CS-160 Lab #4: Machine Language

General

Read through the "Background" section below, then copy and paste the questions out of the "Assignment" section into your word processor and answer the questions. Turn in the questions using the instructions posted on the class web site.

At the top of the every document that you create (word processing or source files) include:

// Your name
// CS-160, Lab #x (replace the X with the Lab #)
// xxxx Term, 20xx (i.e. Winter Term, 2007)

For ALL Word processing documents, you must submit your documents in one of the following formats: MS-Word (NOT Works), RTF (most word processors can save in this format), or Open Document (used by the freely available Open Office suite). They will be returned ungraded if submitted in any other format.

Concepts

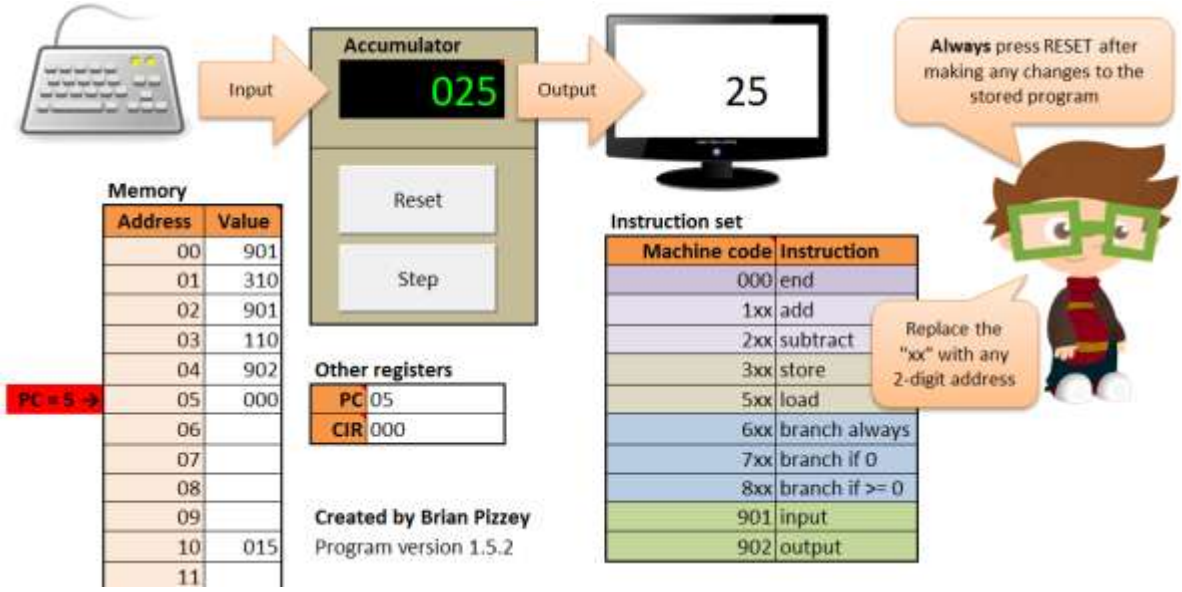
This lab helps you to gain an understanding of program execution flow (the CPU execution cycle) and what the the language of the CPU (machine language) is like.

Background

LMC Machine Code Tutorial

The Little Man Computer is a tool designed to demonstrate in a simplified way how real computers process instructions from memory to do work.

I provide a few different tools that simulate a LMC (see links on Week 4). Your primary one should be the Excel workbook (LMC152.xlsm). It looks like the picture below. (If you do not have access to Microsoft Excel, see Alternate Environment below).



The memory area shows the computer program and any data that are stored in memory.

The Accumulator shows the value currently stored in the accumulator (last value the processor's ALU worked on). The Reset and Step buttons allow you to run the program 1 step at a time or reset it back to the start.

Below the Accumulator, you can see the PC (program counter) and CIR (current instruction register). They always show what memory address has the current instruction and what that instruction is.

Notice that all the memory addresses, and values we are using are in decimal. This is simply to make the program easier for us to use - in a real computer, the values would all be in binary.

Alternate Environment:
If you do not have access to Excel, you can use this simulator:

http://www.yorku.ca/sychen/research/LMC/LittleMan.html

You can type the same programs into it, the memory locations are just arranged in a grid instead of a column. Here is what the first program looks like typed in:

Little Man Computer Memory:

0	1	2	3	4	5	6	7	8	9
901	310	901	110	902	0	0	0	0	0
10	11	12	13	14	15	16	17	18	19
15	0	0	0	0	0	0	0	0	0

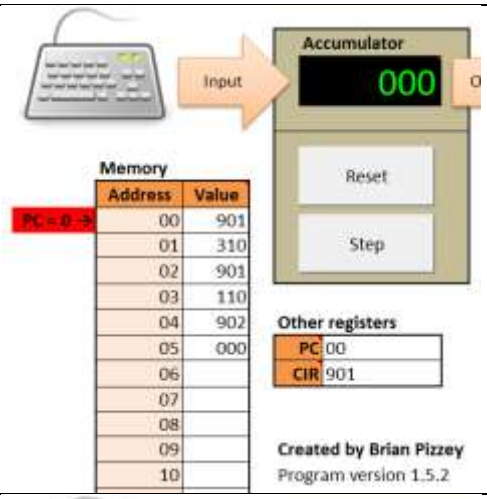
First Run

The program when you first open the sheet will ask for two numbers to be input, add them and show the result. Run it step by step and read along to learn more about what is happening:

The PC starts at instruction 0. That instruction is 901. Which stands for INPUT - get a value from input:

Press Step and type in the value 15.

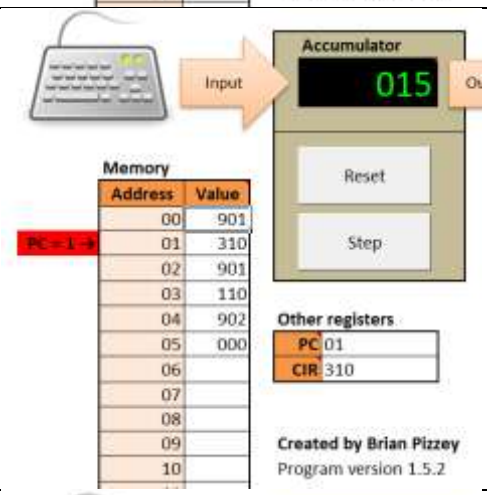
Machine code	Instruction
000	end
1xx	add
2xx	subtract
3xx	store
5xx	load
6xx	branch always
7xx	branch if 0
8xx	branch if >= 0
901	input
902	output



The 15 is now stored in the accumulator.
The PC has been advanced one step - it shows that the new instruction is 310.

3xx stands for STORE - write the accumulator's value to memory. The xx is the memory location to write the value to.

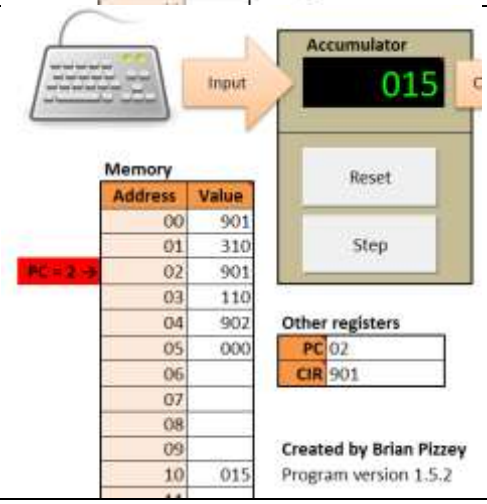
In this case the location is 10 - we are going to store the value 15 at memory location 10.



Hit Step again.

Look down in memory to location 10. The value 15 is stored there now.

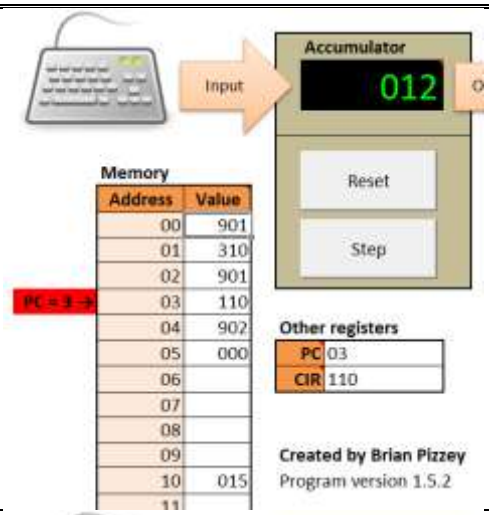
The PC is now 2 - we are about to do 901 - another INPUT.



Hit Step and enter the value 12.

The input replaces the value in the accumulator (that is why we needed to do a STORE - to remember the first number we got from input).

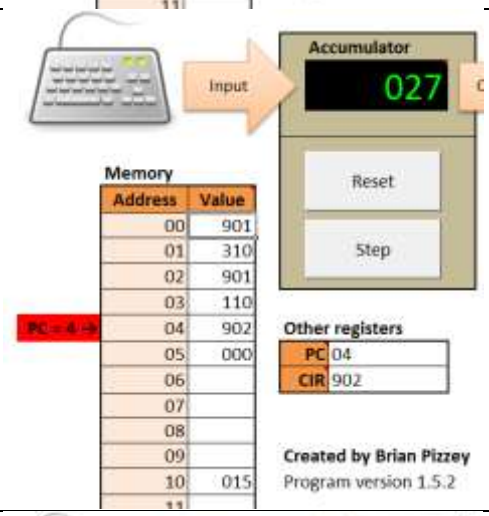
The PC is now 3 and the instruction is 110. 1xx means ADD - take the value stored at location xx in memory and add it to the accumulator.



Press Step.

The 15 we had stored at location 10 of memory is added to the 12 in the accumulator to make 27.

Now the program count is 4, which is instruction 902 - OUTPUT.

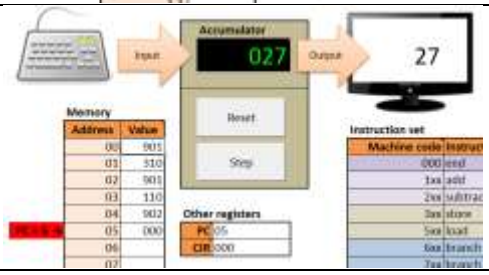


Press Step.

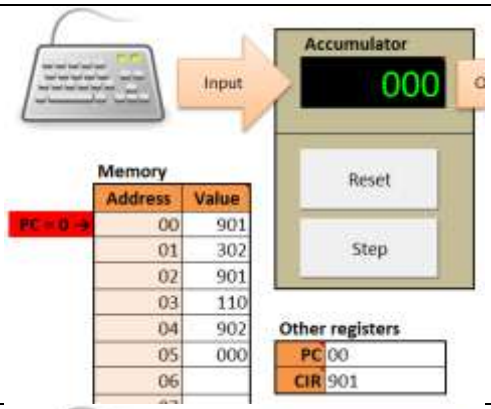
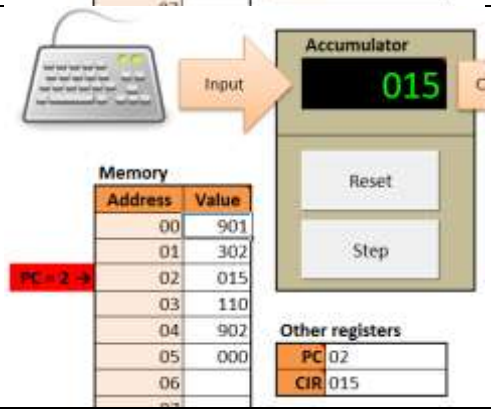
The value in the accumulator is output to the screen.

Now the PC is 5 - the next instruction is 000 - END.

Press Step one more time to see the program terminate.



Modification 1

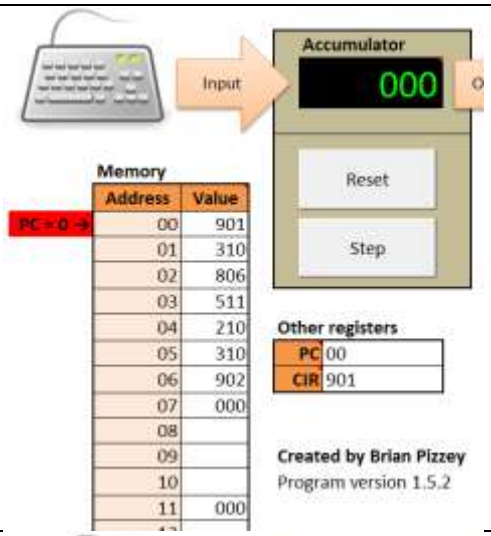
Modify instruction 01 to be 302. Now it says "STORE at location 02". Can you see the problem that will cause? Step your program, enter a number, then step again…	
Here is where we are. About to run instruction 015. Wait, there is no instruction 15!!! The computer is going to crash and end this program. Because memory and data are stored in the same memory, we have to be careful not to overwrite the program with data we store as it runs. In this case, our store instruction (302) wrote over the code that was in location 2, breaking the program.	

Branch

Branch instructions tell the computer to maybe skip to a different part of the instructions.

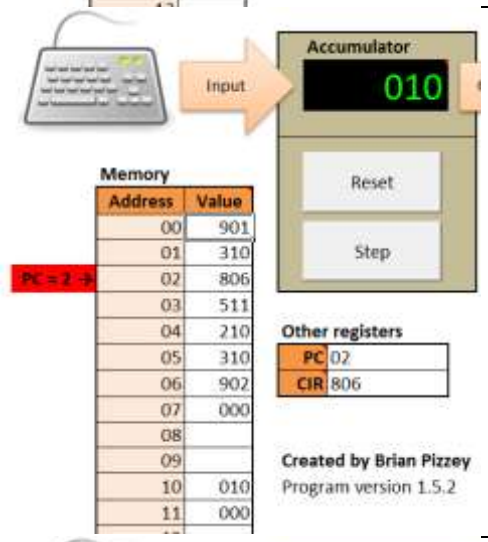
Type in the program shown to the right (change the memory values to match what I have).

Start stepping and enter the number 10…

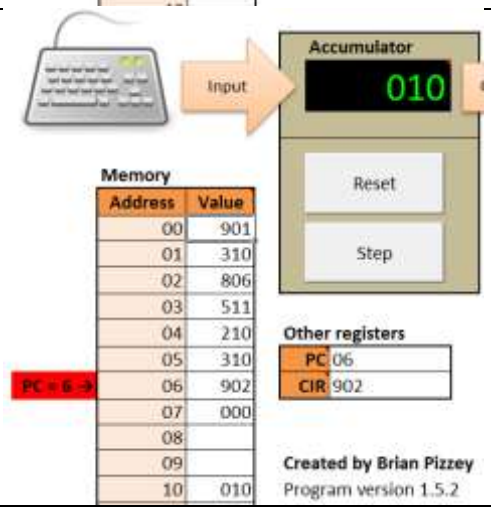


Now we are about to execute 806. 8xx is BRANCH if >= 0. It says go to location xx if the accumulator is greater than or equal to 0.

Since the accumulator is, we will jump to instruction 06…

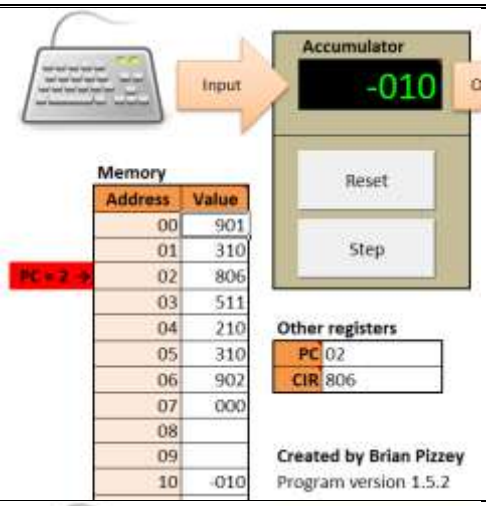


We skip right over instructions 3-5 and will now output the value we input and end the program.



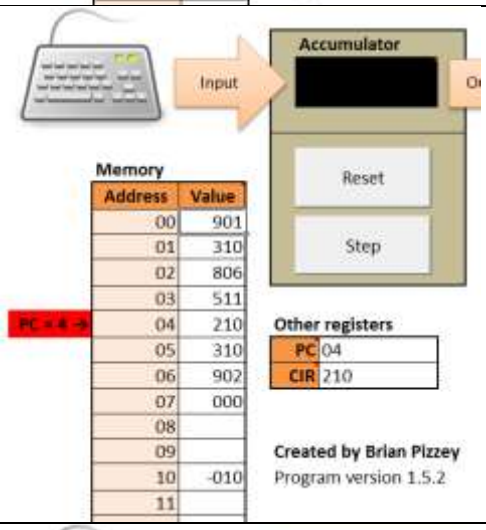
This time, when you get to the branch instruction, the accumulator's value is -10. That is not >= 0 (greater than or equal to).

So we are not going to branch.



511 says to LOAD the value at 11. Since nothing is there, the accumulator is now set to 0 (empty).

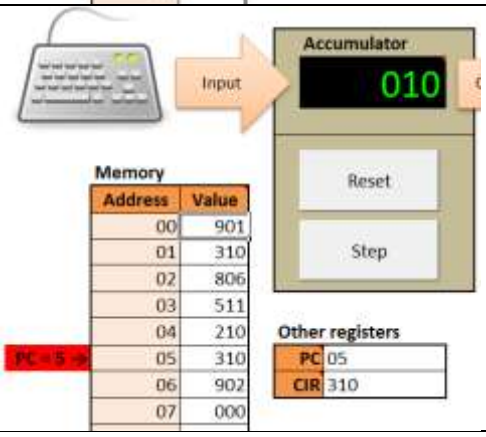
The next instruction, 210, says to subtract the value we stored in memory location 10 from the accumulator. (2xx is subtract location xx from accumulator).



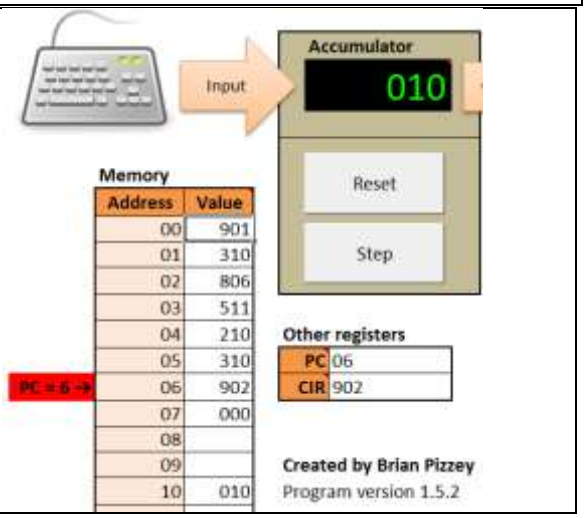
Hit step.

The accumulator had 0, then we subtracted -10 (value in location 10).
0 - (-10) = 10… we just made the negative input positive. This is an absolute value program!

The next steps will store the new value…



Now we are at step 6. From here on out, the program works just like when we entered a positive number.



Repeat With a Branch

Branch instructions can send a program back to repeat earlier instructions. This forces the computer to **loop** - to repeatedly execute the same instructions.

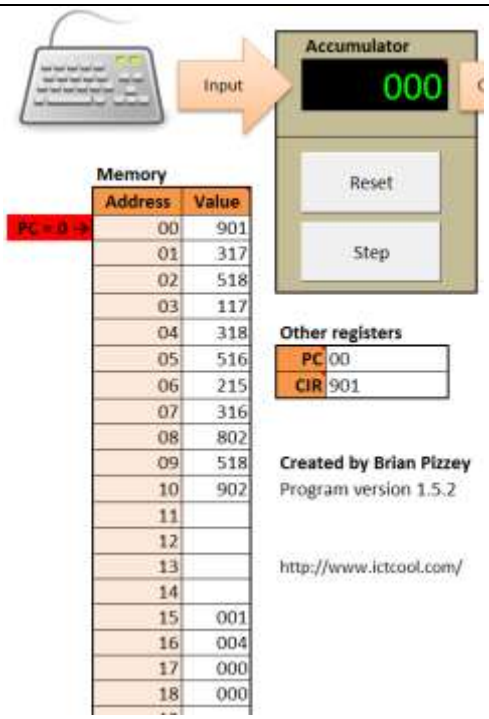
Type this program in and try it out - run it through, enter 10 for the input and see what it prints.

As you run it, here are a couple hints:

- Location 15 is always just the number 1
- Location 16 is a counter - watch how it changes *We repeatedly subtract 15 from it - what will that do?*
- Location 17 stores the input
- Location 18 is where we build up an answer
- Right before we check the branch (instruction 8), we load location 16. That is our counter. The counter determines if we repeat the instructions 2-8 again or not.

Then run it again with 20 for the input. **You will have to reset locations 15-18 before rerunning the program.**

Watch it run, then read on…



The program multiplies your input by 5. It does this by adding up five copies of the input. Follow along with this English description step by step as it runs.

Here is what our code is doing:

1. Get input
2. Store input in #17
3. Load #18 (starts at 0, will hold our answer)
4. Add #17 to what we loaded from #18 (add one copy of input)
5. Load #16 (our counter) - it starts at 4
6. Subtract #15 (the value 1) from the counter we loaded - decreases counter by 1
7. Store the new counter value back in #16
8. If counter is >= 0 we go back to step 2. Counter will have to go **4,3,2,1,0**,-1 When it hits -1 we will get past this line. Notice that the 4,3,2,1,0 is five times before we leave. That is why we end up adding 5 copies of what we started with.
9. Output our answer from location #18 where we have built it up
10. End

LMC Assembly

Because machine code is hard for humans to read and write well, assembly code was created. Assembly is human readable machine code. Each assembly instruction directly corresponds to a machine instruction, but we use words instead of numbers to represent them. Also, instead of having to worry about exact memory locations where we are going to store data, we are able to give memory locations names. Thus we can say things like "Store this in the place I called ANSWER" instead of "Store this in location 9". This makes it much easier to keep track of what operations are happening to what memory and much easier to modify programs (don't have to worry about relocating our data memory if our program gets bigger.

Here is a LMC program in machine codes and assembly:

#	Instruction	Assembly	Machine
0	Input	INP	901
1	Store accumulator in location called FIRST	STA FIRST	306
2	Get input	INP	901
3	Add value from location called FIRST to the accumulator (which currently has second number)	ADD FIRST	106
4	Output the value in the accumulator	OUT	902
5	Stop	HLT	0
6	This is the location called FIRST. It stores DAT (Data). The initial value is 0. (If you do not write an initial value, 0 is assumed). Automatically set to location 6 because that is where it falls. If we added instructions above it, it would be a new location. (But we would not care since we don't ever call the location by number).	FIRST DAT 0	0

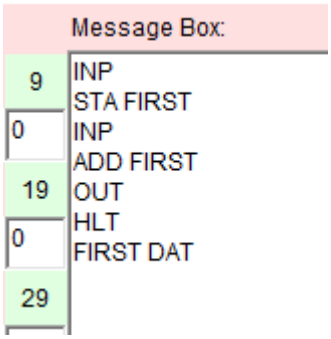
Assembly is still pretty hard to read and write (especially to do complex tasks), but it is much more friendly than machine code.

To try writing assembly, fire up this LMC simulator:
http://www.yorku.ca/sychen/research/LMC/LittleMan.html

Then copy and paste this code:

```
INP
STA FIRST
INP
ADD FIRST
OUT
HLT
FIRST DAT
```

Into the Message Box:



Then press the Compile Program button. The Message Box will show the progress as it converts your assembly to machine code. The program you wrote will be placed into memory.

Little Man Computer Memory:

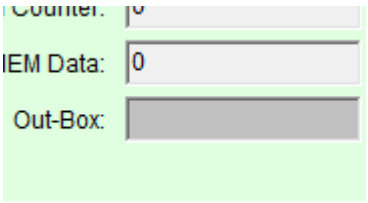
0	1	2	3	4	5	6	7	8	9
901	306	901	106	902	0	0	0	0	0
10	11	12	13	14	15	16	17	18	19
0	0	0	0	0	0	0	0	0	0
20	21	22	23	24	25	26	27	28	29
0	0	0	0	0	0	0	0	0	0
30	31	32	33	34	35	36	37	38	39
0	0	0	0	0	0	0	0	0	0
40	41	42	43	44	45	46	47	48	49
0	0	0	0	0	0	0	0	0	0
50	51	52	53	54	55	56	57	58	59
0	0	0	0	0	0	0	0	0	0
60	61	62	63	64	65	66	67	68	69
0	0	0	0	0	0	0	0	0	0

Message Box:

```
0 : INP
1 : STA FIRST
2 : INP
3 : ADD FIRST
4 : OUT
5 : HLT
6 : FIRST DAT

----- Resolving Labels -----
FIRST is a label for Address : 6

----- Translating Mnemonics -----
Line 0 : INP
   Opcode = 901
Line 1 : STA
   Opcode = 3  Address = 06
Line 2 : INP
   Opcode = 901
Line 3 : ADD
   Opcode = 1  Address = 06
Line 4 : OUT
   Opcode = 902
Line 5 : HLT
   Opcode = 0
Line 6 : DAT
----- Program Successfully Compiled -----
```



You can use this simulator to run your code (it should add two input values). Your answer will appear in the Out-Box area of the window. Or you can take the numeric machine code and use the excel LMC simulator to run it.

You can find a reference for LMC Assembly here:
http://www.yorku.ca/sychen/research/LMC/LMCInstructions.html

You can find more sample programs here:
http://www.yorku.ca/sychen/research/LMC/index.html

Click on one of the examples, then find the assembly code and copy and paste it into the MessageBox. Make sure to clear the message box before pasting in your code (you can't have the output information from your last program in the box, it should only have your new code).