

LAB01 LC3实现乘法操作

L程序部分

01. L程序设计思路

针对输入的两个数，将第二个数(R1)的符号转移到第一个数(R0)上，保证第二个数为正数，并作为计数量，将第一个数逐个加入到R7中，同时将计数量减一，重复操作直至计数量减至0

代码如下：

```
1      0011 0000 0000 0000 ; start the program at location x3000
2      0101 000 000 1 00000 ; set R0 to 0
3      0101 001 001 1 00000 ; set R1 to 0
4      0101 111 111 1 00000 ; set R7 to 0,the location to store the
    result
5      0001 000 000 1 00100 ; R0 ← 4
6      0001 001 001 1 00101 ; R1 ← 5
7
8      0001 010 001 1 00000 ; R2 ← R1
9      0000 011 000000100 ; R2 ≥ 0?
10     1001 000 000 111111 ; R0 ← ~R0
11     0001 000 000 1 00001 ; R0 ← R0 + 1
12     1001 001 001 111111 ; R1 ← ~R1
13     0001 001 001 1 00001 ; R1 ← R1 + 1
14     0000 010 000000011 ; R2 = 0?
15     0001 111 111 0 00 000 ; R7 ← R7 + R0
16     0001 001 001 1 11111 ; R1 ← R1 -1
17     0000 001 111111101 ; back to "R7 ← R7 + R0"
18     1111 0000 00100101 ; halt
```

02. L程序代码行数

对R1符号的判断共三行(8,9,14)，对R1为负的单独操作共四行(10,11,12,13)，将R0加入到R7并更新计数变量同时判断是否循环共三行(15,16,17)，终止一行(18)，总共十一行。

03. P程序测试样例测试结果

Registers

R0	x0001	1
R1	x0000	0
R2	x0001	1
R3	x0000	0
R4	x0000	0
R5	x0000	0
R6	x2FFC	12284
R7	x0001	1
PSR	x0002	2CC: Z
PC	x025D	605
MCR	x0000	0

Console (click to focus)

--- Halting the LC-3 ---

□

Memory

❶ ▶ x025D	xE025	-8155	TRAP_HALT LEA R0,TRAP_HALT_MSG
❷ ▶ x025E	xF022	-4062	PUTS
❸ ▶ x025F	xA1B0	-24144	LDI R0,OS_MCR
❹ ▶ x0260	x23B1	9137	LD R1,MASK_HI
❺ ▶ x0261	x5001	20481	AND R0,R0,R1
❻ ▶ x0262	xB1AD	-20051	STI R0,OS_MCR
❼ ▶ x0263	x0FF9	4089	BRnzp TRAP_HALT
❽ ▶ x0264	xE073	-8077	BAD_TRAP LEA R0,BAD_TRAP_MSG
❾ ▶ x0265	xF022	-4062	PUTS
❿ ▶ x0266	xF025	-4059	HALT
⓫ ▶ x0267	xE038	-8136	EX_PRIV LEA R0,EX_PRIV_MSG
⓬ ▶ x0268	xF022	-4062	PUTS
⓭ ▶ x0269	xF025	-4059	HALT
⓮ ▶ x026A	xE052	-8110	EX_ILL LEA R0,EX_ILL_MSG
⓯ ▶ x026B	xF022	-4062	PUTS
⓰ ▶ x026C	xF025	-4059	HALT
⓱ ▶ x026D	x8000	-32768	BAD_INT RTI
⓲ ▶ x026E	x000A	10	

Registers

R0	x0000	0
R1	x7FFF	32767
R2	x0FA0	4000
R3	x0000	0
R4	x0000	0
R5	x0000	0
R6	x2FFA	12282
R7	x4E20	20000
PSR	x0002	2CC: Z
PC	x0263	611
MCR	x0000	0

Console (click to focus)

--- Halting the LC-3 ---

--- Halting the LC-3 ---

□

Memory

❶ ▶ x3000	x5020	20512	0101000000100000
❷ ▶ x3001	x5260	21088	0101001001100000
❸ ▶ x3002	x5FE0	24544	0101111111100000
❹ ▶ x3003	x1024	4132	0001000000100100
❺ ▶ x3004	x1265	4709	0001001001100101
❻ ▶ x3005	x1460	5216	0001010001100000
❼ ▶ x3006	x0604	1540	0000011000000100
❽ ▶ x3007	x903F	-28609	1001000000111111
❾ ▶ x3008	x1021	4129	0001000000100001
⓫ ▶ x3009	x927F	-28033	1001001001111111
⓬ ▶ x300A	x1261	4705	0001001001100001
⓭ ▶ x300B	x0403	1027	0000010000000011
⓮ ▶ x300C	x1FC0	8128	0001111111000000
⓯ ▶ x300D	x127F	4735	0001001001111111
⓰ ▶ x300E	x03FD	1021	0000001111111101
⓱ ▶ x300F	xF025	-4059	1111000000100101
⓲ ▶ x3010	x0000	0	
⓳ ▶ x3011	x0000	0	
⓴ ▶ x3012	x0000	0	
⓵ ▶ x3013	x0000	0	
⓶ ▶ x3014	x0000	0	
⓷ ▶ x3015	x0000	0	

Registers

R0	x0000	0
R1	x7FFF	32767
R2	x0005	5
R3	x0000	0
R4	x0000	0
R5	x0000	0
R6	x2FF8	12280
R7	x4E20	20000
PSR	x0002	2CC: Z
PC	x0263	611
MCR	x0000	0

Console (click to focus)

--- Halting the LC-3 ---

--- Halting the LC-3 ---

□

Memory

❶ ▶ x3000	x5020	20512	0101000000100000
❷ ▶ x3001	x5260	21088	0101001001100000
❸ ▶ x3002	x5FE0	24544	0101111111100000
❹ ▶ x3003	x1024	4132	0001000000100100
❺ ▶ x3004	x1265	4709	0001001001100101
❻ ▶ x3005	x1460	5216	0001010001100000
❼ ▶ x3006	x0604	1540	0000011000000100
❽ ▶ x3007	x903F	-28609	1001000000111111
❾ ▶ x3008	x1021	4129	0001000000100001
⓫ ▶ x3009	x927F	-28033	1001001001111111
⓬ ▶ x300A	x1261	4705	0001001001100001
⓭ ▶ x300B	x0403	1027	0000010000000011
⓮ ▶ x300C	x1FC0	8128	0001111111000000
⓯ ▶ x300D	x127F	4735	0001001001111111
⓰ ▶ x300E	x03FD	1021	0000001111111101
⓱ ▶ x300F	xF025	-4059	1111000000100101
⓲ ▶ x3010	x0000	0	
⓳ ▶ x3011	x0000	0	
⓴ ▶ x3012	x0000	0	
⓵ ▶ x3013	x0000	0	
⓶ ▶ x3014	x0000	0	
⓷ ▶ x3015	x0000	0	

Registers			Memory		
R0	x0000	0	▶ x3000	x5020	20512 0101000000100000
R1	x7FFF	32767	▶ x3001	x5260	21088 0101001001100000
R2	x01B1	433	▶ x3002	x5FE0	24544 0101111111100000
R3	x0000	0	▶ x3003	x1024	4132 0001000000100100
R4	x0000	0	▶ x3004	x1265	4709 0001001001100101
R5	x0000	0	▶ x3005	x1460	5216 0001010001100000
R6	x2FF6	12278	▶ x3006	x0604	1540 0000011000000100
R7	xB24C	Decimal Value -19892	▶ x3007	x903F	-28609 1001000000111111
PSR	x0002		▶ x3008	x1021	4129 0001000000100001
PC	x0263		▶ x3009	x927F	-28033 1001001001111111
MCR	x0000	0	▶ x300A	x1261	4705 0001001001100001
Console (click to focus)			▶ x300B	x0403	1027 0000010000000011
---			▶ x300C	x1FC0	8128 0001111111000000
Halting the LC-3 ---			▶ x300D	x127F	4735 0001001001111111
---			▶ x300E	x03FD	1021 0000001111111101
Halting the LC-3 ---			▶ x300F	xF025	-4059 1111000000100101
			▶ x3010	x0000	0
			▶ x3011	x0000	0
			▶ x3012	x0000	0
			▶ x3013	x0000	0

Registers			Memory		
R0	x0000	0	▶ x3000	x5020	20512 0101000000100000
R1	x7FFF	32767	▶ x3001	x5260	21088 0101001001100000
R2	xFF17	-233	▶ x3002	x5FE0	24544 0101111111100000
R3	x0000	0	▶ x3003	x1024	4132 0001000000100100
R4	x0000	0	▶ x3004	x1265	4709 0001001001100101
R5	x0000	0	▶ x3005	x1460	5216 0001010001100000
R6	x2FF4	12276	▶ x3006	x0604	1540 0000011000000100
R7	x67C2	26562	▶ x3007	x903F	-28609 1001000000111111
PSR	x0002	2 CC: Z	▶ x3008	x1021	4129 0001000000100001
PC	x0263	611	▶ x3009	x927F	-28033 1001001001111111
MCR	x0000	0	▶ x300A	x1261	4705 0001001001100001
Console (click to focus)			▶ x300B	x0403	1027 0000010000000011
---			▶ x300C	x1FC0	8128 0001111111000000
Halting the LC-3 ---			▶ x300D	x127F	4735 0001001001111111
---			▶ x300E	x03FD	1021 0000001111111101
Halting the LC-3 ---			▶ x300F	xF025	-4059 1111000000100101
			▶ x3010	x0000	0
			▶ x3011	x0000	0
			▶ x3012	x0000	0
			▶ x3013	x0000	0

P程序部分

01. P程序设计思路

由于用LC3实现乘法只能通过加法，那么要想实现更快的乘法，即执行更少的指令，必须减少执行加法的次数，故采取以下两种想法：

(1) 将两个相乘的数中，较大的作为基数，较小的作为计数量，可减少进入加法循环的次数

(2) 选取一个可以接受的执行逐个相加的数，比如16，对于计数量，如果大于16，则逐次减去16，而R7则逐次加上16*R0，从而直接减少加法次数

代码如下：



```
1      0011 0000 0000 0000 ; start the program at location x3000
2      0101 000 000 1 00000 ; set R0 to 0
3      0101 001 001 1 00000 ; set R1 to 0
4      0101 111 111 1 00000 ; set R7 to 0,the location to store the
result
5      0101 110 110 1 00000 ; set R6 to 0
6      0001 000 000 1 00100 ; R0 ← 4
7      0001 001 001 1 00101 ; R1 ← 5
8
9      ;确定可以接受的逐个相加的基数为16
10
11     ;1.let R1,R0 to be positive and record "+-" of the result
12     0001 010 001 1 00000 ; R2 ← R1
13     0000 011 000001001 ; R2 ≥ 0?
14     ;R1<0
15     1001 001 001 111111 ; R1 ← ~R1
16     0001 001 001 1 00001 ; R1 ← R1 + 1,let R1 to be positive
or zero
17     0001 011 000 1 00000 ; R3 ← R0
18     0000 011 000000011 ; R3 >0
19     ;;R0<0
20     1001 000 000 111111 ; R0 ← ~R0
21     0001 000 000 1 00001 ; R0 ← R0 + 1
22     0000 111 000000111 ; 无条件跳转
23     ;;R0≥0
24     0001 110 110 1 00001 ; R6 ← 1 ,R6为1代表结果为负，为0代表结果
为正,let R0 to be positive or zero
25     0000 111 000000101 ;无条件跳转
26     ;R1≥0
27     0001 011 000 1 00000 ; R3 ← R0
28     0000 011 000000011 ; R3 >0
29     ;;R0<0
30     1001 000 000 111111 ; R0 ← ~R0
31     0001 000 000 1 00001 ; R0 ← R0 + 1
32     0001 110 110 1 00001 ; R6 ← 1 ,R6为1代表结果为负，为0代表结果
为正,let R0 to be positive or zero
33     ;;R0≥0
34
35     ;2.compute the result,make R0 store the bigger
```

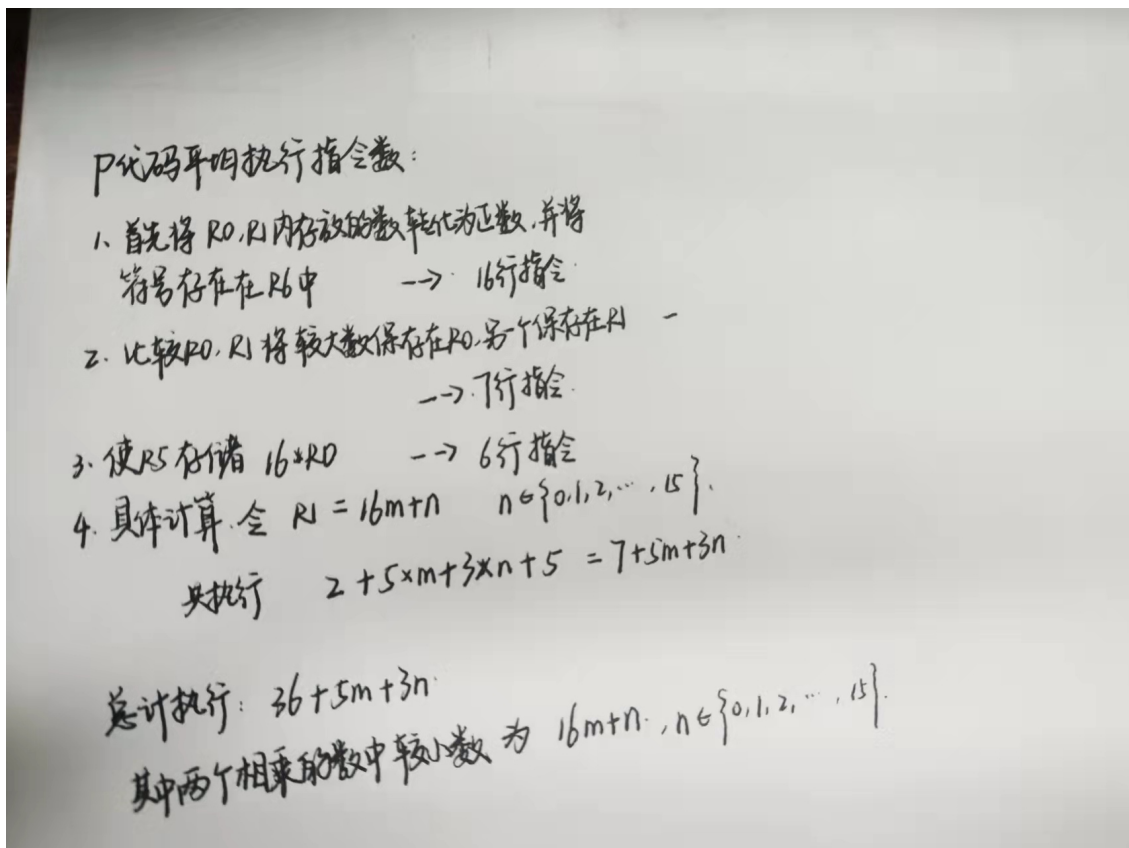
```

36      1001 100 001 111111 ; R4 ← ~R1
37      0001 100 100 1 00001 ; R4 ← R4 + 1
38      0001 101 000 0 00 100 ; let R5 to be R0-R1
39      0000 011 000000011 ; R5 ≥ 0?
40      ;R0 < R1
41      0001 100 000 1 00000 ; R4 ← R0
42      0001 000 001 1 00000 ; R0 ← R1
43      0001 001 100 1 00000 ; R1 ← R4
44
45      ;make R5 to be 16*R0
46      0101 101 101 1 00000 ; set R5 to 0
47      0001 101 101 0 00 000 ; R5 ← R5 + R0
48      0001 101 101 0 00 101 ; R5 ← R5 + R5
49      0001 101 101 0 00 101 ; R5 ← R5 + R5
50      0001 101 101 0 00 101 ; R5 ← R5 + R5
51      0001 101 101 0 00 101 ; R5 ← R5 + R5
52
53      0001 100 001 1 00000 ; R4 ← R1
54      0000 010 000001101 ; R4 = 0 ?
55      ;; R1 > 0
56      0001 100 100 1 10000 ; R4 ← R4-16
57      0000 100 000000100 ; R4 < 0?
58      0001 111 111 0 00 101 ; R7 ← R7 + R5
59      0001 001 001 1 10000 ; R1 ← R1-16
60      0000 001 111111011 ; back to "R4 ← R4-16"
61      0000 010 000000011 ; R1 = 0?
62
63      0001 111 111 0 00 000 ; R7 ← R7 + R0
64      0001 001 001 1 11111 ; R1 ← R1 -1
65      0000 001 111111101 ; back to "R7 ← R7 + R0"
66
67      0001 110 110 1 00000 ; R6 ← R6
68      0000 010 000000010 ; R6 = 0?
69      1001 111 111 111111 ; R7 ← ~R7
70      0001 111 111 1 00001 ; R7 ← R7 + 1
71      1111 0000 00100101 ; halt

```

02. P程序执行指令数

- P程序执行指令数统计方法:



以测试用例为例:

1*1 执行 $36 + 3 = 39$

5*4000 执行 $36 + 5 \times 3 = 51$

4000*5 执行 $36 + 5 \times 3 = 51$

-500*433 执行 $36 + 27 \times 5 + 3 \times 1 = 172$

-114*-233 执行 $36 + 7 \times 5 + 3 \times 2 = 77$

在测试样例上平均执行指令数: 78

03. P程序测试样例测试结果

Registers				Memory			
R0	x0000	0		➤ x3000	x5020	20512	0101000000100000
R1	x7FFF	32767		➤ x3001	x5260	21088	0101001001100000
R2	x0001	1		➤ x3002	x5FE0	24544	0101111111000000
R3	x0001	1		➤ x3003	x5DA0	23968	0101110110100000
R4	xFFF1	-15		➤ x3004	x1024	4132	0001000000100100
R5	x0010	16		➤ x3005	x1265	4709	0001001001100101
R6	x2FF2	12274		➤ x3006	x1460	5216	0001010001100000
R7	x0001	1		➤ x3007	x0609	1545	0000011000001001
PSR	x0002	2	CC: Z	➤ x3008	x927F	-28033	1001001001111111
PC	x0263	611		➤ x3009	x1261	4705	0001001001100001
MCR	x0000	0		➤ x300A	x1620	5664	0001011000100000
Console (click to focus)				➤ x300B	x0603	1539	0000011000000011
---				➤ x300C	x903F	-28609	1001000000111111
---				➤ x300D	x1021	4129	0001000000100001
---				➤ x300E	x0E07	3591	0000111000000111
---				➤ x300F	x1DA1	7585	0001110110100001
---				➤ x3010	x0E05	3589	0000111000000101
---				➤ x3011	x1620	5664	0001011000100000
---				➤ x3012	x0603	1539	0000011000000011
---				➤ x3013	x903F	-28609	1001000000111111
---				➤ x3014	x1021	4129	0001000000100001
---				➤ x3015	x1DA1	7585	0001110110100001
---				➤ x3016	x987F	-26497	1001100001111111
---				➤ x3017	x1921	6433	0001100100100001
---				➤ x3018	x1A04	6660	0001101000000100

Registers				Memory			
R0	x0000	0		➤ x3000	x5020	20512	0101000000100000
R1	x7FFF	32767		➤ x3001	x5260	21088	0101001001100000
R2	x0FA0	4000		➤ x3002	x5FE0	24544	0101111111000000
R3	x0005	5		➤ x3003	x5DA0	23968	0101110110100000
R4	xFFF5	-11		➤ x3004	x1024	4132	0001000000100100
R5	xFA00	-1536		➤ x3005	x1265	4709	0001001001100101
R6	x2FF0	12272		➤ x3006	x1460	5216	0001010001100000
R7	x4E20	20000		➤ x3007	x0609	1545	0000011000001001
PSR	x0002	2	CC: Z	➤ x3008	x927F	-28033	1001001001111111
PC	x0263	611		➤ x3009	x1261	4705	0001001001100001
MCR	x0000	0		➤ x300A	x1620	5664	0001011000100000
Console (click to focus)				➤ x300B	x0603	1539	0000011000000011
---				➤ x300C	x903F	-28609	1001000000111111
---				➤ x300D	x1021	4129	0001000000100001
---				➤ x300E	x0E07	3591	0000111000000111
---				➤ x300F	x1DA1	7585	0001110110100001
---				➤ x3010	x0E05	3589	0000111000000101
---				➤ x3011	x1620	5664	0001011000100000
---				➤ x3012	x0603	1539	0000011000000011
---				➤ x3013	x903F	-28609	1001000000111111
---				➤ x3014	x1021	4129	0001000000100001
---				➤ x3015	x1DA1	7585	0001110110100001
---				➤ x3016	x987F	-26497	1001100001111111
---				➤ x3017	x1921	6433	0001100100100001
---				➤ x3018	x1A04	6660	0001101000000100

Registers

R0	x0000	0
R1	x7FFF	32767
R2	x0005	5
R3	x0FA0	4000
R4	xFFF5	-11
R5	xFA00	-1536
R6	x2FFE	12286
R7	x4E20	20000
PSR	x0002	2CC: Z
PC	x0263	611
MCR	x0000	0

Console (click to focus)

--- Halting the LC-3 ---

□

▶ x30

x5020

20512

0101000000100000

▶ x30

x5260

21088

0101001001100000

▶ x30

x5FE0

24544

0101111111000000

▶ x30

x5DA0

23968

0101110110100000

▶ x30

x1024

4132

0001000000100100

▶ x30

x1265

4709

0001001001100101

▶ x30

x1460

5216

0001010001100000

▶ x30

x0609

1545

0000011000001001

▶ x30

x927F

-28033

1001001001111111

▶ x30

x1261

4705

0001001001100001

▶ x30

x1620

5664

0001011000100000

▶ x30

x0603

1539

0000011000000011

▶ x30

x903F

-28609

1001000000111111

▶ x30

x1021

4129

0001000000100001

▶ x30

x0E07

3591

0000111000000111

▶ x30

x1DA1

7585

0001110110100001

▶ x30

x0E05

3589

0000111000000101

▶ x30

x1620

5664

0001011000100000

▶ x30

x0603

1539

0000011000000011

▶ x30

x903F

-28609

1001000000111111

▶ x30

x1021

4129

0001000000100001

▶ x30

x1DA1

7585

0001110110100001

▶ x30

x987F

-26497

1001100001111111

▶ x30

x1921

6433

0001100100100001

▶ x30

x1A04

6660

0001101000000100

LC3Tools

Registers

R0	x0000	0
R1	x7FFF	32767
R2	x01B1	433
R3	xFE0C	-500
R4	xFFF1	-15
R5	x1F40	8000
R6	x2FFC	12284
R7	xB24C	
PSR	x0002	-19892
PC	x0263	
MCR	x0000	0

Console (click to focus)

--- Halting the LC-3 ---

--- Halting the LC-3 ---

□

▶ x3000

x5020

20512

0101000000100000

▶ x3001

x5260

21088

0101001001100000

▶ x3002

x5FE0

24544

0101111111000000

▶ x3003

x5DA0

23968

0101110110100000

▶ x3004

x1024

4132

0001000000100100

▶ x3005

x1265

4709

0001001001100101

▶ x3006

x1460

5216

0001010001100000

▶ x3007

x0609

1545

0000011000001001

▶ x3008

x927F

-28033

1001001001111111

▶ x3009

x1261

4705

0001001001100001

▶ x300A

x1620

5664

0001011000100000

▶ x300B

x0603

1539

0000011000000011

▶ x300C

x903F

-28609

1001000000111111

▶ x300D

x1021

4129

0001000000100001

▶ x300E

x0E07

3591

0000111000000111

▶ x300F

x1DA1

7585

0001110110100001

▶ x3010

x0E05

3589

0000111000000101

▶ x3011

x1620

5664

0001011000100000

▶ x3012

x0603

1539

0000011000000011

▶ x3013

x903F

-28609

1001000000111111

▶ x3014

x1021

4129

0001000000100001

▶ x3015

x1DA1

7585

0001110110100001

▶ x3016

x987F

-26497

1001100001111111

▶ x3017

x1921

6433

0001100100100001

▶ x3018

x1A04

6660

0001101000000100

LC3Tools

Registers				Memory		
R0	x0000	0		x5020	20512	0101000000100000
R1	x7FFF	32767		x5260	21088	0101001001100000
R2	xFF17	-233		x5FE0	24544	0101111111000000
R3	xF8E	-114		x5DA0	23968	0101110110100000
R4	xFF2	-14		x1024	4132	0001000000100100
R5	x0E90	3728		x1265	4709	0001001001100101
R6	x2FFA	12282		x1460	5216	0001010001100000
R7	x67C2	26562		x0609	1545	00000110000001001
PSR	x0002	2	OC: Z	x927F	-28033	1001001001111111
PC	x0263	611		x1261	4705	0001001001100001
MCR	x0000	0		x1620	5664	0001011000100000
				x0603	1539	0000011000000011
				x903F	-28609	1001000000111111
				x1021	4129	0001000000100001
				x0E07	3591	00001110000000111
				x1DA1	7585	0001110110100001
				x0E05	3589	0000111000000101
				x1620	5664	0001011000100000
				x0603	1539	0000011000000011
				x903F	-28609	1001000000111111
				x1021	4129	0001000000100001
				x1DA1	7585	0001110110100001
				x987F	-26497	10011000001111111
				x1921	6433	0001100100100001
				x1A04	6660	0001101000000100

Console (click to focus)

```

--- Halting the LC-3 ---

--- Halting the LC-3 ---

--- Halting the LC-3 ---
          
```