

# LC3 Assembly Language

Based on slides © McGraw-Hill  
Additional material © 2004/2005 Lewis/Martin  
Modified by Diana Palselia (2007-2008)

## Assembly: Human-Readable Machine Language

Computers like ones and zeros...

0001110010000110

Humans like readable form ...

**ADD** R6, R2, R6 ; increment index reg.

*Opcode Dest Src1 Src2 Comment*

### Assembler

- A program that turns human readable form into machine instructions
- ISA specific
- One assembly instruction translates to one machine instruction

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## LC-3 Assembly Language Syntax

Each line of a program is one of the following:

- An instruction
- An assembler directive (or pseudo-op)
- A comment

Whitespace (between symbols) and Comments (beginning with “;”) are ignored

An instruction has the following format:

**LABEL: OPCODE OPERANDS ; COMMENTS**



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## Opcodes and Operands

### Opcodes

- Reserved symbols that correspond to LC-3 instructions
- Listed in Appendix A
  - > E.g. ADD, AND, LD, LDR, ...
  - > For BR use lower case
    - n: negative, p: positive and z: zero

### Operands

- Registers -- specified by R0, R1, ..., R7
- Literal/Immediate -- indicated by # (decimal) or x (hex) or b (binary)
  - > E.g. "#10" is "xA" is "b1010"
- Label: -- symbolic name of memory location

Opcode, registers and literals are separated by commas

- Number, order, and type correspond to instruction format
- E.g. ADD R1, R1, #3

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## Labels

### Label

- Followed by colon (:) when declared
  - The textbook does not say this. But for our assembler we use the colon
- Placed at the beginning of the line
- Assigns a symbolic name to the memory address corresponding to line
  - `LOOP: ADD R1,R1,#-1`  
`BRp LOOP`
  - Instead Of  
`ADD R1,R1, #-1`  
`BRp x1FF`
  - Instructions with PCOffset use labels i.e. literal offsets this will not compile in our version of LC3
- Consists of:
  - 1-20 alphanumeric characters
    - Capital or lowercase alphabets or a decimal digit
    - Always starts with a letter of alphabet e.g. `Test1` or `test1`

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## Comments

### Comment

- Anything after a semicolon (;) is a comment
- Ignored by assembler
- Tips for useful comments:
  - State what each register is/will be holding
  - Use comments to separate pieces of program
  - Explain your approach

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## Assembler Directives

### Pseudo-operations

- Operations are not part of the ISA
  - More for convenience
- Used by assembler
- Look like instruction, but “opcode” starts with dot

Opcode	Operand	Meaning
<code>.ORIG</code>	address	starting address of program
<code>.END</code>		end of program
<code>.FILL</code>	value	allocate one word, initialize with value
<code>.BLKW</code>	number	allocate multiple words of storage, value unspecified
<code>.STRINGZ</code>	n-character string	allocate n+1 locations, initialize w/characters and null terminator

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## Assembler Directives (cont..)

### `.ORIG`

- `.ORIG x3050` – tells the assembler where in memory to place the 1<sup>st</sup> instruction of the LC3 program

### `.FILL`

- `.FILL x0006` – initializes a memory location with value 6

### `.BLKW`

- `.BLKW 2` – set aside 2 sequential memory locations
- Useful when the actual value of the operand is not known
- The locations will be initialized with zero

### `.STRINGZ`

- `.ORIG x3010`
  - `.STRINGZ "Hello"`
- x3010: x0048  
 x3011: x0065  
 x3012: x006C  
 x3013: x006C  
 x3014: x006F  
 x3015: x0000
- Null terminated string

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## Trap Codes

LC-3 assembler provides “pseudo-instructions” for each trap code, so you don’t have to remember them

Code	Equivalent	Description
HALT	TRAP x25	Halt execution and return control to OS
IN	TRAP x23	Print prompt on console, read (and echo) one character from keybd. Character stored in R0.
OUT	TRAP x21	Write one character (in R0) to console.
GETC	TRAP x20	Read one character from keyboard. Character stored in R0.
PUTS	TRAP x22	Write null-terminated string to console. Address of string is in R0.

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## An Assembly Language Program

```

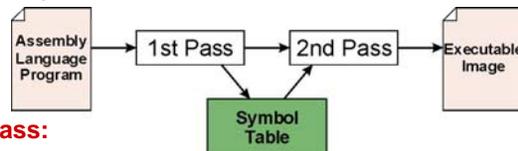
;
; Program to multiply a number by the constant 6
;
        .ORIG  x3000
        LD   R1, SIX
        AND  R2, R2, #0      ;Clear R2
        ADD  R2, R2, #4      R2 = number = 4
        AND  R3, R3, #0      ;Clear R3. It will
                               ;contain the product.
; The inner loop
AGAIN:  ADD  R3, R3, R2
        ADD  R1, R1, #-1
        BRp AGAIN           ;loop until R1 > 0
        HALT                ;control back to OS
;DATA
SIX:    .FILL  x0006        ;initialize location with value 6
        .END                ;end of program
    
```

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## Assembly Process

Program that converts assembly language file (.asm) into an executable file (.obj) for the LC-3 machine (simulator)



### First Pass:

- Scan program file
- Find all labels and calculate the corresponding addresses; this is called the symbol table

### Second Pass:

- Convert instructions to machine language, using information from symbol table

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## First Pass: Constructing the Symbol Table

1. Begin with the `.ORIG` statement, which tells us the address of the first instruction
  - Initialize *location counter* (LC), which keeps track of the current instruction
2. For each non-blank line in the program:
  - a) If line contains a label, put label/LC pair into symbol table
  - b) Increment LC
    - NOTE: If statement is `.BLKW` or `.STRINGZ`, increment LC by the number of words allocated
    - A line with only a comment is considered “blank”
3. Stop when `.END` statement is reached

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## Assembly Process Example: First Pass

```

.ORIG x3000
x3000 AND R2,R2,#0
x3001 LD R3,PTR
x3002 TRAP x23
x3003 LDR R1,R3,#0
x3004 ADD R4,R1,#-4
x3005 TEST: BRz OUTPUT
x3006 NOT R1,R1
x3007 ADD R1,R1,#1
x3008 ADD R1,R1,R0
x3009 BRnp GETCHAR
x300A ADD R2,R2,#1
x300B GETCHAR:ADD R3,R3,#1
x300C LDR R1,R3,#0
x300D BRnzp TEST
x300E OUTPUT: LD R0,ASCII
x300F ADD R0,R0,R2
x3010 TRAP x21
x3011 TRAP x25
x3012 ASCII: .FILL x0030
x3013 PTR: .FILL x4000
.END

```

Symbol	Address
TEST	x3005
GETCHAR	x300B
OUTPUT	x300E
ASCII	x3012
PTR	x3013

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## Second Pass: Generating Machine Code

For each executable assembly language statement

- Generate the corresponding machine language instruction
- If operand is a label, look up the address from the symbol table

Potential errors:

- Improper number or type of arguments
  - E.g. NOT R1,#7  
ADD R1,R2  
ADD R3,R3,NUMBER
- Immediate argument too large
  - E.g. ADD R1,R2,#1023
- Address (associated with label) more than 256 from instruction
  - Can't use PC-relative addressing mode

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## Assembly Process Example: Second Pass

```

.ORIG x3000
x3000 AND R2,R2,#0
x3001 LD R3,PTR
x3002 TRAP x23
x3003 LDR R1,R3,#0
x3004 ADD R4,R1,#-4
x3005 TEST: BRz OUTPUT
x3006 NOT R1,R1
x3007 ADD R1,R1,#1
x3008 ADD R1,R1,R0
x3009 BRnp GETCHAR
x300A ADD R2,R2,#1
x300B GETCHAR:ADD R3,R3,#1
x300C LDR R1,R3,#0
x300D BRnzp TEST
x300E OUTPUT: LD R0,ASCII
x300F ADD R0,R0,R2
x3010 TRAP x21
x3011 TRAP x25
x3012 ASCII: .FILL x0030
x3013 PTR: .FILL x4000
.END

```

```

0101 010 010 1 0000
0010 011 000010001
1111 0000 00100011
.
.

```

Symbol	Address
TEST	x3005
GETCHAR	x300B
OUTPUT	x300E
ASCII	x3012
PTR	x3013

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## Style Guidelines

Improve the readability of your programs

- Formatting: start labels, opcode, operands in same column
- Use comments to explain what each register does
- Give explanatory comment for most instructions
- Use meaningful symbolic names
- Provide comments between program sections
- Each line must fit on the page -- no wraparound or truncations
  - Long statements split in aesthetically pleasing manner

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