** directive as the first line in the program. Although the use of this line is optional, its use will make sure that FALSIM will start simulation by picking up the first instruction stored at address 0 of the memory. (Address 0 is called the reset address of the processor). A **jump [first]** instruction can be placed at address 0, so that control is transferred to the first executable statement of the main program. Thus, the label **first** serves as the identifier of the “entry point” in the source file. The **.org** directive can also be used anywhere in the source file to force code at a particular address in the memory.
 - Address 2 in the memory is reserved for the pointer to the Interrupt Service Routine (ISR). The **.sw** directive can be used to store the address of the first instruction in the ISR at this location.
 - Address 4 to 125 can be used for addresses of data and pointers¹. However, the main program must start at address 126 or less², otherwise FALSIM will generate an error at the **jump [first]** instruction.
 - The main program should be followed by any subprograms or procedures. Each procedure should be terminated with a **ret** instruction. The ISR, if any, should be placed after the procedures and should be terminated with the **iret** instruction.
 - The last line in the source file should be the **.end** directive.
 - The **.equ** directive can be used anywhere in the source file to assign values to variables.
 - It is the responsibility of the programmer to make sure that code does not overwrite data when the assembly process is performed, or vice versa. As an example, this can happen if care is not exercised during the use of the **.org** directive in the source file.

3. Using FALSIM:

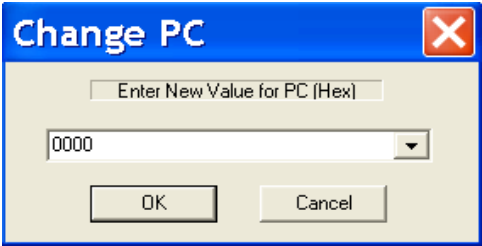
¹ Any address between 4 and 14 can be used in place of the displacement field in load or store instructions. Recall that the displacement field is just 5 bits in the instruction word.

² This restriction is because of the fact that the immediate operand in the **movi** instruction must fit an 8-bit field in the instruction word.

- To start FALSIM (the FALCON-A assembler and simulator), double click on the FALSIM icon. This will display the assembler window, as shown in the Figure 1.
- Select one or both assembler options shown on the top right corner of the assembler window labeled as “2”. If no option is selected, the symbol table and the instruction table will not be generated in the list (.lstfa) file.
- Click on the select assembly file button labeled as “1”. This will open the dialog box as shown in the Figure 2.
- Select the path and file containing the source program that is to be assembled.
- Click on the open button. FALSIM will assemble the program and generate two files with the same filename, but with different extensions. A list file will be generated with an extension .lstfa, and a binary (executable) file will be generated with an extension .binfa. FALSIM will also display the list file and any error messages in two separate panes, as shown in Figure 3.
- Double clicking on any error message highlights and displays the corresponding erroneous line in the program listing window pane for the user. This is shown in Figure 4. The highlight feature can also be used to display any text string, including statements with errors in them. If the assembler reported any errors in the source file, then these errors should be corrected and the program should be assembled again before simulation can be done. Additionally, if the source file had been assembled correctly at an earlier occasion, and a correct binary (.binfa) file exists, the simulator can be started directly without performing the assembly process.
- To start the simulator, click on the start simulation button labeled as “6”. This will open the dialog box shown in Figure 6.
- Select the binary file to be simulated, and click open as shown in Figure 7.
- This will open the simulation window with the executable program loaded in it as shown in Figure 8. The details of the different panes in

this window were given in section 1 earlier. Notice that the first instruction at address 0 is ready for execution. All registers are initialized to 0. The memory contains the address of the ISR (i.e., 64h which is 100 decimal) at location 2 and the address of the printer driver at location 4. These two addresses are determined at assembly time in our case. In a real situation, these addresses will be determined at execution time by the operating system, and thus the ISR and the printer driver will be located in the memory by the operating system (called re-locatable code). Subsequent memory locations contain constants defined in the program.

- Click single step button labeled as “**19**”. FALSIM will execute the **jump [main]** instruction at address 0 and the PC will change to 20h (32 decimal), which is the address of the first instruction in the main program (i.e., the value of main).
- Although in a real situation, there will be many instructions in the main program, those instructions are not present in the dummy calling program. The first useful instruction is shown next. It loads the address of the printer driver in r6 from the pointer area in the memory. The registers r5 and r7 are also set up for passing the starting address of the print buffer and the number of bytes to be printed. In our dummy program, we bring these values in to these registers from the data area in the memory, and then pass these values to the printer driver using these two registers. Clicking on the single step button twice, executes these two instructions.
- The execution of the call instruction simulates the event of a print request by the user. This transfers control to the printer driver. Thus, when the **call r4, r6** instruction is single stepped, the PC changes to 32h (50 decimal) for executing the first instruction in the printer driver.
- Double click on memory location 000A, which is being used for holding the PB (printer busy) flag. Enter a 1 and click the change memory button. This will store a 0001 in this location, indicating that a previous print job is in progress. Now click single step and note that this value is brought from memory location 000E into register r1. Clicking single step again will cause the **jnz r1, [message]** instruction to execute, and control will transfer to the message routine at address 0046h. The **nop** instruction is used here as a place holder.

- Click again on the single step button. Note that when the **ret r4** instruction executes, the value in r4 (i.e., 28h) is brought into the PC. The blue highlight bar is placed on the next instruction after the **call r4, r6** instruction in the main program. In case of the dummy calling program, this is the **halt** instruction.
- Double click on the value of the PC labeled as “20”. This will open a dialog box shown below. Enter a value of the PC (i.e., 26h) corresponding to the **call r4, r6** instruction, so that it can be executed again. A “list” of possible PC values can also be pulled down using, and 0026h can be selected from there as well.A screenshot of a 'Change PC' dialog box. It has a blue title bar with the text 'Change PC' and a red close button. The main area is light gray and contains a label 'Enter New Value for PC (Hex)' above a text input field. The input field contains '0000' and has a dropdown arrow on its right. Below the input field are two buttons: 'OK' and 'Cancel'.
- Click single step again to enter the printer driver again.
- Change memory location 000A to a 0, and then single step the first instruction in the printer driver. This will bring a 0 in r1, so that when the next **jnz r1, [message]** instruction is executed, the branch will not be taken and control will transfer to the next instruction after this instruction. This is **mivi r1, 1** at address 0036h.
- Continue single stepping.
- Notice that a 1 has been stored in memory location 000A, and r1 contains 11h, which is then transferred to the output port at address 3Ch (60 decimal) when the **out r1, controlp** instruction executes. This can be verified by double clicking on the top left corner of the I/O port pane, and changing the address to 3Ch. Another way to display the value of an I/O port is to scroll the I/O window pane to the desired position.
- Continue single stepping till the **int** instruction and note the changes in different panes of the simulation window at each step.
- When the **int** instruction executes, the PC changes to 64h, which is the address of the first instruction in the ISR. Clicking single step executes this instruction, and loads the address of **temp** (i.e., 0010h) which is a

temporary memory area for storing the environment. The five **store** instructions in the ISR save the CPU environment (working registers) before the ISR change them.

- Single step through the ISR while noting the effects on various registers, memory locations, and I/O ports till the **iret** instruction executes. This will pass control back to the printer driver by changing the PC to the address of the **jump [finish]** instruction, which is the next instruction after the **int** instruction.
- Double click on the value of the PC. Change it to point to the **int** instruction and click single step to execute it again. Continue to single step till the **in r1, statusp** instruction is ready for execution.
- Change the I/O port at address 3Ah (which represents the status port at address 58) to 80 and then single step the **in r1, statusp** instruction. The value in r1 should be 0080.
- Single step twice and notice that control is transferred to the **movi r7, FFFF³** instruction, which stores an error code of -1 in r1.

³ The instruction was originally **movi r7, -1**. Since it was converted to machine language by the assembler, and then reverse assembled by the simulator, it became **movi r7, FFFF**. This is because the machine code stores the number in 16-bits after sign-extension. The result will be the same in both cases.

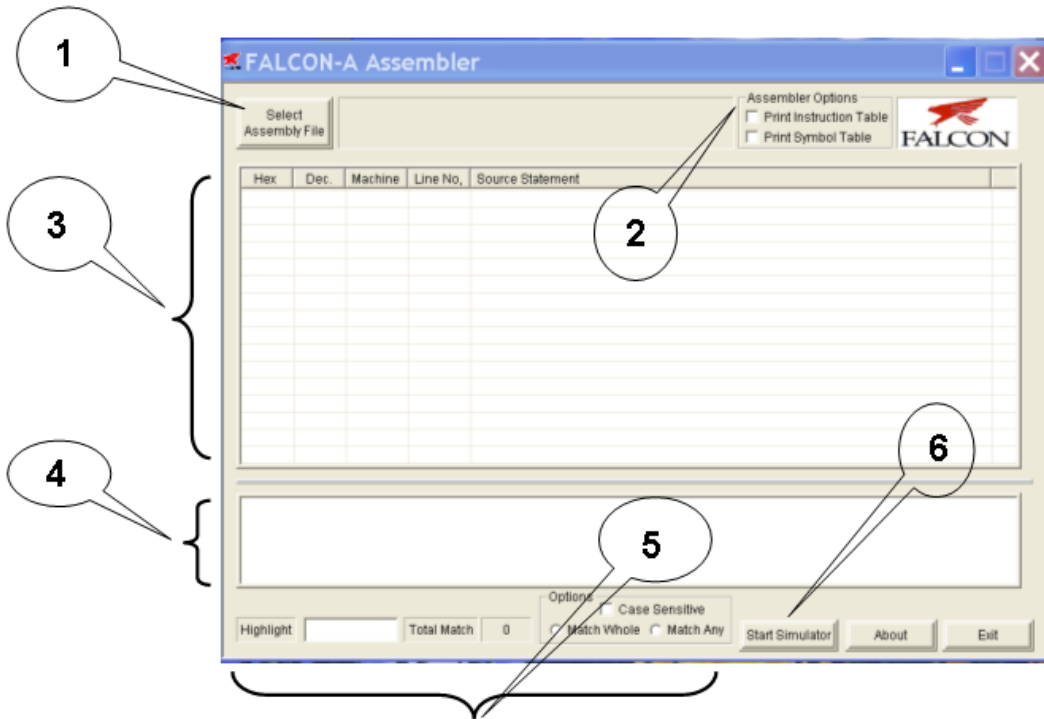


Figure 1

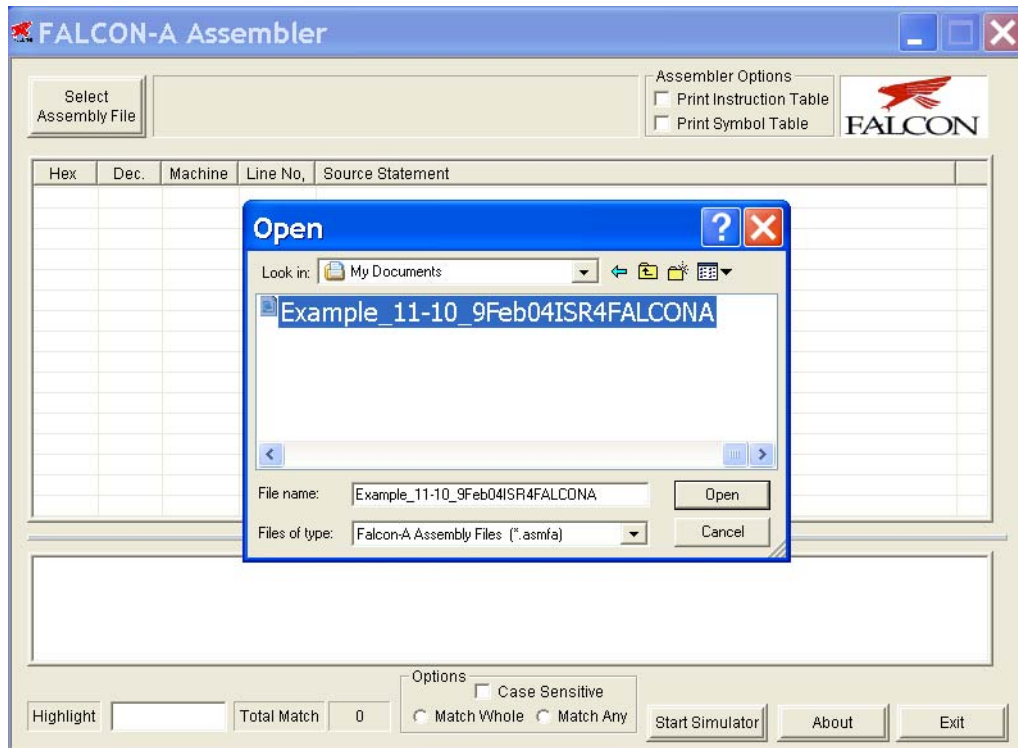


Figure 2

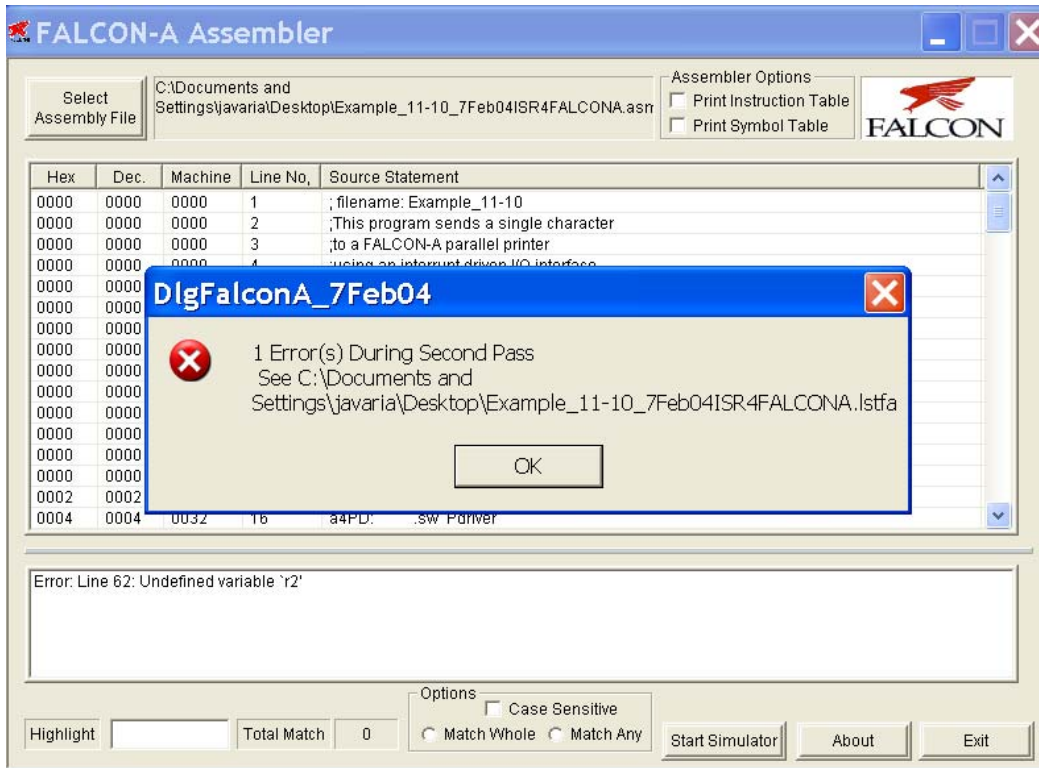


Figure 3

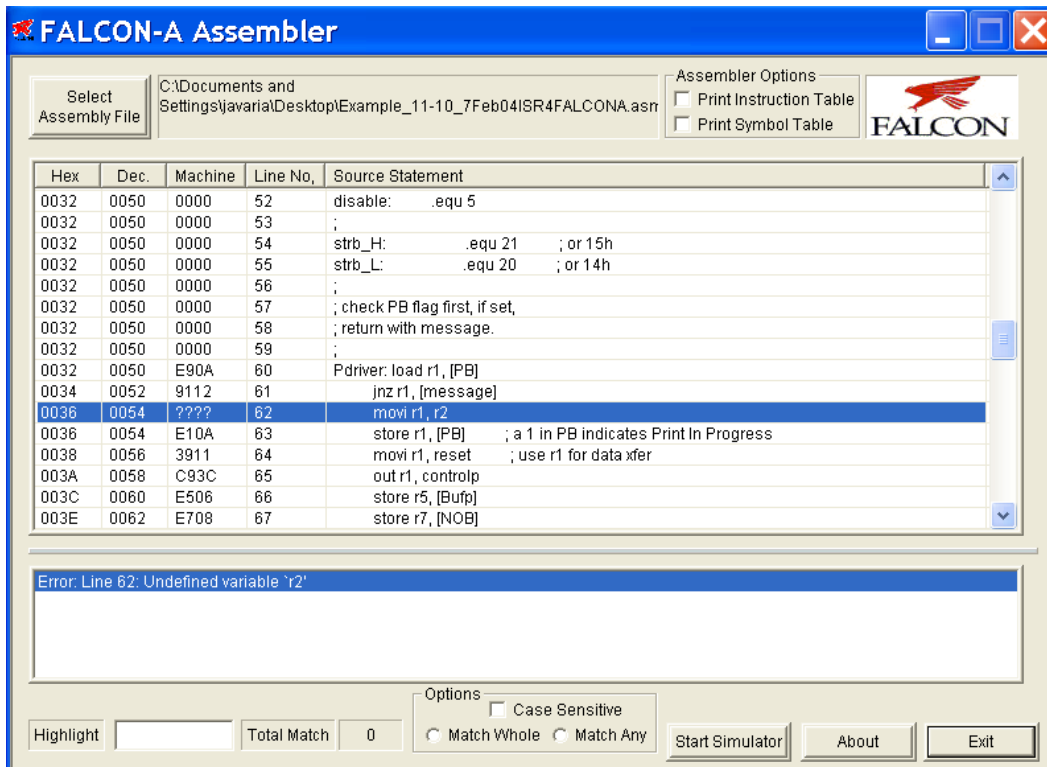


Figure 4

The figure consists of two screenshots of the FALCON-A Simulator. The top screenshot shows the main interface with callouts 11 through 17. The bottom screenshot shows the same interface with an 'Open' dialog box open, with callouts 14 through 16. The 'Open' dialog shows a file named 'Example_11-10_9Feb04ISR4FALCONA.prnterDriver' selected in the 'My Documents' folder.

Top Screenshot (Callouts 11-17):

- 11: Load Binary File button
- 12: Registers table (Reg #, Value, Value, Value, Value)
- 13: Instruction table (Address, Instruction, Assembly, RTL)
- 14: Total Match, Highlight, Return To Assembler buttons
- 15: Match, Case, All, Part radio buttons
- 16: Memory (00h-800h) table (Memory, 0-1, 2-3, 4-5, 6-7)
- 17: Processor's State (IR, PC) and bottom controls (Change Register, Display Memory, Change Memory Words, Help, Execute, Single Step, Change PC, Change I/O, Display I/O)

Bottom Screenshot (Callouts 14-16):

- 14: Open dialog box title bar
- 15: Look in: My Documents
- 16: Example_11-10_9Feb04ISR4FALCONA.prnterDriver file selected

Figure 7

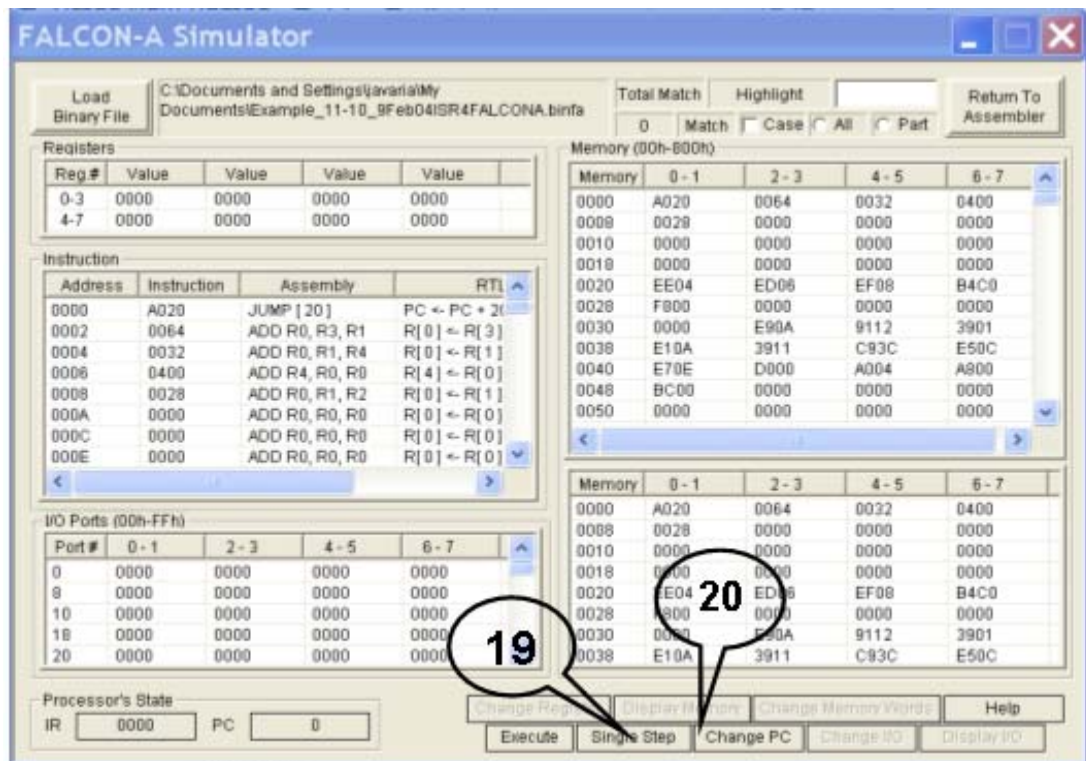


Figure 8

4. FALCON-A assembly language programming techniques:

- If a signed value, x , cannot fit in 5 bits (i.e., it is outside the range -16 to +15), FALSIM will report an error with a **load r1, [x]** or a **store r1, [x]** instruction. To overcome this problem, use **movi r2, x** followed by **load r1, [r2]**.
- If a signed value, x , cannot fit in 8 bits (i.e., it is outside the range -128 to +127), even the previous scheme will not work. FALSIM will report an error with the **movi r2, x** instruction. The following instruction sequence should be used to overcome this limitation of the FALCON-A. First store the 16-bit address in the memory using the **.sw** directive. Then use two load instructions as shown below:

```
a:  .sw    x
      load r2, [a]
      load r1, [r2]
```

This is essentially a “memory-register-indirect” addressing. It has been made possible by the **.sw** directive. The value of **a** should be less than 15.

- A similar technique can be used with immediate ALU instructions for large values of the immediate data, and with the transfer of control (call and jump) instructions for large values of the target address.
- Large values (16-bit values) can also be stored in registers using the **mul** instruction combined with the **addi** instruction. The following instructions bring a 201 in register r1.

```
movi r2, 10
movi r3, 20
mul r1, r2, r3      ; r1 contains 200 after this instruction
addi r1, r1, 1      ; r1 now contains 201
```

- Moving from one register to another can be done by using the instruction **addi r2, r1, 0**.
- Bit setting and clearing can be done using the logical (and, or, not, etc) instructions.
- Using shift instructions (shifl, asr, etc.) is faster than **mul** and **div**, if the multiplier or divisor is a power of 2.