Assembly & A86 Assembler

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Based on the slides by Abdullatif Köksal, with his permission.

Assembly

- Assembly language is *any* **low-level programming language** in which there is a very strong correspondence between the instructions in the language and the architecture's machine code instructions.

  What is machine code?
  Machine code is a computer program written in machine language instructions **that can be executed directly by a computer's central processing unit (CPU).**

Assembly

- Assembly language is *any* **low-level programming language** in which there is a very strong correspondence between the instructions in the language and the architecture's machine code instructions.

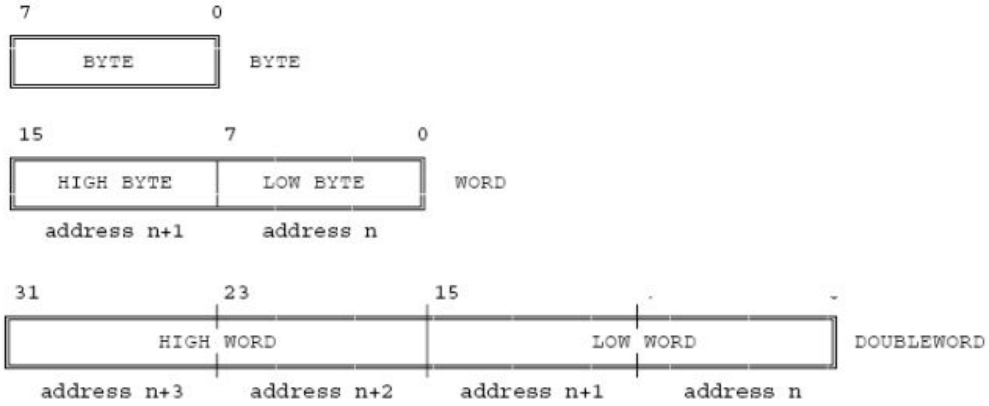
- Because assembly depends on the machine code instructions, **every assembler has its own assembly language which is designed for exactly one specific computer architecture.**
- Assembly code is converted into executable machine code by a utility program referred to as an assembler.

A86 Assembler

- It is designed for the Intel 86-family of microprocessors.
- You have to install XP as a virtual machine.

Bit, Byte, Words, etc

- Bit: Represent two values (0, 1)
- Byte: 8 bits
- Word: 2 bytes, 16 bits
- Double word: 4 bytes, 32 bits



http://www.mwftr.com/uC12/416_05_F12_x86_Assembly%202.pdf

Variables

- A variable is a unit of program data residing at a specific location in memory.
- You can define variables in A86 like in Java.
- You can find address of a variable with OFFSET command.

```
READ_FLAG       DB    0          ; Byte variable, initial value 0
FILE_COUNT      DW    ?          ; Word variable, no initial value
POPULATION      DD    100000     ; Dword variable, initial value 100000
MSG             DB    "Hello"    ; We can define string variable with a value
MSG             DB    "Hello World.$"
```

Registers

- We have 4 general purpose 2 byte (1 word) registers

- Each of them can be divided into two (high & low)

  AX = AH AL
  BX = BH BL
  CX = CH CL
  DX = DH DL

- We also have segment, pointer, and data transfer registers. For details, check out the references.

Variables vs Registers

- You can use variables to store data. However, arithmetic operations have to execute on registers.

- You can move data between variables and registers but you have to **check out the data type.**

MOV: Move

- It copies a piece of data from one location to another.

Mnemonic	Operands	Size	Operation	Flags
MOV	DEST, SRC	B/W	(DEST) <- (SRC)	None

MOV: Move

- It copies a piece of data from one location to another.

AX	=	AH	AL
BX	=	BH	BL
CX	=	CH	CL
DX	=	DH	DL

```
MOV BX,AX    ; Copies the contents of the AX register into the BX register.
MOV CH,DH    ; Copies the top byte of the DX register into the top byte of the CX register.
MOV BH,DL    ; Copies the bottom byte of the DX register into the top byte of BX.
MOV AH,12    ; Puts the value 12 decimal into the top half of the AX register.
MOV AH,0Ch   ; Does the same as the above except that the number is given in hexadecimal.
           ; Hexadecimal numbers MUST begin with a digit and end with a "h".
```

MOV: Move

- It copies a piece of data from one location to another.
- It can copy characters too (directly or via their ASCII Table).

```
MOV DL,"*"   ; This puts the character "*" into DL (lower half of DX).
MOV DL,42    ; This does the same thing, as characters are stored as numbers. ( ASCII char 42 =
"*")
```

ASCII Table

Dec	Hex	Oct	Char	Dec	Hex	Oct	Char	Dec	Hex	Oct	Char	Dec	Hex	Oct	Char
0	0	0		32	20	40	[space]	64	40	100	@	96	60	140	`
1	1	1		33	21	41	!	65	41	101	A	97	61	141	a
2	2	2		34	22	42	"	66	42	102	B	98	62	142	b
3	3	3		35	23	43	#	67	43	103	C	99	63	143	c
4	4	4		36	24	44	$	68	44	104	D	100	64	144	d
5	5	5		37	25	45	%	69	45	105	E	101	65	145	e
6	6	6		38	26	46	&	70	46	106	F	102	66	146	f
7	7	7		39	27	47	'	71	47	107	G	103	67	147	g
8	8	10		40	28	50	(	72	48	110	H	104	68	150	h
9	9	11		41	29	51	)	73	49	111	I	105	69	151	i
10	A	12		42	2A	52	*	74	4A	112	J	106	6A	152	j
11	B	13		43	2B	53	+	75	4B	113	K	107	6B	153	k
12	C	14		44	2C	54	,	76	4C	114	L	108	6C	154	l
13	D	15		45	2D	55	-	77	4D	115	M	109	6D	155	m
14	E	16		46	2E	56	.	78	4E	116	N	110	6E	156	n
15	F	17		47	2F	57	/	79	4F	117	O	111	6F	157	o
16	10	20		48	30	60	0	80	50	120	P	112	70	160	p
17	11	21		49	31	61	1	81	51	121	Q	113	71	161	q
18	12	22		50	32	62	2	82	52	122	R	114	72	162	r
19	13	23		51	33	63	3	83	53	123	S	115	73	163	s
20	14	24		52	34	64	4	84	54	124	T	116	74	164	t
21	15	25		53	35	65	5	85	55	125	U	117	75	165	u
22	16	26		54	36	66	6	86	56	126	V	118	76	166	v
23	17	27		55	37	67	7	87	57	127	W	119	77	167	w
24	18	30		56	38	70	8	88	58	130	X	120	78	170	x
25	19	31		57	39	71	9	89	59	131	Y	121	79	171	y
26	1A	32		58	3A	72	:	90	5A	132	Z	122	7A	172	z
27	1B	33		59	3B	73	;	91	5B	133	[	123	7B	173	{
28	1C	34		60	3C	74	<	92	5C	134	\	124	7C	174	|
29	1D	35		61	3D	75	=	93	5D	135	]	125	7D	175	}
30	1E	36		62	3E	76	>	94	5E	136	^	126	7E	176	~
31	1F	37		63	3F	77	?	95	5F	137	_	127	7F	177	

MOV: Move

- It copies a piece of data from one location to another.
- It can copy characters too (directly or via their ASCII Table).
- It can copy address of a variable. (*OFFSET*)

```
MSG   DB  "Hello World.$"        ; A string variable with a value.

MOV DX, OFFSET MSG               ; DX points to (holds the address of) the string
```

MOV: Move

- It copies a piece of data from one location to another.
- It can copy characters too(directly or via their ASCII Table).
- You have to be careful about data size.

```
MOV AX,BH       ; Invalid operation, as you cannot move an 8 bit quantity to a 16 bit one.
MOV CH,BX       ; Similar to above, you cannot put a 16 bit quantity into an 8 bit one.
MOV 12,DL       ; You cannot put a value into the number 12. If you see this is a program what
                ; is probably meant is MOV DL,12 - put 12 into DL.
MOV DL,AL,CL    ; You cannot have 3 operands!
MOV AH          ; Neither can you have only 1! You must have exactly 2: destination and source
```

Stack: PUSH, POP

- A temporary storage area in memory to quickly store and retrieve data
- Pushing a number in a stack, and popping in the reverse order.

```
PUSH AX ; AX onto stack
PUSH DX ; DX onto stack

POP BX  ; pop into BX
POP CX  ; pop into CX
```

INT: Interrupt

- It calls an interrupt (like a function) to perform a special task.
  - Take input
  - Print to screen
  - Exit

- You have to put some values in registers to indicate the specific task.

INT: Interrupt - Useful Subfunctions

Interrupt.	SubFunction.	Input.	Output.
10h (VIDEO INTERRUPT)	00 (SET_MODE) Sets the Video mode	AL=mode number -	-
	0Ch (WRITE_DOT) Puts a dot on the screen Graphics modes only	DX=row CX=column AL=colour	-
	0Dh (READ_DOT) Reads a dot on screen Graphics modes only	DX=row CX=column -	AL=colour - -
16h (KBD_IO)	00 (AWAIT_CHAR) Reads a character from keyboard	-	AL=character AH=scan_code
	01 (PREVIEW_KEY) Checks to see if a key is ready Does not remove key from buffer	-	Zero flag set - key ready AL=character AH=scancode
21h (DOS_INTERRUPT)	01 (KEYBOARD_INPUT) Reads and displays one character	-	AL=character read -
	02 (DISPLAY_OUTPUT) Displays one character on screen	DL=character -	-
	08 (NO_ECHO_INPUT) Same as 01 but not displayed	-	AL=character -
	09 (PRINT_STRING) Displays a string on screen String must end with "$"	DX=address of string - -	-
	0A (BUFFERED_INPUT) Reads a string from keyboard	DX=address of buffer First character=max length -	Second char of buffer=length of input Rest of buffer=input string followed by carriage return (0Dh)
	4Ch (EXIT)	AL=exit code	-

http://www.csn.ul.ie/~darkstar/assembler/intlist.html

INT: Interrupt - DOS Interrupts (21h)

Subfunction (AH)	Input	Output
01 (KEYBOARD_INPUT) Reads and displays one character	-	AL=character read
02 (DISPLAY_OUPUT) Displays one character on screen	DL=character	-
08 (NO_ECHO_INPUT) Same as 01 but not displayed	-	AL=character read
09 (PRINT_STRING) Displays a string on screen String must end with “$”	DX=address of string	-
0A (BUFFERED_INPUT) Reads a string from keyword	DX=address of buffer First character=max length	Second char of buffer = length of input Rest of the buffer = input string followed by carriage return (0Dh)
4Ch (EXIT)	AL=exit code	-

INT: Exit

```
Exit:
  MOV AH,4Ch
  MOV AL,00   ;Exit code
  INT 21h
```

Subfunction (AH)	Input	Output
4Ch (EXIT)	AL=exit code	-

INT: Print Character

```
Output_char:
 MOV AH,02h
 MOV DL,"!"; you can put ASCII code too
 INT 21h
```

Subfunction (AH)	Input	Output
02 (DISPLAY_OUPUT) Displays one character on screen	DL=character	-

INT: Print String

```
Output:
    MOV DX, OFFSET MSG ; MSG is a variable that holds string
    MOV AH,09h
    INT 21h
```

Subfunction (AH)	Input	Output
09 (PRINT_STRING) Displays a string on screen String must end with “$”	DX=address of string	-

INT: Read Input

```
Read:
    MOV AH,01h
    INT 21h ; Character is in AL
```

Subfunction (AH)	Input	Output
01 (KEYBOARD_INPUT) Reads and displays one character	-	AL=character read

Labels and Jump

- We can have labels that indicates functional parts of the code.
- You can jump to label by JMP command.

First Exercise: Print Char

- In this exercise, we will print ! in the terminal step by step.

First Exercise: Print Char

- In this exercise, we will print ! in the terminal step by step.

1. Find an appropriate interrupt command to print character.
   You have to call **INT 21h** with **02 subfunction** (put in AH) and make sure that character in DL register.

Subfunction (AH)	**Input**	**Output**
02 (DISPLAY_OUPUT) Displays one character on screen	DL=character	-

First Exercise: Print Char

- In this exercise, we will print ! in the terminal step by step.

1. Find an appropriate interrupt command to print character.

   You have to call **INT 21h** with **02 subfunction**(put in AH) and make sure that character in DL register.

```
Output_char:
    MOV DL,"!"              ; DL points to ! character
    MOV AH,02               ; subfunction 2 output a character
    int 21h                 ; Output the message
```

First Exercise: Print Char

- In this exercise, we will print ! in the terminal step by step.

1. Find an appropriate interrupt command to print character.
   You have to call **INT 21h** with **02 subfunction**(put in AH) and make sure that character in DL register.

```
Output_char:
    MOV DL,"!"              ; DL points to ! character
    MOV AH,02               ; subfunction 2 output a character
    int 21h                 ; Output the message
```

2. Exit

```
Exit:
    MOV AH,4Ch
    MOV AL,00
    INT 21h
```

First Exercise: Print Char

- How to skip output char with jump command?
- Put ASCII code into DL instead of character.
- How to print string?

First Exercise: Print Char

- How to skip output char with jump command?
  JMP Exit at the beginning.

- Put ASCII code into DL instead of character.
  MOV DL, 33

- How to print string?

Second Exercise: Hello World

- In this exercise, we will print hello world in the terminal step by step.

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- In this exercise, we will print hello world in the terminal step by step.

1. Define a string (you have to put in the variable)

```
MSG   DB  "Hello World.$"        ; A string variable with a value.
```

Second Exercise: Hello World

- In this exercise, we will print hello world in the terminal step by step.

1. Define a string (you have to put in the variable)

```
JMP Output
MSG    DB   "Hello World.$"        ; A string variable with a value.
```

2. Find an appropriate interrupt command to print string.

   You have to call **INT 21h** with **09 subfunction** (put in AH) and make sure that address of the string is in the DX.

Subfunction (AH)	**Input**	**Output**
09 (PRINT_STRING) Displays a string on screen String must end with “$”	DX=address of string	-

Second Exercise: Hello World

- In this exercise, we will print hello world in the terminal step by step.

1. Define a string (you have to put in the variable)

```
JMP Output
MSG    DB   "Hello World.$"          ; A string variable with a value.
```

2. Find an appropriate interrupt command to print string.

You have to call **INT 21h** with **09 subfunction**(put in AH) and make sure that address of the string is in the DX.

```
Output:
    MOV DX, OFFSET MSG                  ; DX points to (holds the address of) the string
    MOV AH,09                    ; subfunction 9 output a string
    INT 21h                 ; Output the message
```

Second Exercise: Hello World

- In this exercise, we will print hello world in the terminal step by step.

1. Define a string(you have to put in the variable)

```
JMP Output
MSG   DB  "Hello World.$"        ; A string variable with a value.
```

2. Find an appropriate interrupt command to print string.

You have to call **INT 21h** with **09 subfunction**(put in AH) and make sure that address of the string is in the DX.

```
Output:
    MOV DX, OFFSET MSG      ; DX points to (holds the address of) the string
    MOV AH,09               ; subfunction 9 output a string
    INT 21h                 ; Output the message
```

3. Exit

```
Exit:
   MOV AH,4ch
   MOV AL,00               ; Exit code 0
   INT 21h                 ; Terminate program
```

Second Exercise: Hello World

- What would happen if we don’t skip the variable definition?
- What would happen if you don’t add dollar sign at the end of the string?
- How to print new line?

```
cr      dw 13,10,"$"    ; carriage return, line feed
print_cr:
    mov ah,09
    mov dx,offset cr    ; print out a carriage return character
    int 21h
```

Arithmetic Operations

INC AL ; Increments value in AL by one and writes in AL again.

DEC AL ; Decrements value in AL by one and writes in AL again.

ADD AX, BX ; Add value in AX and value in BX and writes into AX. (AX = AX + BX)

SUB AX, BX ; Value in AX minus value in BX and writes into AX. (AX = AX - BX)

Mnemonic	Operands	Size	Operation	Flags
ADD	DEST, SRC	B/W	(DEST) <- (DEST) + (SRC)	AF, CF, OF, PF, SF, ZF
SUB	DEST, SRC	B/W	(DEST) <- (DEST) - (SRC)	AF, CF, OF, PF, SF, ZF

Arithmetic Operations

Multiplication uses AL by default as multiplicand and writes into AX for 8-bit values:

```
MUL CH          ; ( AL*CH -> AX)
```

Mnemonic	Operands	Size	Operation	Flags
MUL	SRC	B	(AX) <- (AL) * (SRC)	CF (carry), OF (overflow)
	SRC	W	(DX:AX) <- (AX) * (SRC)	CF, OF

Arithmetic Operations

Division uses AX by default as dividend and writes result into AL and remainder in AH for 8-bit values:

```
DIV 7          ;AH = AX % 7,
               ;AL = AX / 7
```

Mnemonic	Operands	Size	Operation
DIV	SRC	B	(AX) / (SRC) Quotient: AL Remainder: AH
	SRC	W	(DX:AX) / (SRC) Quotient: AX Remainder: DX

Arithmetic Operations

Shift left:

```
SHL AX, 2    ; Shifts AX left by 2 bits, equivalent to multiply by 4
```

Shift right

```
SHR AX, 3    ; Shift AX right by 3 bits, equivalent to divide by 8
```

Compare: CMP

CMP compares two values and based on the comparison you can jump to different labels. (If else and for loop)

```
CMP AX,6        ; will compare AX and 6
CMP AH,BL       ; will compare AH and BL
var1 DW 0
CMP AX,var1     ; will compare AX and the value in var1
```

Mnemonic	Operands	Size	Operation	Flags
CMP	DEST, SRC	B/W	(DEST) - (SRC)	AF, CF, OF, PF, SF, ZF

Compare: CMP

Numbers	Condition	Flag Conditions
Signed	(dest) > (src)	SF = OF, ZF = 0
	(dest) < (src)	SF <> OF, ZF = 0
	(dest) = (src)	ZF = 1
Unsigned	(dest) > (src)	CF = 0, ZF = 0
	(dest) < (src)	CF = 1, ZF = 0
	(dest) = (src)	ZF = 1

Conditional Jumps

- JMP - Jump **no matter what** (doesn't check conditions)
- JE - Jump on **equal**
- JNE - Jump on **not equal**
- JNAE - Jump on **not above or equal**
- JA - Jump on **above** (if the first thing is **greater**)
- JB - Jump on **below** (if the first thing is **less**)
- JC - Jump on **carry**

Third Exercise: Print Maximum

Read 16-bit integer inputs from command line, and print out the maximum.

1. Set up variables

```
jmp start
                    ; 5 dup 0 = 0 0 0 0 0. dup 0 means fill array with 0

number db 5 dup 0   ; string which will store output. db because a character is byte long.
5 elements because result will be at most 2^15 - 1 ( =32767)

cr      dw 10,"$"   ; carriage return, line feed
temp    dw 0
start:
   mov cx,0       ; cx will hold the current integer
   mov bx,0       ; bx will hold the maximum number so far
```

Third Exercise: Print Maximum

2. Read characters and compare maximum

```
16  morechar:
17    mov ah,01h
18    int 21h     ; reads a character to al
19    mov dx,0      ; dx becomes 0
20    mov dl,al     ; store the input character in dl
21    mov ax,cx
22    cmp dl,0D     ; check if the character is enter (array is over)
23    je compare
24    cmp dl,' '      ; check if the character is space (current integer is finished)
25    je compare
26    sub dx,'0'      ; convert from ascii to real numeric value
27    mov temp,dx     ; 3 lines later, when we multiply ax and cx, dx changes. so, copy dx's value to temp
28    mov ax,cx
29    mov cx,10d
30    mul cx      ; multiply ax by 10
31    add ax,temp
32    mov cx,ax     ; put result to cx again
33    jmp morechar
34
35  compare:
36    cmp cx, bx
37    jl compare_end    ; if cx < bx then jump to compare_end
38    mov bx, cx      ; bx becomes cx
39
40  compare_end:
41    mov cx, 0     ; now cx is zero, we are ready for the next integer
42    cmp dl,' '      ; only if character was space, go back to reading
43    je morechar
```

17-18 read current character

22 if it is enter compare last integer and end it

24 if it is space compare last integer and wait for the next one

26 convert to numeric value

28-32
last_characters*10+cur_char

For example; if you read 78 up to this point when 3 comes:
78*10+3 = 783

Third Exercise: Print Maximum

3. Convert decimal to characters

```
45  setup_string:
46    mov ax,bx     ; put result to ax
47    mov bx,offset number+4  ; put a $ at end of buffer
48    mov b[bx],"$"     ; we will fill buffer from back
49    dec bx
50
51  convert_decimal:
52    mov dx,0
53    mov cx,10d
54    div cx      ; divide ax by 10 to get the last digit
55    add dx,48d      ; convert remainder (last digit) to its ASCII respresentation
56    mov [bx],dl     ; and move to buffer for output
57    dec bx
58    cmp ax,00     ; check if we have got all digits
59    jnz convert_decimal
```

45:
This adds the $ sign at the end of the address of number and decrements current pointer:
0 0 0 0 0 $

51:
Divides maximum number(which is in ax) by 10
add char value of it to the current pointer
decrease the pointer
repeats until it sees 0 again

Third Exercise: Print Maximum

3. Print and close

```
61    print_cr:
62      mov ah,09
63      mov dx,offset cr    ; print out a carriage return character
64      int 21h
65
66    printout:
67      mov dx,bx      ; give the address of string to dx
68      inc dx       ; we decremented once too many, go forward one
69      mov ah,09
70      int 21h
71
72    close:
73      mov ah,04ch      ; exit the program with 0
74      mov al,00
75      int 21h
76
```

61:
Prints new line to avoid overwriting

66:
Prints string of the integer(last value is $)

72:
Close

References

1. http://www.csn.ul.ie/~darkstar/assembler
2. https://fruttenboel.verhoeven272.nl/asm/a86man.htm
3. https://www.wikiwand.com/en/Assembly_language
4. https://www.wikiwand.com/en/Machine_code
5. https://cysecguide.blogspot.com/2016/12/ascii-code-table.html
6. https://patater.com/gbaguy/x86asm.htm