

# Lab 5

**This Lab assignment is due on next Friday in MySTU. There is no collaboration on labs.**

## LC-3 Tools

The LC-3 tools are already installed and configured on server 192.168.69.12

You can setup the PATH of LC-3 tools by

1. Log into server 192.168.69.12 by “ssh”.
2. Overwrite your `.bashrc` by command

```
cp /eda-tools/rhel/bash-scripts/.bashrc ~
```

3. Exit the server.

Do the following to start your work.

- Log into server 192.168.69.12 by “ssh -Y”.
- Create a folder for your lab5 assignment in directory “computer\_system\_18sp”. Name it “lab5”. Change to this folder.
- Download “lab05.tar.gz” from MySTU and save it in “lab5” folder. Extract the file with command

```
tar zxvf lab05.tar.gz
```

Inside the new lab5 directory you should find two files, **lab5.bin** and **lab5\_questions.txt**.

In this lab, you will learn how to write a program for the LC-3 in machine language and run it in the LC-3 simulator. You will run an extremely simple program which has been provided for you. You will then make a small modification to the program and run it again. You will answer a few questions about the experience in the lab5\_questions.txt file in the lab5 directory in your home directory. Please write your answers in the file of lab5\_questions.txt.

## A sample program

Inside the lab5 directory, you'll see a sample program called lab5.bin containing the following:

```
0011 0000 0000 0000 ; specifies where the program will be stored (x3000)
0101 010 010 1 00000 ; clear R2 by ANDing it with x00000
0001 010 010 1 01100 ; add the decimal number 12 to R2, and store result in R2
1111 0000 0010 0101 ; halt
```

All of the text that appears after the semicolon are called **comments** and are ignored by the computer. Their purpose is to make the code readable. Without them, it would be very difficult to know what is going on in the above program, but with them it is much easier. **All of the code you write should be well commented.**

Let's read through this sample program:

The first line of the sample program specifies where in the LC-3's memory space our program will be stored. In this case, the program will be stored starting at 0x3000.



Don't mistake the first line of an LC-3 program for an instruction. This line specifies where the program is stored in memory.

The second line is an **AND** instruction. Refer to [Appendix A](#) in the textbook for a complete description of the instruction set of the LC-3.

The third line is an **ADD**. (Note that it is ADD and not AND – the two look similar and can be easily confused with one another!)

The final line is a **TRAP** instruction which is being used here to halt the program.

Before moving on, you should have done the following:

- Read through the sample program

- Look up AND, ADD, and TRAP in Appendix A
- Understand each line of the Program
- **Answer question #1 in lab5\_questions.txt**

## LC-3 Convert

Before we can run the program, it needs to be converted from its text format into an executable **object file**. To do this, we need to use a program called **lc3convert**. lc3convert converts a text file containing a program in binary (or hexadecimal) into an object file which can be run by the simulator.

Open a terminal and use 'cd' to navigate to the directory where the sample program is stored. Use 'ls' to display the contents of the directory (you should use this often) -- you should notice a file named 'lab5.bin'. Run the following command:

```
lc3convert lab5.bin
```

Now use 'ls' to look at the contents of the directory. You should notice a new file 'lab5.obj' has appeared. This is our **object file** which can be run in the simulator.

Before moving on, you should have done the following:

- Use lc3convert to convert lab5.bin into an object file

## LC-3 Simulator

Since we don't have an actual LC-3 computer, we will need to run our LC-3 programs in a **simulator**. There are two simulator programs available to us: **lc3sim** and **lc3sim-tk**.

First we will use **lc3sim**. Run the following command, taking note that we are giving lc3sim the **object file** (.obj) and NOT the human-readable text file (lab5.bin).

```
lc3sim lab5.obj
```

A bunch of text will appear on the screen. Only the last few lines are interesting to us -- they show us the contents of the LC-3's registers before your program has been run.

You will also notice that instead of our usual shell prompt we see "(lc3sim)" at the bottom of the terminal. **This means we are not at the shell anymore, so our usual commands such as 'cd', 'ls', 'pwd', etc. will not work!** We can only use lc3sim commands here. **To see a list of the lc3sim commands, use 'help'.** If we wanted to quit the lc3sim program and return to the shell, we would use 'quit' -- but don't do this yet! We still want to run our program.

To run our program, we will use the 'continue' command:

```
continue
```

**COOL TIP:** lc3sim accepts **abbreviated commands**, meaning that you can actually type 'cont' or 'c' instead of 'continue'.

After our program has finished running (a fraction of a second), the contents of the registers are displayed again. **Compare the contents of the registers before you ran the program to the contents after you ran the program.** (If they are far apart on your screen because you had typed 'help' to display the list of the commands, you can use 'reset' and 'continue' again to display them close together.) The difference between the registers' contents will be subtle. **What is the difference? Is it what you expected?**

Before we exit lc3sim, we will explore one other lc3sim command -- 'step'. Reset your LC-3 simulator by using the 'reset' command. Now, instead of running the entire program using 'continue', **use 'step' to run a single instruction.** The contents of the registers will be displayed after only running the first step. Notice that the PC (program counter) has incremented by 1. lc3sim also displays the next instruction to be run, in this case an ADD.

**Use 'step' again to run the ADD command**, then look at the contents of the registers again. You should notice the same change that you noticed when you ran the whole program before. You can **exit lc3sim now using the 'quit' command.** (If you choose to keep stepping through the program, you will notice that it steps "into" the halt instruction, and numerous other instructions are encountered which aren't part of our program. Don't worry about this for now.)

The ability to 'step' through a program is a very useful tool for **debugging** a program. Think about why this is.

There are many other useful commands which allow you to display and manipulate the contents of registers and memory. Learning how to use them will be useful for future labs and MPs

Before moving on, you should have done the following:

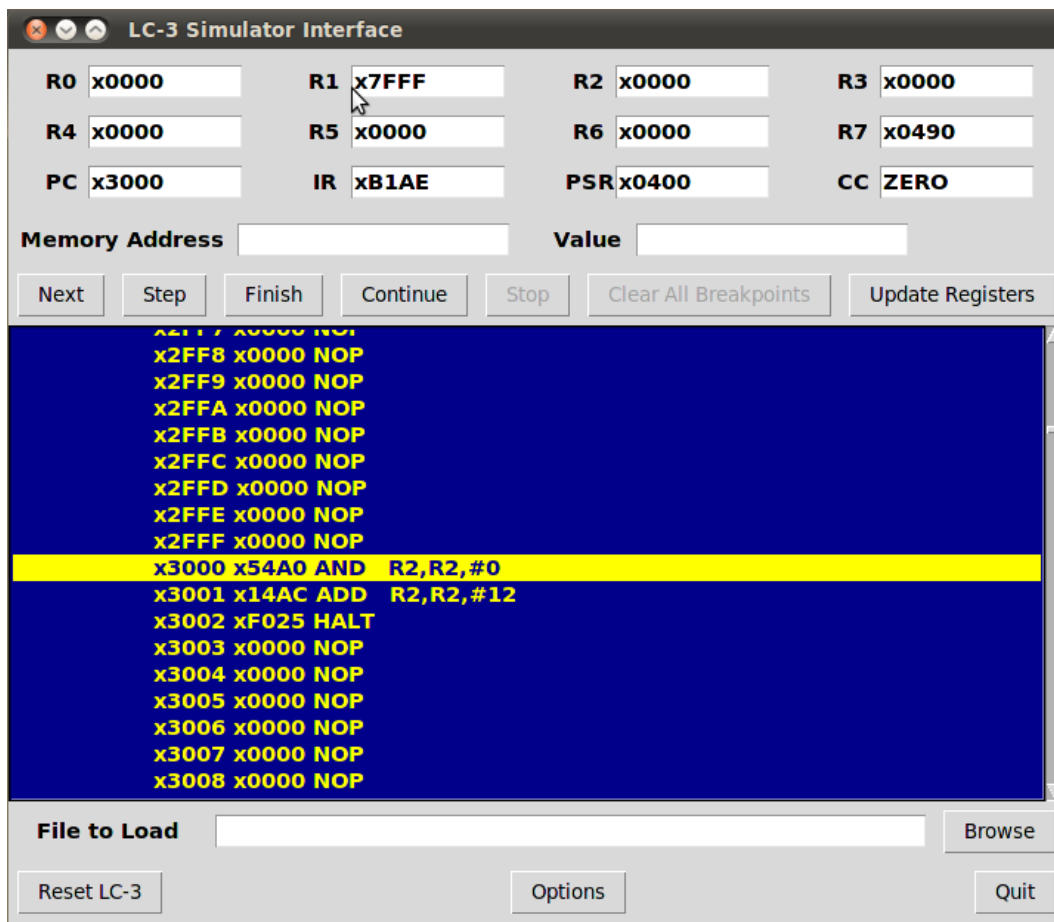
- Use lc3sim to run the program using 'continue'
- Observe the change in the contents of registers
- Run the program again using 'step'
- Use 'quit' to return to the shell
- Use 'help' to get a list of valid commands
- Answer remaining questions in lab5\_questions.txt

## Graphical Simulator (lc3sim-tk)

Another way we can run our program is to use lc3sim-tk. Run the following command in your terminal:

```
lc3sim-tk lab5.obj
```

Ignore the warning message which says no symbols are available. You will see two windows, one of which looks like the image below. We can focus on this one for now.



Using what you learned in the previous section about running your program using lc3sim, it shouldn't be difficult for you to figure out how to use the graphical version.

The simulator interface displays the contents of the registers at the top of the screen. It also displays the full contents of the LC-3's memory, including our program. **Notice that our program is stored starting at memory address x3000, just as we specified in the first line of lab5.bin.** The program is displayed in hexadecimal here, not in binary like in lab5.bin, but if you look closely you can see that the values are the same.

Use the 'continue' button to run the program. (Don't worry about how the blue window jumps to x0494, which is outside of our program's memory space, after the program has finished running.) **Look at the register contents at the top of the window, particularly R2, and notice what has changed.** You are probably getting used to this by now.

At the bottom-left of the window, click "Reset LC-3" to reset the simulator. Now run your program again using the 'step'

button, which you will notice works quite like using the 'step' command in the command-line lc3sim.

Before moving on, you should have done the following:

- Load our program in lc3sim-tk
- Run the program using 'Continue'
- Reset the simulator
- Run the program step-by-step using 'Step'
- Observe the change to the registers

## Modifying the Code

In this section, you will make a small modification to the example program to change its functionality. Originally, the program clears register R2 and adds 12 to this register. Your task is to **make the program add an additional 24 to R2, so that the final stored result is 36. You must do this by adding two instructions to lab5.bin. Normally you can just double click on the file to open it. If that doesn't work, you can open it with the file editor gedit (right click on the file and choose open it with other application).** You may add your instructions as indicated below:

```
0011 0000 0000 0000 ; specifies where the program will be stored (x3000)

0101 010 010 1 00000 ; clear R2 by ANDing it with x00000
0001 010 010 1 01100 ; add the decimal number 12 to R2, and store result in R2
;;;PUT YOUR INSTRUCTIONS AFTER THIS LINE;;;

1111 0000 0010 0101 ; halt
```

A possibly obvious hint is that **the instructions you should add will look exactly like another instruction already in the program.** Refer to [Appendix A](#) for a description of the ADD instruction. This should give you everything you need to know.



If you think this sounds difficult, you're probably over-thinking it. It's easy. Ask for help if you don't understand.

**Add comments to the lines you've added, so that we can see that you understand what's going on.**

After you've modified lab5.bin in your text editor, save the file. Use **lc3convert** again to convert lab5.bin into an object file – it will overwrite the object file we made earlier.



If lc3convert gives you errors, **stop** and go back to lab5.bin in your text editor. Find the formatting mistake in your file (for example, wrong number of binary digits on a line, or forgot to use semicolon before your comment) and fix it. Save the file and try lc3convert again. If you can't get it to convert successfully, ask for help.

Now you can run your object file in the simulator – you may use either lc3sim or lc3sim-tk. Run your program step-by-step, watching the value contained in R2. At the end of your program, does R2 contain what you expected it to contain?

Before moving on, you should have done the following:

- Add two instructions to lab5.bin to add 24 to R2
- Write a comment on each instruction you added explaining what it does
- Save lab5.bin and use lc3convert to make an object file
- Run your object file in the simulator
- Use 'step' to watch changes in R2 and notice when they occur

## What to Turn In

Submit to MySTU.

- Your modified **lab5.bin** and your file of **lab5\_questions.txt** after answering the questions in and saving the file.
- Demonstrate your simulation in front of a Teaching Assistant, answer the questions, and sign your name.

You're done! Feel free to play around with adding other kinds of instructions and watch their effects in the simulator. **You will learn a lot by following your curiosity and experimenting!**