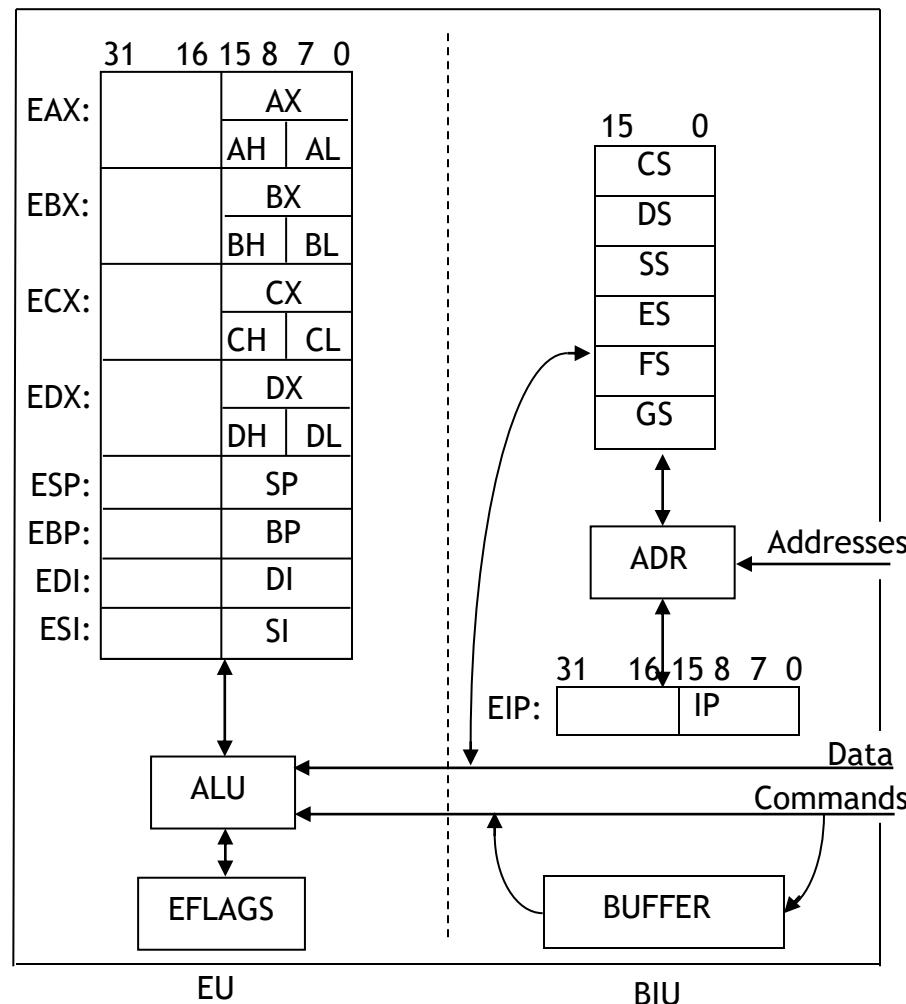


## 2.6. THE x86 MICROPROCESSOR ARCHITECTURE (IA-32)

### 2.6.1. x86 Microprocessor's structure

The x86 microprocessor has two main components:

- **EU (Executive Unit)** – run the machine instr. by means of **ALU (Arithmetic and Logic Unit)** component.
- **BIU (Bus Interface Unit)** - prepares the execution of every machine instruction. Reads an instruction from memory, decodes it and computes the memory address of an operand, if any. The output configuration is stored in a 15 bytes buffer, from where EU will take it.



**EU** and **BIU** work in parallel – while **EU** runs the current instruction, **BIU** prepares the next one. These two actions are synchronized – the one that ends first waits after the other.

## **2.6.2. The EU general registers**

**EAX** - *accumulator*. Used by the most of instructions as one of their operands.

**EBX** – *base register*.

**ECX** - *counter register* – mostly used as numerical upper limit for instructions that need repetitive runs.

**EDX** – *data register* - frequently used with EAX when the result exceed a doubleword (32 bits).

"Word size" refers to the number of bits processed by a computer's CPU in one go (these days, typically 32 bits or 64 bits). Data bus size, instruction size, address size are usually multiples of the word size. So, for a CPU the "word size" is a basic attribute/feature influencing the above mentioned elements.

Just to confuse matters, for backwards compatibility, Microsoft Windows API defines a WORD as being 16 bits, a DWORD as 32 bits and a QWORD as 64 bits, regardless of the processor. So, WORD and DWORD **DATA TYPES** are ALWAYS on 16 and 32 bits respectively FOR THE ASSEMBLY LANGUAGE , regardless of the CPU's "word size" (16, 32 or 64 bits CPU).

**ESP** and **EBP** are *stack registers*. The stack is a LIFO memory area.

Register **ESP** (*Stack Pointer*) points to the last element put on the stack (the element from the top of the stack).

Register **EBP** (*Base pointer*) points to the first element put on the stack (points to the stack's basis).

**EDI** and **ESI** are *index registers* usually used for accessing elements from bytes and words strings. Their functioning in this context (*Destination Index* and *Source Index*) will be clarified in chapter 4.

EAX, EBX, ECX, EDX, ESP, EBP, EDI, ESI are doubleword registers (32 bits). Every one of them may also be seen as the concatenation of two 16 bits subregisters. The upper register, which contains the most significant 16 bits of the 32 bits register, doesn't have a name and it isn't available separately. But the lower register could be used as single so we have the 16 bits registers **AX**, **BX**, **CX**, **DX**, **SP**, **BP**, **DI**, **SI**. Among these registers, AX, BX, CX and DX are also a concatenation of two 8 bits subregisters. So we have **AH**, **BH**, **CH**, **DH** registers which contain the most significant 8 bits of the word (the upper part of AX, BX, CX and DX registers) and **AL**, **BL**, **CL**, **DL** registers which contain the least significant 8 bits of the word (the lower part).

### **2.6.3. Flags**

A *flag* is an indicator represented on 1 bit. A configuration of the FLAGS register shows a synthetic overview of the execution of each instruction. For x86 the EFLAGS register (the status register) has 32 bits but only 9 are actually used.

31	30	...	12	11	10	9	8	7	6	5	4	3	2	1	0
x	x	...	x	OF	DF	IF	TF	SF	ZF	x	AF	x	PF	x	CF

**CF** (*Carry Flag*) is the transport flag. It will be set to 1 if in the LPO there was a transport digit outside the representation domain of the obtained result and set to 0 otherwise. For example, in the addition

$$\begin{array}{r} 1001\ 0011 + \\ \underline{0111\ 0011} \\ \textcolor{red}{1} 0000\ 0110 \end{array} \quad \begin{array}{r} 147 + \\ \underline{115} \\ 262 \end{array}$$

there is transport and CF is set therefore to 1

$$\begin{array}{r} 93h + \\ \underline{73h} \\ 106h \end{array} \quad \begin{array}{r} -109 + \\ \underline{115} \\ 06 \end{array}$$

**CF flags the UNSIGNED overflow !**

**PF** (*Parity Flag*) – Its value is set so that together with the bits 1 from the least significant byte of the representation of the LPO's result an odd number of 1 digits to be obtained.

**AF** (*Auxiliary Flag*) shows the transport value from bit 3 to bit 4 of the LPO's result. For the above example the transport is 0.

**ZF** (*Zero Flag*) is set to 1 if the result of the LPO was zero and set to 0 otherwise.

**SF** (*Sign Flag*) is set to 1 if the result of the LPO is a strictly negative number and is set to 0 otherwise.

**TF** (*Trap Flag*) is a debugging flag. If it is set to 1, then the machine stops after every instruction.

**IF** (*Interrupt Flag*) is an interrupt flag. If set to 1 interrupts are allowed, if set to 0 interrupts will not be handled.

More details about IF can be found in chapter 5 (Interrupts).

**DF** (*Direction Flag*) – for operating string instructions. If set to 0, then string parsing will be performed in an ascending order (from the beginning to its end) and in a descending order if set to 1.

**OF** (*Overflow Flag*) flags the signed overflow. If the result of the LPO (considered in the signed interpretation) didn't fit the reserved space, then OF will be set to 1 and will be set to 0 otherwise.

## Flags categories

The flags can be split into 2 categories:

- a). with a previous effect generated by the Last Performed Operation (LPO): CF, PF, AF, ZF, SF and OF
- b). having a future effect after their setting by the programmer, to influence the way the next instructions are run: CF, TF, DF and IF.

**We have 2 flags categories:**

- a). **reporting the status of the LPO (having a so called previous effect) – CF, PF, AF, ZF, SF, OF**
  - ADC ; Conditional JUMPS (23 instructions – ja = jnbe; jg = jnle ; jz; ...)
- b). **flags to be set by the programmer having a future effect on instructions that follows – CF, TF, IF, DF**
  - HOW ?... by using SPECIAL instructions – 7 instructions

## Specific instructions to set the flags values

Considering the b) category, it is normal that the assembly language provide specific instructions to set the values of the flags that will have a future effect. So, we have 7 such instructions:

CLC – the effect is CF=0 ; STC – sets CF=1 ; CMC – complements the value of the CF ; 3 instructions for CF

CLD – sets DF=0 ; STD – sets DF=1 ; 2 instructions for DF

CLI – sets IF=0 ; STI – sets IF=1 ; 2 instructions for IF – they can be used by the programmer only on 16 bits programming ; on 32 bits, the OS restricts the access to these instructions !

Given the major risk of accidentally setting the value from TF and also its absolutely special role to develop debuggers, there are NO instructions to directly access the value of TF !!

## **2.6.4. Address registers and address computation**

*Address of a memory location* – nr. of consecutive **bytes** from the beginning of the RAM memory and the beginning of that memory location.

An uninterrupted sequence of memory locations, used for similar purposes during a program execution, represents a *segment*. So, a segment represents a logical section of a program's memory, featured by its *basic address* (beginning), by its *limit* (size) and by its *type*. Both basic address and segment's size have 32 bits value representations.

In the family of 8086-based processors, the term **segment** has two meanings:

1. A block of memory of discrete size, called a *physical segment*. The number of bytes in a physical memory segment is
  - o (a) 64K for 16-bit processors
  - o (b) 4 gigabytes for 32-bit processors.
2. A variable-sized block of memory, called a *logical segment* occupied by a program's code or data.

We will call *offset* the address of a location relative to the beginning of a segment, or, in other words, the number of bytes between the beginning of that segment and that particular memory location. An offset is valid only if his numerical value, on 32 bits, doesn't exceed the segment's limit which refers to.

We will call *address specification* a pair of a *segment selector* and an *offset*. A **segment selector** is a numeric value of 16 bits which selects uniquely the accessed segment and his features. A segment selector is defined and provided by the operating system !In hexadecimal an address **specification** can be written as:

**S<sub>3</sub>S<sub>2</sub>S<sub>1</sub>S<sub>0</sub> : 0706050403020100**

In this case, the selector s<sub>3</sub>s<sub>2</sub>s<sub>1</sub>s<sub>0</sub> shows a segment access which has the base address as b<sub>7</sub>b<sub>6</sub>b<sub>5</sub>b<sub>4</sub>b<sub>3</sub>b<sub>2</sub>b<sub>1</sub>b<sub>0</sub> and a limit l<sub>7</sub>l<sub>6</sub>l<sub>5</sub>l<sub>4</sub>l<sub>3</sub>l<sub>2</sub>l<sub>1</sub>l<sub>0</sub>. The base and the limit are obtained by the processor after performing a segmentation process.

To give access to the specific location, the following condition must be accomplished:

$$0706050403020100 \leq l_7l_6l_5l_4l_3l_2l_1l_0.$$

Based on such a specification the actual segmentation address computation will be performed as:

$$a_7a_6a_5a_4a_3a_2a_1a_0 := b_7b_6b_5b_4b_3b_2b_1b_0 + 0706050403020100$$

where  $a_7a_6a_5a_4a_3a_2a_1a_0$  is the computed address (hexadecimal form). The above output address is named a *linear address. (or segmentation address)*.

An address specification is also named FAR address. When an address is specified only by offset, we call it NEAR address.

A concrete example of an address specification is: **8:1000h**

To compute the linear address corresponding to this specification, the processor will do the following:

1. It checks if the segment with the value 8 was defined by the operating system and blocks the access such a segment wasn't defined; (memory violation error...)
2. It extracts the base address (B) and the segment's limit (L), for example, as a result we may have B – 2000h and L = 4000h;
3. It verifies if the offset exceeds the segment's limit:  $1000h > 4000h$  ? if so, then the access would be blocked;
4. It adds the offset to B and obtains the linear address 3000h ( $1000h + 2000h$ ). This computation is performed by the **ADR** component from **BIU**.

This kind of addressing is called *segmentation* and we are talking about the *segmented addressing model*.

When the segments start from address 0 and have the maximum possible size (4GiB), any offset is automatically valid and segmentation isn't practically involved in addresses computing. So, having  $b_7b_6b_5b_4b_3b_2b_1b_0 = 00000000$ , the address computation for the logical address  $s_3s_2s_1s_0 : 0706050403020100$  will result in the following linear address:

$$a_7a_6a_5a_4a_3a_2a_1a_0 := 00000000 + 0706050403020100$$

$$a_7a_6a_5a_4a_3a_2a_1a_0 := 0706050403020100 \\ \Rightarrow$$

This particular mode of using the segmentation, used by most of the modern operating systems is called the *flat memory model*.

The x86 processors also have a memory access control mechanism called *paging*, which is independent of address segmentation. Paging implies dividing the *virtual* memory into *pages*, which are associated (translated) to the available physical memory. (1 page =  $2^{12}$  bytes = 4096 bytes).

The configuration and the control of segmentation and paging are performed by the operating system. Of these two, only segmentation interferes with address specification, paging being completely transparent relative to the user programs.

Both addresses computing and the use of segmentation and paging are influenced by the execution mode of the processor, the x86 processors supporting the following more important execution modes:

- *real mode*, on 16 bits (using memory word of 16 bits and having limited memory at 1MiB);
- ***protected mode on 16 or 32 bits, characterized by using paging and segmentation;***
- *8086 virtual mode*, allows running real mode programs together with the protected ones;
- *long mode on 64 and 32 bits*, where paging is mandatory while segmentation is deactivated.

In our course we will focus on the architecture and the behavior of x86 processors in protected mode on 32 bits.

The x86 architecture allows 4 types of segments:

- *code segment*, which contains instructions ;
- *data segment*, containing data which instructions work on;
- *stack segment*;
- *extra segment*; (supplementary data segment)

Every program is composed by one or more segments of one or more of the above specified types. At any given moment during run time there is only at most one active segment of any type. Registers **CS** (*Code Segment*), **DS** (*Data Segment*), **SS** (*Stack Segment*) and **ES** (*Extra Segment*) from **BIU** contain the values of the selectors of the active segments, correspondingly to every type. So registers CS, DS, SS and ES **determine** the starting addresses and the dimensions of the 4 active segments: code, data, stack and extra segments. Registers FS and GS can store selectors pointing to other auxiliary segments without having predetermined meaning. Because of their use, CS, DS, SS, ES, FS and GS are called *segment registers* (or *selector registers*). Register **EIP** (which offers also the possibility of accessing its less significant word by referring to the **IP** subregister) contains the offset of the current instruction inside the current code segment, this register being managed exclusively by **BIU**.

Because addressing is fundamental for understanding the functioning of the x86 processor and assembly programming, we review its concepts to clarify them:

<b>Notion</b>	<b>Representation</b>	<b>Description</b>
Address specification, logical address, FAR address	Selector <sub>16</sub> :offset <sub>32</sub>	Defines completely both the segment and the offset inside it.
Selector	16 bits	Identifies one of the available segments. As a numeric value it codifies the position of the selected segment descriptor within a descriptor table.
Offset, NEAR address	Offset <sub>32</sub>	Defines only the offset component (considering that the segment is known or that the flat memory model is used).
Linear address (segmentation address)	32 bits	Segment beginning + offset, represents the result of the segmentation computing.
Physical effective address	At least 32 bits	Final result of segmentation plus paging eventually. The final address obtained by BIU points to physical memory (hardware).

## **2.6.5. Machine instructions representation**

A x86 machine instruction represents a sequence of 1 to 15 bytes, these values specifying an operation to be run, the operands to which it will be applied and also possible supplementary modifiers.

A x86 machine instruction has maximum 2 operands. For most of the instructions, they are called *source* and *destination* respectively. From these two operands, **only one may be stored in the RAM memory**. The other one must be either one **EU register**, either an **integer constant**. Therefore, an instruction has the general form:

*instruction\_name destination, source*

The internal format of an instruction varies between 1 and 15 bytes, and has the following general form (*Instructions byte-codes from OllyDbg*):

*[prefixes] + code + [ModeR/M] + [SIB] + [displacement] + [immediate]*

The *prefixes* control how an instruction is executed. These are optional (0 to maxim 4) and occupy one byte each. For example, they may request repetitive execution of the current instruction or may block the address bus during execution to not allow concurrent access to operands and results.

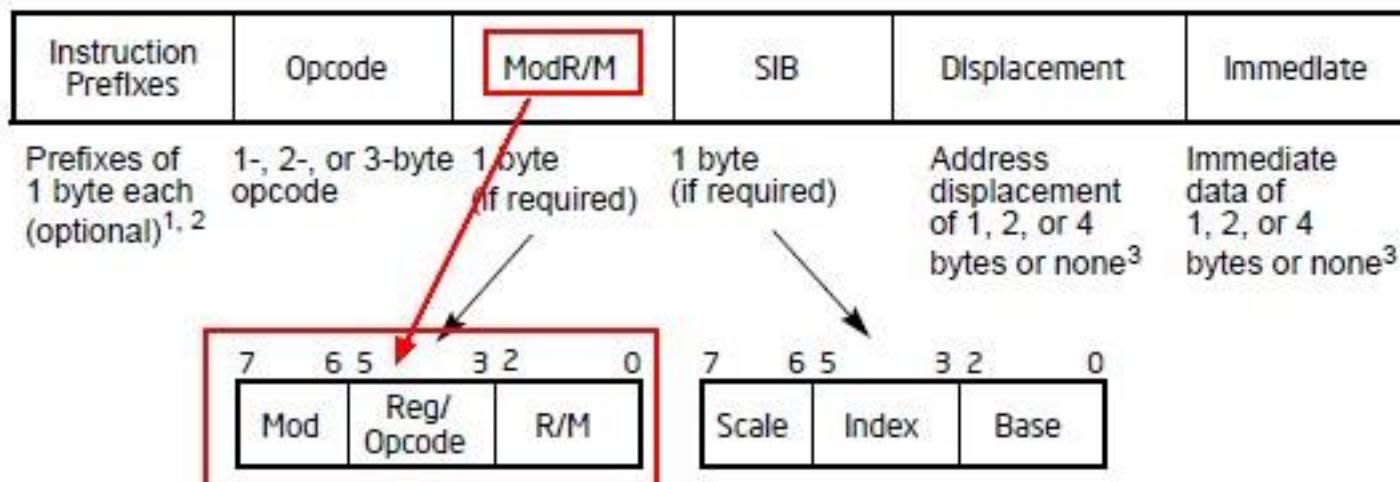
The operation to be run is identified by 1 to 2 bytes of *code* (opcode), which are the only mandatory bytes, no matter of the instruction. The byte *ModeR/M* (register/memory mode) specifies for some instructions the nature and the exact storage of operands (register or memory). This allows the specification of a register or of a memory location described by an offset.

Number of Bytes	0 or 1	0 or 1	0 or 1	0 or 1
	Instruction prefix	Address-size prefix	Operand-size prefix	Segment override

(a) Optional instruction prefixes

(b) General instruction format

Although the diagram seems to imply that instructions can be up to 16 bytes long, in actuality the x86 will not allow instructions greater than 15 bytes in length.



For more complex addressing cases than the one implemented directly by ModeR/M, combining this with SIB byte allows the following formula for an offset (<http://datacadamia.com/intel/modrm>):

$$\begin{array}{c} \text{[base]} + [\text{index} \times \text{scale}] + \text{[constant]} \\ (\text{SIB}) \qquad \qquad \qquad (\text{displacement+immediate}) \end{array}$$

where for base and index the value of two registers will be used and the scale is 1, 2, 4 or 8. The allowed registers as base or/ and as indexes are: EAX, EBX, ECX, EDX, EBP, ESI, EDI. The ESP register is available as base but cannot be used as index ([http://www.c-jump.com/CIS77/CPU/x86/lecture.html#X77\\_0100\\_sib\\_byte\\_layout](http://www.c-jump.com/CIS77/CPU/x86/lecture.html#X77_0100_sib_byte_layout)).

Most of the instructions use for their implementation either only the opcode or the opcode followed by ModeR/M.

The *displacement* is present in some particular addressing forms and it comes immediately after ModeR/M or SIB, if SIB is present. This field can be encoded either on a byte or on a doubleword (32 bits).

The most common addressing mode, and the one that's easiest to understand, is the *displacement-only* (or *direct*) addressing mode. The displacement-only addressing mode consists of a 32-bit constant that specifies the address of the target location. The displacement-only addressing mode is perfect for accessing simple scalar variables. Intel named this the displacement-only addressing mode because a 32-bit constant (displacement) follows the MOV opcode in memory. On the 80x86 processors, this displacement is an offset from the beginning of memory (that is, address zero).

**Displacement mode, the operand's offset** is contained as part of the instruction as an 8-, 16-, or 32-bit displacement. The displacement addressing mode is found on few machines because, as mentioned earlier, it leads to long instructions. In the case of the x86, the displacement value can be as long as 32 bits, making for a 6-byte instruction. **Displacement addressing can be useful for referencing global variables.**

As a consequence of the impossibility of appearing more than one ModeR/M, SIB and displacement fields in one instruction, the x86 architecture doesn't allow encoding of two memory addresses in the same instruction.

With the *immediate value* we can define an operand as a numeric constant on 1, 2 or 4 bytes. When it is present, this field appears always at the end of instruction.

## **2.6.6. FAR addresses and NEAR addresses.**

To address a RAM memory location two values are needed: one to indicate the segment and another one to indicate the offset inside that segment. For simplifying the memory reference, the microprocessor implicitly chooses, in the absence of other specification, the segment's address from one of the segment registers CS, DS, SS or ES. The implicit choice of a segment register is made after some particular rules specific to the used instruction.

An address for which only the offset is specified, the segment address being implicitly taken from a segment register is called a *NEAR address*. A NEAR address is always inside one of the 4 active segments.

An address for which the programmer explicitly specifies a segment selector is called a *FAR address*. So, a FAR address is a COMPLETE ADDRESS SPECIFICATION and it may be specified in one of the following 3 ways:

- $s_3s_2s_1s_0 : \text{offset\_specification}$  where  $s_3s_2s_1s_0$  is a constant;
- segment register: offset\_specification, where segment registers are CS, DS, SS, ES, FS or GS;
- FAR [variable], where variable is of type QWORD and contains the 6 bytes representing the FAR address.

The internal format of an FAR address is: at the smallest address is the offset, and at the higher (by 4 bytes) address (the word following the current doubleword) is the word which stores the segment selector.

The address representation follows the little-endian representation presented in Chapter 1, paragraph 1.3.2.3: the less significant part has the smallest address, and the most significant one has the higher address.

## **2.6.7. Computing the offset of an operand. Addressing modes.**

For an instruction there are 3 ways to express a required operand:

- *register mode*, if the required operand is a register; `mov eax, 17`
- *immediate mode*, when we use directly the operand's value (not its address and neither a register holding it);  
`mov eax, 17`
- *memory addressing mode*, if the operand is located somewhere in memory. In this case, its offset is computed using the following formula:

$$\text{offset\_address} = [ \text{base} ] + [ \text{index} \times \text{scale} ] + [ \text{constant} ]$$

So *offset\_address* is obtained from the following (maximum) four elements:

- the content of one of the registers EAX, EBX, ECX, EDX, EBP, ESI, EDI or ESP as base;
- the content of one of the registers EAX, EBX, ECX, EDX, EBP, ESI or EDI as index;
- scale to multiply the value of the index register with 1, 2, 4 or 8;
- the value of a numeric constant, on a byte or on a doubleword.

From here results the following modes to address the memory:

- *direct addressing*, when only the *constant* is present;
- *based addressing*, if in the computing one of the base registers is present;
- *scale-indexed addressing*, if in the computing one of the index registers is present.

These three mode of addressing could be combined. For example, it can be present direct based addressing, based addressing and scaled-indexed etc.

A non direct addressing mode is called ***indirect addressing*** (based and/or indexed). So, an indirect addressing is a one for which we have at least one register specified between squared brackets.

In the case of the jump instructions another type of addressing is present called *relative addressing*.

*Relative addressing* indicates the position of the next instruction to be run relative to the current position. This "distance" is expressed as the number of bytes to jump over. The x86 architecture allows relative SHORT addresses, described on a byte and having values between -128 and 127, but also relative NEAR addresses, represented on a doubleword with values between -2147483648 and 2147483647.

Jmp Below2 ; this instruction will be translated into (see OllyDbg) usually in something as **Jmp [0084]↓**

.....

.....

Below2:

    Mov eax, ebx

## Examples - implicit rules for prefixing an offset with the corresponding segment register

Mov eax, [ebx+esp] ; ESP – base... EBX – index ;EAX  $\leftarrow$  dword ptr [SS:esp+ebx]...  
Mov eax, [esp + ebx] ; ESP – base... EBX – index ;EAX  $\leftarrow$  ...SS:...

Mov eax, [ebx+esp\*2] ; syntax error BECAUSE ESP can be ONLY a base register !  
Mov eax, [ebx+ebp\*2] ; mov eax, DWORD PTR [DS:EBX+EBP\*2]

Mov eax, [ebx+ebp] ; ...DS...  
Mov eax, [ebp+ebx] ; ...SS...

Mov eax, [ebx\*2+ebp] ; ...SS...

Mov eax, [ebx\*1+ebp] ;...SS...  
Mov eax, [ebp\*1+ebx] ; ...DS...

Mov eax, [ebx\*1+ebp\*1] ; ;...SS... - the first found scaled element is taken as index  
!! EBP - base

Mov eax, [ebp\*1+ebx\*1] ; ...DS... - the first found scaled element is taken as index  
!! EBX - base

Mov eax, [ebp\*1+ebx\*2]; ...SS...

Mov eax, [v] ; ...[DS:v]

## JMP instruction analysis. NEAR and FAR jumps.

We present below a very relevant example for understanding the control transfer to a label, highlighting the differences between a direct transfer vs. an indirect one.

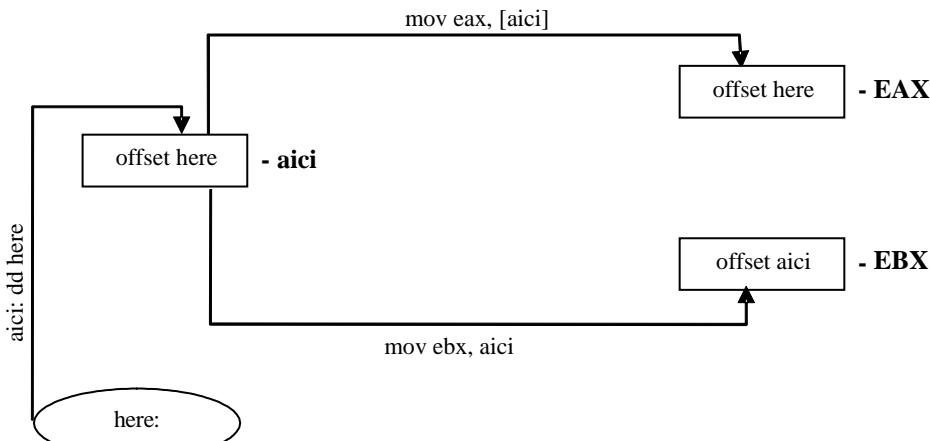
segment data

aici DD here ;equiv. with aici := offset of label here from code segment

segment code

mov eax, [aici] ;we load EAX with the contents of variable aici (that is the offset of here inside the code segment – same effect as **mov eax, here**)

mov ebx, aici ;we load EBX with the offset of aici inside the data segment  
; (probable 00401000h)



**Fig. 4.4.** Initializing variable aici and registers EAX and EBX.

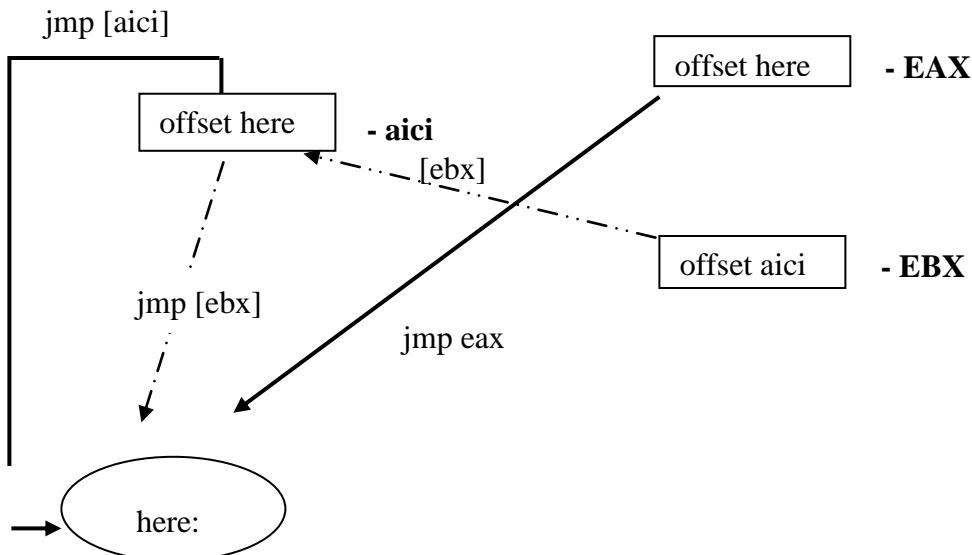
jmp [aici] ;jump to the address indicated by the value of variable aici (which is the address of here), so this is an instruction equiv with jmp here ; what does in contrast **jmp aici ??? - the same thing as jmp ebx ! jump to CS:EIP with EIP=offset (aici) from SEGMENT DATA (00401000h) ; jump to some instructions going until the first „access violation”**

jmp here ;jump to the address of here (or, equiv, jump to label here); **jmp [here] ?? – JMP DWORD PTR DS:[00402014] – most probably „Access violation”....**

jmp eax ;jump to the address indicated by the contents of EAX (accessing register in direct mode), that is to label here ; in contrast, what does **jmp [eax] ??? JMP DWORD PTR DS:[EAX] – most probably „Access violation”....**

jmp [ebx] ;jump to the address stored in the memory location having the address the contents of EBX (indirect register access – the only indirect access from this example) – what does in contrast **jmp ebx ??? - jump to CS:EIP with EIP=offset (aici) from the SEGMENT DATA (00401000h) ; jump to some instructions going until the first „access violation”**

in EBX we have the address of variable `aici`, so the contents of this variable will be accessed. In this memory location we find the offset of label `here`, so a jump to address `here` will be performed - **consequently, the last 4 instructions from above are all equivalent to `jmp here`**



**Fig. 4.5.** Alternative ways for performing jumps to the label `here`.

`jmp [ebp] ; JMP DWORD PTR SS:[EBP]`

---

**here:**  
`mov ecx, 0ffh`

---

Explanations on the interaction between the implicit association rules of an offset with the corresponding segment register and performing the corresponding jump to the specified offset

**JMP [var\_mem] ; JMP DWORD PTR DS:[004010??]**

<b>JMP [EBX]</b>	<b>; JMP DWORD PTR DS:[EBX]</b>
<b>JMP [EBP]</b>	<b>; JMP DWORD PTR SS:[EBP]</b>
<b>JMP here</b>	<b>; JMP DWORD PTR DS:[00401014] - will perform the jump DIRECTLY to that offset in code segment</b>

accordingly to the implicit association rules of an offset with the corresponding segment register

In this case do we have to expect that the jump to be made in the data segment at the specified offset and the processor to interpret that data as instructions code ? (taking into consideration the implicit offset positioning relative to DS) ?? That is, the FAR jumping address to be DS:[00401000] and DS:[reg] respectively ?

**NO ! NOT AT ALL !** Something like that doesn't happen. First of all, the IMPLICIT jump type is NEAR (check in OllyDbg how NASM is generating the corresponding object code by DWORD PTR, so it takes into consideration JUST the OFFSET - relative to DS or SS !). Being NEAR jump instructions, these will be made IN THE SAME MEMORY (CODE) SEGMENT in which those three instructions appear, so the jumps will be made in fact to CS:[var\_mem] and CS:[reg] respectively.

So... a NEAR jump, even if it is implicitly prefixed with DS or SS doesn't make a jump into the data segment or in the stack segment! **Prefixing is useful here only for allowing to load the corresponding OFFSET value of a "complete" address specification.**

It follows that even if we use explicit prefixing, like for example

**jmp [ss: ebx + 12]**  
**jmp [ss:ebp + 12] equiv with jmp [ebp + 12]**

because the jump is still a NEAR one, it will be made inside the same (current) code segment, that is to CS : EIP, namely to CS : offset value

**So, prefixing a target of a jump with a segment register has only the task of correctly indicate the actual segment from which the required offset is relative to, offset to which the NEAR jump will be performed inside the current code segment !**

**If we wish to make a jump to a different segment (namely to perform a FAR jump) we must EXPLICITLY specify that by using the **FAR** type operator:**

**jmp far [ss: ebx + 12] => CS : EIP <- the far address (48 bits)**  
(9b 7a 52 61 c2 65) → EIP = 61 52 7a 9b ; CS= 65 c2  
„**Mov CS:EIP, [adr]**“ ;

The FAR operator specifies here that not only EIP must be loaded with what we have at the specified address, but also CS must be loaded with a new value (this makes in fact the jump to be a FAR one).

In short and as a conclusion we have :

- the value of the pointer representing the address where the jump has to be made can be stored anywhere in memory, this meaning that any offset specification that is valid for a MOV instruction can be also present as an operator for a JMP instruction (for example **jmp [gs:ebx + esi\*8 - 1023]**)
- the contents of the pointer (the bytes taken from that specific memory address) may be near or far, depending on how the programmer specifies or not the FAR operator, being thus applied either only to EIP (if the jump is NEAR), either to the pair CS:EIP if the jump is FAR.

Any jump can be considered hypothetically equivalent to MOV instructions such as:

- **jmp [gs:ebx + esi \* 8 - 1023] <=> "mov EIP, DWORD [gs:ebx + esi \* 8 - 1023]"**
- **jmp FAR [gs:ebx + esi \* 8 - 1023] <=> "mov EIP, DWORD [gs:ebx + esi \* 8 - 1023]" + "mov CS, WORD [gs:ebx + esi \* 8 - 1023 + 4]"**

At the address [gs:ebx + esi \* 8 - 1023] we found in the particular memory example used the configuration:

7B 8C A4 56 D4 47 98 B7.....

"Mov CS:EIP, [memory]" → EIP = 56 A4 8C 7B  
CS = 47 D4

## **JMP through labels – always NEAR !**

segment data use32 class=DATA

a db 1,2,3,4

start3:

mov edx, eax ; ok ! – the control is transferred here and this instruction is executed !

segment code use32 class=code

start:

mov edx, eax

jmp start2 - ok – NEAR jmp - JMP 00403000 (offset code segment = 00402000)  
jmp start3 – ok – NEAR jmp – JMP 00401004 (offset data segment = 00401000)

jmp far start2 - Segment selector relocations are not supported in PE file

jmp far start3 - Segment selector relocations are not supported in PE file

;The two jumps above jmp start2 and jmp start3 respectively will be done to the specified  
;labels, start2 and start3 but they will not be considered FAR jumps (the proof is that the  
;specification of this attribute above in the other two variants of the instructions will lead  
;to a syntax error!)

;They will be considered NEAR jumps due to the FLAT memory model used by the OS

add eax,1

final:

push dword 0

call [exit]

segment code1 use32 class=code

start2:

mov eax, ebx

.....

push dword 0

call [exit]

## Final conclusions.

- NEAR jumps – can be accomplished through all of the three operand types (label, register, memory addressing operand)
- FAR jumps (this meaning modifying also the CS value, not only that from EIP) – can be performed ONLY by a memory addressing operand on 48 bits (pointer FAR). Why only so and not also by labels or registers ?
- by labels, even if we jump into another segment (an action possible as you can see above) this is not considered a FAR jump because CS is not modified (due to the implemented memory model – Flat Memory Model). Only EIP will be changed and the jump is technically considered to be a NEAR one.
- Using registers as operands we may not perform a far jump, because registers are on 32 bits and we may so specify maximum an offset (NEAR jump), so we are practically in the case when it is impossible to specify a FAR jump using only a 32 bits operand.

**October 27, 2022**

- main task of an assembler = generating the corresponding bytes
- at any given moment ONLY ONE segment of every type may be ACTIVE
- in 16 bits programming the segment registers CS, DS, SS, ES contained the STARTING ADDRESSES of the currently active segments
- in 32 bits programming the segment registers CS, DS, SS, ES contain the values of the SELECTORS of the currently active segments
- at any given moment during run time the CS:EIP combination of registers expresses /contain the address of the currently executed instruction
- these values are handled exclusively by BIU
- an assembly language instruction doesn't support/allow both of its explicit operands to be from the RAM memory
- that is because BIU may "bring" only one memory operand at a time (for 2 memory operands we would need 2 BIU, 2 segment registers sets etc)

$$\text{offset\_address} = [\text{base}] + [\text{index} \times \text{scale}] + [\text{constant}] \\ (\text{SIB}) \quad (\text{displacement} + \text{immediate})$$

*[prefixes] + code + [ModeR/M] + [SIB] + [displacement] + [immediate]*

- the first 2 elements from the offset address computation formula (base and index\*scale) are expressed by the SIB byte from the internal format formula
- the third element: the constant, if present, is expressed by the displacement and/or immediate fields
- SIB and displacement participate ONLY to the offset computation of the memory operand, if there is any
  - "immediate" field may be also involved in offset computation, but it can also appear INDEPENDENTLY from a memory operand, expressing in such a case an immediate operand (mov eax, 7 ; 7 is "immediate" and no memory operand present in the instruction)
- if Modr/m tells us that we have a register operand the next 3 fields from the internal format formula are absent (because if the operand is a register it can NOT be in the same time also a memory operand or an immediate value )
- if Modr/m tells us that we have a memory operand => SIB byte is mandatory, followed MAYBE by displacement and/or immediate
  - the field "immediate" may participate to the offset computation of a memory operand (providing the "constant" field from the offset computation formula) or may appear only by itself expressing the immediate value of an operand (example: mov ebx, 12345678h)

- the displacement field expresses the direct addressing memory access

- immediate field = numerical constants

- in the instructions used in our programs we will use almost exclusively only offsets, these being implicitly prefixed by one of the segment registers CS, DS, SS or ES. (ex. in debugger image - push variabila -> DS:[40100...])

- offset = an address

- direct addressing means direct access to the memory operand based on its offset, without needing / specifying any register in the offset specification formula (so no base or index !)

- if registers appear in the offset computation formula (base or index) => indirect addressing

CS:EIP – The FAR (complete, full) address of the currently executing instruction

EIP – automatically incremented by the current execution

CS – contains the segment selector of the currently active segment and it can be changed only if the execution will switch to another segment

Mov cs, [var] - forbidden

Mov eip, eax - forbidden

Jmp FAR somewhere ; CS and EIP will be both modified !

Jmp start1 ; NEAR jmp – only the offset will be modified, so EIP !

## 2's complement. Discussions and examples.

Mathematically, the two's complement REPRESENTATION of a NEGATIVE number is the value  $2^n - V$ , where  $V$  is the absolute value of the represented number

## 2's complement. Discussions and examples.

Mathematically, the two's complement representation of a NEGATIVE number is the value  $2^n - V$ , where  $V$  is the absolute value of the represented number

1001 0011 (= 93h = 147), so in the UNSIGNED interpretation  $1001\ 0011 = 147$

Being a binary number starting with 1, in the SIGNED interpretation, this number is negative. Which is its value ?  
Answer: Its value is:  $- (2's \text{ complement of the initial binary configuration})$

So, we have to determine the 2's complement of the configuration 1001 0011

How can we obtain the 2's complement of a number (represented in memory so we are talking about base 2) ?

Variant 1 (Official): Subtracting the binary contents of the location from 100 ...00 (where the number of zero's are exactly the same as the number of bits of the location to be complemented).

$$\begin{array}{r} 1\ 0000\ 0000 - \\ \underline{1001\ 0011} \\ 01101101 \end{array} = 6Dh = 96+13 = 109 \text{ (so the 2's complement on 8 bits of 147 is 109)}$$

So, the value of 1001 0011 in the SIGNED interpretation is -109

**Variant 2 (derived from the 2's complement definition – faster from a practical point of view):** reversing the values of all bits of the initial binary number (value 0 becomes 1 and value 1 becomes 0), after which we add 1 to the obtained value.

According to this rule, we start from 1001 0011 and reverse the values of all bits, obtaining 0110 1100 after which we add 1 to the obtained value:  $0110\ 1100 + 1 = 0110\ 1101 = 109$

So, the value of 1001 0011 in the SIGNED interpretation is -109

**Variant 3 (MUCH MORE faster practically for obtaining the binary configuration of the 2's complement):** We left unchanged the bits starting from the right until to the first bit 1 inclusive and we reverse the values of all the other bits (all the bits from the left of this bit with value 1).

Applying this rule, we start from 1001 0011 and left unchanged all the bits starting from the right until to the first bit 1 inclusive (in our case this means only the first bit 1 from the right – which is the only one that is left unchanged) and all other bits will be reversed, so we obtain...0110 1101 = 6DH = 109

So, the value of 1001 0011 in the SIGNED interpretation is -109

**Variant 4 (the MOST faster practical alternative, if we are interested ONLY in the absolute value in base 10 of the 2's complement):**

**Rule derived from the definition of the 2's complement:** The sum of the absolute values of the two complementary values is the cardinal of the set of values representable on that size.

On 8 bits we can represent  $2^8$  values = 256 values ([0..255] or [-128..+127])

- On 16 bits we can represent  $2^{16}$  values = 65536 values ([0..65535] or [-32768,+32767])
- On 32 bits we can represent  $2^{32}$  valori = 4.294.967.296 values (...)

So, on 8 bits, the 2's complement of 1001 0011 (= 93h = 147) is 256 – 147 = 109, so the corresponding value in SIGNED interpretation for 1001 0011 is -109.

- [0..255] – admissible representation interval for “UNSIGNED integer represented on 1 byte”  
[-128..+127] – admissible representation interval for “SIGNED integer represented on 1 byte”

- [0..65535] – admissible representation interval for “UNSIGNED integer represented on 2 bytes = 1 word”  
[-32768..+32767] – admissible representation interval for “SIGNED integer represented on 2 bytes = 1 word”

Why do we need to study the 2's complement ? is it useful for us as programmers ? In which way ?...

1001 0011 (= 93h = 147), so in the UNSIGNED interpretation **1001 0011= 147**

Which is the signed interpretation of 1001 0011 ?

- a). 01101101
- b). -109
- c). 6Dh
- d). +147

Which is the signed interpretation of 93h ?

- a). 01101101
- b). -109
- c). 6Dh
- d). +147

Which is the signed interpretation of 147 in base 10 ?

- a). 01101101
- b). -109
- c). 6Dh
- d). +147

**STUPID QUESTION – we cannot have DIFFERENT interpretations in base 10 of numbers ALREADY expressed in base 10  
– 147 IS ALREADY AN INTERPRETATION !!)**

1 0000 0000 –  
1001 0011

---

$$\boxed{01101101} = 6Dh = 96+13 = 109 \text{ (so the 2's complement on 8 bits of 147 is 109)}$$

So, the value of 1001 0011 in the SIGNED interpretation is ... **-109**

147 and -109 are two complementary values, in the sense that 1001 0011 = either 147, or -109 depending on the interpretation.

So the complement of 147 is -109. Is it also true the other way around ? Is -147 the complement of the 109 ?...

Let's check...  $109 = \boxed{01101101}$ , the 2's complement of  $\boxed{01101101}$  is  $10010011 = 147$ , so... Which is the conclusion then ?...

Mathematically, the two's complement representation of a NEGATIVE number is the value  $2^n - V$ , where V is the absolute value of the represented number. So the whole discussion about the 2's complement makes practical sense ONLY WHEN we refer to the BINARY REPRESENTATION of a NEGATIVE number from base 10!!! Or to the SIGNED INTERPRETATION of a binary number starting with 1 !! That is, ONLY when we discuss the INTERPRETATION of numbers that in base 2 start with 1 !!!!!! When we have a binary number starting with 0, its INTERPRETATION WILL BE THE SAME in both SIGNED and UNSIGNED, i.e.  $01101101 = 109$  IN BOTH INTERPRETATIONS !! As a result, the fact that 147 is itself "109's complement of 2 as an absolute value" does not help us at all...

**So: all the discussion about complementary values makes sense only if our attention is focused on the NEGATIVE NUMBERS topic!! Ex: we start from a representation in base 2 that begins with 1 and we ask ourselves what will be the associated negative number in the SIGNED interpretation !! Or: we start from an absolute value (109 or 147) and ask ourselves which is the representation in base 2 for -109 or for -147 !! So everything must be around NEGATIVE numbers!!**

An approach that starts from a representation in base 2 that begins with 0 and asks ONLY what will be the "complementary value of that representation" (without this complementary value being then used for something concrete) does not make sense out of the context of interpreting a SIGNED number as negative.

The fact that there is a range of values for which the interpretation of a binary configuration is the same in both interpretations happens (taking the byte size as an example) because  $[0..255] \cap [-128..+127] = [0..+127]$  and thus any number in the range  $[0..+127]$  will represent both the SIGNED and the UNSIGNED version of the given binary configuration! This REPRESENTATION in base 2 will be a sequence of bits starting with 0, such a sequence being characterized by the fact that in base 10 its value will be the same (a positive one!) in both interpretations. These numbers are part of the intersection of the unsigned interpretation  $[0..255]$  with the signed one  $[-128 ..+127]$ .

So the intersection of the admissible representation intervals on a dimension N consists ONLY of the values that in binary begin with bit 0! As a result, binary values starting with bit 1 are NOT common to these "complementary" ranges, meaning that the signed and unsigned interpretations of any binary configuration starting with 1 WILL ALWAYS BE DIFFERENT and they will NEVER be parts of the same admissible representation interval !!! The absolute values of the two interpretations represent two complementary values.  
Ex: -128, 128; 147, -109; -1, 255; -3, 253; -127, 129 will NEVER be part of the same admissible representation interval. (However, it does NOT apply also to 127, -129 !!! – explanation ... later ☺)

So... which is the binary representation for -147? Or how much is 10010011 in the signed interpretation?  
 $147 = 10010011$ , so... how do we get -147?

More generally, let's see which are the **types of questions** that we can ask starting from a given binary configuration and thus determine what are the situations in which the need to use the 2's complement arises:

- a) If we have a REPRESENTATION of type  $\overline{0xxx} \dots$  having the value  $+abc$  in the UNSIGNED interpretation, which will be the value of this REPRESENTATION in the SIGNED interpretation ?

R: The same ! A number that begins with 0 in base 2 has the same value in base 10 both in signed and unsigned interpretation, being a positive number (109 is +109 in both interpretations).

- b). If we have a REPRESENTATION of type  $\overline{0xxx} \dots$  having the value  $+abc$ , which will be the binary REPRESENTATION of  $-abc$  ? (Ex: if we consider 109, how is -109 represented in base 2 ?)

R: It is only in such a question that "the 2's complement starts to play a role", and the answer is: its REPRESENTATION will be "the 2's complement of the initial binary configuration". For the value  $109 = 01101101$ , the 2's complement of  $01101101$  is  $10010011$ , so  $-109 = 10010011$

As a result we can conclude that the complementary value of an integer that begins with 0, will begin with 1 (exception making only the value 0) and will fit as a complementary value in the SIGNED interpretation on the same representation size as the initial value !! (-109 is also a byte , similar to 109).

- c). If we have a REPRESENTATION of type  $\overline{1xxx} \dots$  having the value  $+abc$  in the UNSIGNED interpretation, which will be the value in the SIGNED interpretation ?

R: The value is:  $- (\text{the 2's complement of the initial binary configuration})$ . For our example we have:  
 $10010011 = 147 \text{ (unsigned)} = - (\text{the 2's complement of } 10010011) = -(01101101) = -109$ .

- d). If we have a REPRESENTATION of type  $\overline{1xxx} \dots$  having the value  $+abc$ , which will be the binary REPRESENTATION for the value  $-abc$  ? (Ex: if we consider  $10010011 = +147$ , which is the binary representation for -147 ?)

R: The answer can only be one similar to b): its REPRESENTATION will be "the 2's complement of the initial binary configuration". But: if a number begins with 1 in its binary representation and has the value  $+abc$  in the UNSIGNED interpretation, then its negative variant  $-abc$  will also have to begin with 1 as its associated binary REPRESENTATION (because otherwise it would not still be a negative number in the SIGNED interpretation). But, complementing a binary value of the form  $1xxx\dots$  will provide naturally a binary value STARTING WITH 0 on a representation size identical to the initial one !!! - excepting ONLY the values of the form  $\overline{100}\dots$  (-128, +128, -32768, +32768 etc).

As a result, we conclude that if we start from a representation of the form  $1xxx\dots$  of value  $+abc$  WE CANNOT obtain the value  $-abc$  ON THE SAME REPRESENTATION SIZE !!!!!

Proof :  $147 = 10010011$  ( $147 \in [0..255]$ , but  $-147 \notin [-128..+127]$  , so  $-147$  is NOT representable on one byte, even if  $+147$  is !!!!!!)

So not only that the complementation cannot be done correctly on the same representation size as the initial value as a METHODOLOGY, but also the analysis of the admissible representation intervals confirms this SEMANTICALLY!!!!

So... obtaining  $-147$  starting from  $147 = 10010011$  must be done in the following way:

- i). The binary representation of  $147$  begins with 1, but we must take into account that  $-147 \notin [-128..+127]$ , but  $-147 \in [-32768..+32767]$  which leads to the conclusion that  $-147$  is NOT representable as a byte BUT ONLY AS A WORD !!
- ii). On a WORD size,  $147 = 00000000\ 10010011$  (so a binary number beginning with 0) and according to b), we have that  $-147 =$  "the 2's complement of the initial binary configuration"

The 2's complement of the configuration 00000000 10010011 is 11111111 01101101, so  
 $-147 = 11111111 01101101 = \text{FF6Dh}$

Let's check that:  $11111111 01101101 = \text{FF6Dh} = 65389$  in the UNSIGNED interpretation, the sum of the absolute values of the two complementary values being  $65389 + 147 = 65536$  = the cardinal of the set of values representable on 1 WORD, so the above two interpretations of the binary configuration 11111111 01101101 are correct and consistent !!

As a result, we may conclude that the involvement of the “2's complement” is manifest in 3 cases :

Binary format	Interpretation	Value	In what way is involved “2's complement”	Answer
0xxx	Unsigned	+abc	-	-
	Signed	+abc	How do we represent -abc ?	2's complement of 0xxx
1xxx	Unsigned	+def	-	-
	Signed	-(2's compl. of 1xxx)	How do we represent -def ?	2's complement of 1xxx's UNSIGNED extension on $2 * \text{sizeof}(1xxx)$

(with the exception of the representations of the form  $\overline{100} \dots (-128, +128, -32768, +32768 \text{ etc})$ .

Let's notice that the “2's complement” is NOT involved in any way when we approach only unsigned representations ! Example:

Binary number	Interpretation	Value	In what way is involved “2's complement”	Answer
01101101	Unsigned	+109	-	-
	Signed	+109	How is -109 represented ?	10010011
10010011	Unsigned	+147	-	-
	Signed	$-(01101101) = -109$	How is -147 represented ?	The 2's complement of 00000000 10010011 which is 11111111 01101101

Columns 3 and 4 from above can be summarized as follows:

Number X in binary representation begins with	-X begins with	-X is represented on	Examples:
0	1	Same sizeof as X	$109 = 01101101 ; -109 = 10010011$
1	1	$2 * \text{sizeof}(X)$	$147 = 10010011; -147 = 11111111 01101101$

(exceptions are the representations of the form  $\overline{100} \dots$  ( $-128, +128, -32768, +32768$  etc)).

As a conclusion: the 2's complement of a number that has the same value in both interpretations (and only a positive number can have the same value in both interpretations!) CANNOT be represented as a negative number in base 2 on the same sizeof as the initial number representation. More precisely, the 2's complement of 109, being 147, what we want to emphasize is that -147 cannot be represented on a byte!

Which is the MINIMUM number of BITS on which we can represent -147 ?

- On n bits we may represent  $2^n$  values:
  - either the UNSIGNED values  $[0..2^n - 1]$
  - or the SIGNED values  $[-2^{n-1}, 2^{n-1}-1]$

On 8 bits we can though represent  $2^8$  values (=256 values), either  $[0..2^8-1] = [0..255]$  in the UNSIGNED interpretation, either  $[-2^{8-1}, 2^{8-1}-1] = [-2^7, 2^7-1] = [-128..+127]$  in the SIGNED interpretation

On 9 bits...  $[0..511]$  or  $[-256..+255]$  and because  $-147 \in [-256..+255]$  it follows that the MINIMUM number of bits on which we may represent -147 is 9 and -147 representation is:

(...On 9 bits we may represent 512 numbers,  $512-147 = 365 = 16Dh = 1\ 0110\ 1101 \dots$ )

So  $1\ 0110\ 1101 = 16Dh = 256 + 6*16 + 13 = 256 + 96 + 13 = 365$  in the UNSIGNED interpretation !

$1\ 0110\ 1101 = -(2's\ complement\ of\ 1\ 0110\ 1101) = -(0\ 1001\ 0011) = -(093h) = -147$

As a DATA TYPE in ASM, obviously that we have to enroll any value as being a byte, word or dword, so  $-147 \in [-32768..+32767]$  and accordingly to the above discussion we have  $-147 = 11111111\ 01101101 = FF6Dh$  as a value represented on 1 word = 2 bytes.

Which is the MINIMUM number of BITS on which we can represent 3 ?

Answer: 2 bits;  $3 = 11b$

On 2 bits we may represent  $2^2$  values (=4 values), either  $[0..2^2-1] = [0..3]$  in UNSIGNED interpretation , either  $[-2^{(2-1)}, 2^{(2-1)}-1] = [-2^1, 2^1-0] = [-2..+1]$  in SIGNED interpretation.

Which is the MINIMUM number of BITS on which we can represent -3 ?

Answer: 3 bits; because on 2 bits AREN'T possible due to the above explanation and on 3 bits we have that:

On 3 bits we may represent  $2^3$  values (=8 values), either  $[0..2^3-1] = [0..7]$  in UNSIGNED interpretation, either  $[-2^{(3-1)}, 2^{(3-1)}-1] = [-2^2, 2^2-1] = [-4..+3]$  in the SIGNED interpretation

As a result,

(...On 3 bits we may represent 8 numbers,  $8-3 = 5 = 101b$ ...) - so  $101b$  is the representation of -3 on 3 bits

**101b = 5 in UNSIGNED interpretation !**

**101b = -(2's complement of 101) = -(011) = -3 in the SIGNED interpretation**

---

Finally, we have to clarify one thing: Who is for who the “2’s complement”? And relative to what ?

One binary configuration compared to another ? Or a signed decimal number versus an unsigned one ? Or two absolute values relative to each other ?... We will see that all these 3 expressions are used in practice...

“2’s complement” is reffering to REPRESENTATIONS or to INTERPRETATIONS... ?

Because it is called **the 2's complement** it is referring to BASE 2, so we are referring first of all as a definition to REPRESENTATIONS:

- The 2's complement of **01101101** is **10010011** (this helps us to answer the question "which is the binary representation of -109 ?")
- The 2's complement of **10010011** is **01101101** (this helps us to answer the question "which is the value in the SIGNED interpretation of 10010011 ?")

On the other hand, we ALSO refer to the INTERPRETATIONS, more precisely to the UNSIGNED INTERPRETATIONS of the two complementary binary representations - 01101101 and 10010011 for example - saying that "109 and 147 are two complementary values" (semantically equivalent to "The absolute values of the two interpretations of a binary number starting with 1 represent two complementary values"). That is, 147 and 109 are 2 complementary values, in the sense that the REPRESENTATION of 1001 0011 = either +147 or -109 depending on the interpretation. **BUT** there is NO representation that has either the value -147, either 109 !!

That is why, in order to distinguish the clarity of what is meant to be emphasized, the expression is often forced in a sense that may be somehow incorrect relative to the definition but relevant as a conclusion in cases like the one above, in the following manner: 147 and 109 are two complementary values, in the sense that "**-109 is the complement of +147**", but "**-147 is NOT the complement of +109**" !!! The forcing here is represented by the appearance of the SIGNS in the expression... but on the other hand, what is meant to be expressed becomes clear.

So... it does NOT make sense to discuss **complementary values in base 10** starting from a REPRESENTATION that begins with 0 in base 2 !! ... for example in the sense that starting from 01101101 (109) its complementary value is 10010011 (147). For these concepts to make sense, goals like "representing a negative number" or "interpreting a binary configuration as a signed number" must be involved in the discussion FROM START.

So the involvement of "2's complement" is UNIDIRECTIONAL!!! making sense starting ONLY from the SIGNED interpretation and the representation of negative numbers! This is actually what the above "forcing" expresses finally...

## OVERFLOW CONCEPT ANALYSIS

**CF** (*Carry Flag*) is the transport flag. It will be set to 1 if in the LPO there was a transport digit outside the representation domain of the obtained result and set to 0 otherwise. For example, in the addition

$$\begin{array}{r} 1001\ 0011 + \ 147 + \\ \underline{0111\ 0011} \quad \underline{115} \quad \text{there is transport and CF is set therefore to 1} \\ \textbf{1} \ 0000\ 0110 \quad 262 \end{array} \qquad \begin{array}{r} 93h + \ -109 + \\ \underline{73h} \quad \underline{115} \\ 106h \quad 06 \end{array}$$

**CF flags the UNSIGNED overflow !**

**OF** (*Overflow Flag*) flags the signed overflow. If the result of the LPO (considered in the signed interpretation) didn't fit the reserved space (admissible representation interval), then OF will be set to 1 and will be set to 0 otherwise. For the above example, OF=0.

**Definition (general, compressed and incomplete).** An *overflow* is mathematical situation/condition which expresses the fact that the result of an operation didn't fit the reserved space for it. (neither -147 "fits" in the range [-128..+127] nor on a single byte, but it is more difficult to intuit that the definition includes and refers to this case as well..)

**Definition (more exact and complete).** At the level of the assembly language an *overflow* is a situation/condition which expresses the fact that the result of the LPO didn't fit the reserved space for it OR does not belong to the admissible representation interval for that size OR that operation is a mathematical nonsense in that particular interpretation (signed or unsigned).

## CF vs. OF. The overflow concept.

1001 0011 +	147 +	93h +	-109 +
<u>1011 0011</u>	<u>179</u>	<u>B3h</u>	<u>- 77</u>
<b>1 0100 0110</b>	326	1 46h	- 186 !!!
(binary      (unsigned interpr.)		(hexa repr.)    (signed interpretation)	
representation)			

326 and -186 are the correct results in base 10 for the corresponding interpretations for the above OPERANDS

From the discussion on the admissible representation intervals and respectively from the analysis of the type of problems "Which is the minimum number of bits on which can be represented... 326 and -186 respectively" it will result that

326 € [0..511] and -186 € [-256..+255] and thus the MINIMUM number of bits on which 326 and -186 can be represented is 9, and the representation of -186 is:  $512 - 186 = 326 = 1\ 46h = 1\ 0100\ 0110$

As a result, ALL the above operations are MATHEMATICALLY CORRECT on 9 bits and the final operands and results CANNOT fit in the reserved space, IF the operations are on 9 bits !!

But unfortunately, the above addition is performed at the 8-bit processor level (since in assembly language we have ADD b+b → b) and as a result, MATHEMATICALLY, it will NOT perform correctly on 8 bits, nor 326 nor -186 not fitting 1 byte!! (WHICH will NOT run correctly on 8 bits exactly? – base 2, base 10, base 16 ?... NONE will run correctly on 8 bits !!! and that's why CF and OF = 1 both...)

This is signaled SIMULTANEOUSLY by the flags CF (for unsigned interpretation) and OF (for signed interpretation), both flags being set to the value 1.

As a result, what we will get as results and especially as EFFECTS on 1 byte the following:

$\begin{array}{r} 1001\ 0011 \\ + \ 147 \\ \hline 1011\ 0011 \end{array}$	$\begin{array}{r} 147 \\ + \ 79 \\ \hline 70 \end{array}$	<p>a carry of the most significant digit occurs so the value 1 is placed in CF</p>
<b>(unsigned)</b>  <b>CF=1</b>		
		<b>93h +</b> <b>B3h</b> <b>1 46h</b> <b>(hexa)</b>
		<b>-109 +</b> <b>-77</b> <b>+70 !!!!</b> <b>(signed)</b>  <b>OF=1</b>

By setting both CF and OF to 1, the « message » from the assembly language is that both interpretations in base 10 of the above base 2 addition are incorrect mathematical operations !

---

$\begin{array}{r} 0101\ 0011 \\ + \ 83 \\ \hline 0111\ 0011 \end{array}$	$\begin{array}{r} 83 \\ + \ 115 \\ \hline 198 \end{array}$	<p>53h +      83 +</p>
<b>(unsigned)</b>		<b>73h</b> <b>C6h</b> <b>(hexa)</b>
		<b>115</b> <b>198 !!!!</b> <b>(signed)</b>

- 198 is the correct result in base 10 for both the corresponding interpretations of the binary OPERANDS from the above addition, BUT now we have to see if the result fits on 8 bits (YES – it fits, therefore we will have CF=0) and respectively if the result of the binary operation in the signed interpretation, it is consistent with the correctness of the mathematical operation performed (it is NOT, because 11000110 is NOT a positive number in the signed interpretation!), so what we will get as results on 1 byte will be:

BUT, in **ASSEMBLY** language we have ADD b+b → b, so what we obtain as interpretations on 1 byte are :

$\begin{array}{r} 0101\ 0011 \\ + \ 83 \\ \hline 0111\ 0011 \end{array}$	$\begin{array}{r} 83 \\ + \ 115 \\ \hline 198 \end{array}$	<p>a carry DOES NOT occur so CF=0</p>
<b>(unsigned)</b>  <b>CF=0</b>		<b>53h +</b> <b>73h</b> <b>C6h</b> <b>(hexa)</b>
		<b>83 +</b> <b>115</b> <b>- 58 !!!!</b> <b>(signed)</b>  <b>OF=1</b>

Setting CF to 0 expresses the fact that the unsigned interpretation in base 10 of the above base 2 addition is a correct one and the operation functions properly both at the level of the interpretation of the OPERANDS and the RESULT. OF will however be set by the processor to the value 1, this meaning that the signed interpretation of the base 2 addition above reflects an incorrect operation (more precisely the RESULT obtained is an incorrect one in the signed interpretation!)

OF will be set to 1 (*signed overflow*) if for the addition operation we are in one of the following two situations (overflow rules for addition in signed interpretation). These are the only 2 situations that can issue overflow status for the addition operation:

0.....+	or	1.....+	(Semantically, the two situations denote the impossibility of mathematical acceptance of the 2 operations: we cannot add two positive numbers and obtain a negative result and we cannot add two negative numbers and obtain a positive result).
0.....		1.....	
-----		-----	
1.....		0.....	

In the case of subtraction, we also have two overflow rules in the signed interpretation, a consequence of the two overflow rules for addition:

1.....-	sau	0.....-	(Semantically, the two situations denote the impossibility of mathematical acceptance of the two operations: we cannot subtract a positive number from a negative one and obtaining a positive one, neither can we subtract a negative number from a positive one and obtaining a negative one).
0.....		1.....	
-----		-----	
0.....		1.....	

<b>1</b> 0110 0010 -	98 -	62h -	98 -
1100 1000	200	C8h	-56
1001 1010	-102	9Ah	154 !!!
<b>(unsigned OPERANDS)</b>		<b>(hexa)</b>	<b>(signed OPERANDS)</b>

However, if we also take into account the interpretations of the RESULT obtained, we have:

<b>1</b>	0110 0010 -	98 -	62h -	98 -
	1100 1000	200	C8h	-56
	1001 1010	154	9Ah	-102 !!!!
	(unsigned)		(hexa)	(signed)
	<b>CF=1</b>			<b>OF=1</b>

We need significant digit borrowing for performing the subtraction, therefore CF=1

Both interpretations of the result obtained in base 2 ARE MATHEMATICALLY INCORRECT, so CF and OF will both be set to the value 1.

None of the interpretations above is mathematically correct, because in base 10, the subtraction 98-200 should provide -102 as the correct result, but instead 154 is provided in the unsigned interpretation for the subtraction - which is an incorrect result! In the SIGNED interpretation we have:  $98 - (-56) = -102$  (Again an incorrect value!!) instead of the correct one  $98 + 56 = 154$  (the value of 154 result interpretation is valid only in unsigned representation).

In conclusion, in order to be mathematically correct, the final results of the two subtractions from above should be switched between the two interpretations; so the two interpretations associated to the binary subtraction are both mathematically incorrect. For this reason the 80x86 microprocessor will set CF=1 and OF =1.

Technically speaking, the microprocessor will set OF=1 only in one of the 4 situations presented above (2 for addition and 2 for subtraction).

The multiplication operation does not produce overflow at the level of 80x86 architecture, the reserved space for the result being enough for both interpretations. Anyway, even in the case of multiplication, the decision was taken to set both CF=OF=0, in the case that the size of the result is the same as the size of the operators ( $b*b = b$ ,  $w*w = w$  or  $d*d = d$ ) (« no multiplication overflow », CF = OF = 0). In the case that  $b*b = w$ ,  $w*w = d$ ,  $d*d = qword$ , then CF = OF = 1 (« multiplication overflow »).

The worst effect in case of overflow is in the case for the division operation: in this situation, if the quotient does not fit in the reserved space (the space reserved by the assembler being byte for the division word/byte, word for the division doubleword/word and respectively doubleword for division quadword/doubleword) then the « division overflow » will signal a ‘Run-time error’ and the operating system will stop the running of the program and will issue one of the 3 semantic equivalent messages: ‘Divide overflow’, ‘Division by zero’ or ‘Zero divide’.

In the case of a correct division CF and OF are undefined. If we have a division overflow, the program crashes, the execution stops and of course it doesn’t matter which are the values from CF and OF...

w/b → b **1002/3 = 334** = **division overflow – fatal – Run time error** (‘Divide overflow’, ‘Division by zero’ sau ‘Zero divide’) – technically an **INT 0** will be issued !

**number/0 – Zero divide = IT IS OVERFLOW because INFINITE does NOT fit anything !!!!!!!**

**Why do we need CF and OF in EFLAGS SIMULTANEOUSLY??** Isn't a single flag enough to show us IN TURN if we have an overflow or not, either in the signed interpretation or in the unsigned one ? NO, because when performing an addition or subtraction operation in base 2, in fact 2 operations are actually performed SIMULTANEOUSLY in base 10: one in the signed interpretation and the other in the unsigned interpretation.

As a result, two different flags are needed SIMULTANEOUSLY to deal each of them with one of the 2 possible interpretations in base 10: CF – for the unsigned interpretation ; OF – for the signed one.

This happens because the operation of addition or subtraction expressed IN BASE 2 is performed IDENTICALLY, therefore, REGARDLESS OF THE signed or unsigned INTERPRETATION of the operands and the result !!!! This is also the reason why there is **NO IADD or ISUB** in assembly language! Because even if they existed, they would NOT work differently from ADD and SUB respectively!

**ADD = IADD, SUB = ISUB – because in base 2 the addition and subtraction are performed in the same way INDEPENDENTLY OF THE INTERPRETATION !!!**

- **So, why do we need then IMUL and IDIV ??**

Because unlike addition and subtraction, which work the same in base2, regardless of the interpretation (signed or unsigned), SIGNED and UNSIGNED multiplication and division work DIFFERENTLY in the signed case compared to the unsigned case !!

As a result, in case of addition and subtraction there is no need to specify BEFORE the computation how we want the operands and the result to be interpreted, because the 2 operations work anyway the same BINARY regardless of how we want to interpret them. It is enough to decide AFTER performing the operation how we want the operands and the result to be interpreted.

In contrast, multiplication and division do NOT work BINARY the same in the 2 interpretations, here there is the need to specify BEFORE a multiplication or division how we want the operands to be interpreted and this is done precisely by specifying MUL and DIV (if we want unsigned operands ) or respectively IMUL and IDIV (if we want signed operands).

# CHAPTER 3

## ASSEMBLY LANGUAGE BASICS

**Machine Language** of a Computing System (CS) – the set of the machine instructions to which the processor directly reacts. These are represented as bit strings with predefined semantics.

**Assembly Language** – a programming language in which the basic instructions set corresponds with the machine operations and which data structures are the machine primary structures. This is a **symbolic language. Symbols - Mnemonics + labels.**

The basic elements with which an **assembler** works with are:

- \* **labels** – user-defined names for pointing to data or memory areas.
- \* **instructions** - mnemonics which suggests the underlying action. The assembler generates the bytes that codifies the corresponding instruction.
- \* **directives** - indications given to the assembler for correctly generating the corresponding bytes. Ex: relationships between the object modules, segment definitions, conditional assembling, data definition directives.
- \* **location counter** – an integer number managed by the assembler for every separate memory segment. At any given moment, the value of the location counter is the number of the generated bytes correspondingly with the instructions and the directives already met in that segment (the current offset inside that segment). The programmer can use this value (read-only access!) by specifying in the source code the '\$' symbol.

NASM supports two special tokens in expressions, allowing calculations to involve the current assembly position: the \$ and \$\$ tokens. \$ evaluates to the assembly position at the beginning of the line containing the expression; so you can code an infinite loop using JMP \$.

\$\$ evaluates to the start of the current section; so you can tell how far into the section are by using (\$-\$).

## Directive SECTION

```
section .data
    db 'hello'
    db 'h', 'e', 'l', 'l', 'o'
    data_segment_size equ $-$
```

\$-\$ = the distance from the beginning of the segment AS A SCALAR (constant numerical value)!!!!!!

\$ - is an offset = POINTER TYPE !!!! It is an address !!!

\$\$ - is an offset =POINTER TYPE !!!! It is an address !!!

\$ means "address of here".

\$\$ means "address of start of current section".

So \$-\$ means "current size of section".

For the example above, this will be 10, as there are 10 bytes of data given.

## 3.1. SOURCE LINE FORMAT

In the x86 assembly language the source line format is:

**[label[:]] [prefixes] [mnemonic] [operands] [;comment]**

We illustrate the concept through some examples:

here: jmp here	; label + mnemonic + operand + comment
repz cmpsd	; prefix + mnemonic + comment
start:	; label + comment
	; just a comment (which could be missed)
a dw 19872, 42h	; label + mnemonic + 2 operands + comment
len equ \$-a ;	label + mnemonic + \$-a (operand) + comment

The allowed characters for a *label* are:

- Letters: A-Z, a-z;
- Digits: 0-9;
- Characters \_, \$, \$\$, #, @, ~, . and ?

A valid variable name starts with a letter, \_ or ?.

These rules are valid for all valid *identifiers* (symbolic names, such as variable names, label names, macros, etc).

All identifiers are *case sensitive*, the language making the distinction between upper and lower case letters while analyzing user defined identifiers. This means that the Abc identifier is different from the abc identifier. For implicit names which are part of the language (such as keywords, mnemonics, registers) there are no differences between upper and lower case letters (they are *case insensitive*).

The assembly language offers two categories of labels:

1). ***Code labels***, present at the level of instructions sequences for defining the destinations of the control transfer during a program execution. **They can appear also in data segments!**

2). ***Data labels***, which provide symbolic identification for some memory locations, from a semantic point of view being similar with the *variable* concept from the other programming languages. **They can appear also in code segments!**

**The value associated with a label in assembly language is an integer number representing the address of the instruction or directive following that label.**

The distinction between accessing a variable's address or its associated content is made as follows:

- When specified in ***straight brackets, the variable name denotes the value of the variable***; for example, [p] specifies accessing the value of the variable, in the same way in which \*p represents dereferencing a pointer (accessing the content indicated by the pointer) in C;
- In any other context, ***the name of the variable represents the address of the variable***; for example, p is always the address of the variable p;

Examples:

mov EAX, et ; loads into EAX register the **address** (offset) of data or code starting at label et  
 mov EAX, [et] ; loads into EAX register the **content** from address et (4 bytes)  
 lea eax, [v] ; loads into EAX register the address (offset) of variable v (4 bytes)

(similar as effect with MOV eax, v)

As a generalization, ***using straight brackets always indicates accessing an operand from memory***. For example, mov EAX, [EBX] means the transfer of the memory content whose address is given by the value of EBX into EAX (4 bytes are taken from memory starting at the address specified in EBX as a pointer).

There are 2 types of *mnenomics*: *instructions names* and *directives names*. *Directives* guide the assembler. They specify the particular way in which the assembler will generate the object code. *Instructions* are actions that guide the processor.

*Operands* are parameters which define the values to be processed by the instructions or directives. They can be **registers, constants, labels, expressions, keywords or other symbols**. Their semantics depends on the mnemonic of the associated instruction or directive.

## 3.2. EXPRESSIONS

*expression* - operands + operators. *Operators* indicate how to combine the operands for building an expression. **Expressions are evaluated at assembly time** (their values are computable at assembly time, except for the operands representing registers contents, that can be evaluated only at run time – the offset specification formula).

### **3.2.1. Operands specification modes**

Instructions operands may be specified in 3 different ways, called *specification modes*.

The 3 operand types are: ***immediate operands***, ***register operands*** and ***memory operands***. Their values are computed at assembly time for the immediate operands and for the direct addressed operands (the offset part only!), at loading time for memory operands in direct addressing mode (as a complete FAR address – segment address is determinable here so the whole FAR address is known now !) – this step involves a so called ADDRESS RELOCATION PROCESS (adjusting an address by fixing its segment part), and at run time for the registers operands and for indirectly accessed memory operands.

??:offset (assembly time)      0708:offset (loading time)

#### **3.2.1.1. Immediate operands**

*Immediate operands* are constant numeric data computable at assembly time.

Integer constants are specified through binary, octal, decimal or hexadecimal values. Additionally, the use of the \_ (underscore) character allows the separation of groups of digits. The numeration base may be specified in multiple ways:

- Using the H or X suffixes for hexadecimal, D or T for decimal, Q or O for octal and B or Y for binary; in these cases the number must start with a digit between 0 and 9, to eliminate confusions between constants and symbols, for example 0ABCH is interpreted as a hexadecimal number, but ABCH is interpreted as a symbol.
- Using the C language convention, by adding the 0x or 0h prefixes for hexadecimal, 0d or 0t for decimal, 0o or 0q for octal, and 0b or 0y for binary.

Examples:

- the hexadecimal constant B2A may be expressed as: 0xb2a, 0xb2A, 0hb2a, 0b12Ah, 0B12AH

- the decimal value 123 may be specified as: 123, 0d123, 0d0123, 123d, 123D, ...
- 11001000b, 0b11001000, 0y1100\_1000, 001100\_1000Y represent various ways of expressing the binary number 11001000

**The offsets of data labels and code labels** are values computable at assembly time and they remain constant during the whole program's run-time.

mov eax, et ; transfer into the EAX register the offset associated to the et label

will be evaluated at assembly time as (for example):

```
mov eax, 8      ; 8 bytes „distance” relative to the beginning of the data segment
mov eax, [var] – in OllyDBG you will find mov eax, DWORD PTR [DS:004027AB]
```

These values are constant because of the allocation rules in programming languages in general. These rules state that the memory allocation order of declared variables (more precisely the distance relative to the start of the data segment in which a variable is allocated) as well as the distances of destination jumps in the case of **goto** - style instructions are constant values during the execution of a program.

In other words, a variable once allocated in a memory segment will never change its location (i.e. its position relative to the start of that segment). This information is determinable at assembly time based upon the order in which variables are declared in the source code and due to the dimension of representation inferred from the associated type information.

### 3.2.1.2. Register operands

*Direct using - mov eax, ebx*

*Indirect usage and addressing – used for pointing to memory locations - mov eax, [ebx]*

### **3.2.1.3. Memory addressing operands**

There are 2 types of memory operands: *direct addressing operands* and *indirect addressing operands*.

The *direct addressing operand* is a constant or a symbol representing the address (segment and offset) of an instruction or some data. These operands may be *labels* (for ex: jmp et), *procedures names* (for ex: call proc1) or *the value of the location counter* (for ex: b db \$-a).

***The offset of a direct addressing operand is computed at assembly time.*** The address of every operand relative to the executable program's structure (establishing the segments to which the computed offsets are relative to) is computed ***at linking time***. The actual physical address is computed ***at loading time***.

The effective address always refers to a segment register. This register can be explicitly specified by the programmer, or otherwise a segment register is implicitly associated by the assembler. The implicit rules for performing this association **WITH AN EXPLICIT SPECIFIED OFFSET OPERAND** are:

- **CS** for code labels target of the control transfer instructions (jmp, call, ret, jz etc);
- **SS** in SIB addressing when using EBP or ESP as *base* (no matter of *index* or *scale*);
- **DS** for the rest of data accesses;

Explicit segment register specification is done using the segment prefix operator ":"  
ES can be used only in explicit specifications (like ES:[Var] or ES:[ebx+eax\*2-a] ) or IN CERTAIN STRING INSTRUCTIONS (MOVSB)

JMP FAR CS:....

JMP FAR DS:.... or JMP FAR [label2]

### **3.2.1.4. Indirect addressing operands**

*Indirect addressing operands* use registers for pointing to memory addresses. Because the actual registers values are known only at run time, indirect addressing is suited for dynamic data operations.

The general form for indirectly accessing a memory operand is given by the offset computing formula:

$$[\text{base\_register} + \text{index\_register} * \text{scale} + \text{constant}]$$

*Constant* is an expression which value is computable at assembly time. For ex. [ebx + edi + table + 6] denotes an indirect addressed operand, where both *table* and 6 are constants.

The operands *base\_register* and *index\_register* are generally used to indicate a memory address referring to an array. In combination with the scaling factor, the mechanism is flexible enough to allow direct access to the elements of an array of records, with the condition that the byte size of one record to be 1, 2, 4 or 8. For example, the upper byte of the DWORD element with the index given in ECX, part of a record vector which address (of the vector) is in edx can be loaded in dh by using the instruction

```
mov dh, [edx + ecx * 4 + 3]
```

From a syntactic point of view, when the operand is not specified by the complete formula, some of the components missing (for example when "\* scale" is not present), the assembler will solve the possible ambiguity by an analysis process of all possible equivalent encoding forms, choosing the shortest finally. For example, having

```
push dword [eax + ebx] ; saves on the stack the doubleword from the address eax+ebx
```

the assembler is free to consider eax as the base and ebx as an index or vice versa, ebx as the basis and eax as index.

In a similar way, for

pop DWORD [ecx] ; restores the top of the stack in the variable which address is given in ecx

the assembler can interpret ecx either as a base or as an index. What is really important to keep in mind is that all codifications considered by the assembler are equivalent and its final decision has no impact on the functionality of the resulted code.

Also, in addition to solving such ambiguities, the assembler also allows non-standard expressions, with the condition to be in the end transformable into the above standard form. Other examples:

lea eax, [eax\*2] ; load in eax the value of eax\*2 (which is, eax becomes 2\*eax)

In this case, the assembler may decide between coding as base = eax + index = eax and scale = 1 or index = eax and scale = 2.

lea eax, [eax\*9 + 12] ; eax will be eax \* 9 + 12

Although the scale cannot be 9, the assembler will not issue an error message here. This is because it will notice the possible encoding of the address like: base = eax + index = eax with scale = 8, where this time the value 8 is correct for the scale. Obviously, the statement could be made clearer in the form

lea eax, [eax + eax \* 8 + 12]

For indirect addressing it is essential to specify between square brackets at least one of the components of the offset computation formula.

### 3.2.2. Using operators

Operators – used for combining, comparing, modifying and analyzing the operands. Some operators work with integer constants, others with stored integer values and others with both types of operands.

It is very important to understand the difference between operators and instructions. **Operators perform computations only with constant SCALAR values computable at assembly time (scalar values = constant immediate values), with the exception of adding and/or subtracting a constant from a pointer (which will issue a pointer data type) and with the exception of the offset computation formula (which supports the ‘+’ operator).** Instructions perform computations with values that may remain unknown (and this is generally the case) until run time. Operators are relatively similar with those in C. **Expression evaluation is done on 64 bits**, the final results being afterwards adjusted accordingly to the sizeof available in the available usage context of that expression.

For example the addition operator (+) performs addition at assembly time and the ADD instruction performs addition during run time. We give below the operators that are used by the x86 assembly language expressions in NASM !.

Priority	Operator	Type	Result
7	-	unary, prefix	Two's complement (negation): $-X = 0 - X$
7	+	unary, prefix	No effect (provides symmetry to „-“): $+X = X$
7	~	unary, prefix	One's complement: <code>mov al, ~0 =&gt; mov AL, 0xFF</code>
7	!	unary, prefix	Logic negation: $!X = 0$ when $X \neq 0$ , else 1
6	*	Binary, infix	Multiplication: $1 * 2 * 3 = 6$
6	/	Binary, infix	Result (quotient) of unsigned division: $24 / 4 / 2 = 3$
6	//	Binary, infix	Result (quotient) of signed division: $-24 // 4 // 2 = -3$ ( <b><math>-24 / 4 / 2 \neq -3!</math></b> )
6	%	Binary, infix	Remainder of unsigned division: $123 \% 100 \% 5 = 3$
6	%%	Binary, infix	Remainder of signed division: $-123 \% \% 100 \% \% 5 = -3$
5	+	Binary, infix	Sum: $1 + 2 = 3$
5	-	Binary, infix	Subtraction: $1 - 2 = -1$

4	<code>&lt;&lt;</code>	Binary, infix	Bitwise left shift: $1 << 4 = 16$
4	<code>&gt;&gt;</code>	Binary, infix	Bitwise right shift: $0xFE >> 4 = 0x0F$
3	<code>&amp;</code>	Binary, infix	AND: $0xF00F \& 0xFF6 = 0x0006$
2	<code>^</code>	Binary, infix	Exclusive OR: $0xFF0F ^ 0xFFFF = 0x0FF0$
1	<code> </code>	Binary, infix	OR: $1   2 = 3$

The indexing operator has a widespread use in specifying indirectly addressed operands from memory. The role of the [] operator regarding indirect addressing has been explained in Paragraph 3.2.1.

### 3.2.2.3. Bit shifting operators

*expression >> how\_many*      and      *expression << how\_many*

`mov ax, 01110111b << 3; AX = 00000011 10111000b`

`add bh, 01110111b >> 3; the source operator is 00001110b`

### 3.2.2.4. Bitwise operators

Bitwise operators perform bit-level logical operations for the operand(s) of an expression. The resulting expressions have constant values.

OPERATOR	SYNTAX	MEANING
<code>~</code>	<code>~ expresie</code>	Bits complement
<code>&amp;</code>	<code>expr1 &amp; expr2</code>	Bitwise AND
<code> </code>	<code>expr1   expr2</code>	Bitwise OR
<code>^</code>	<code>expr1 ^ expr2</code>	Bitwise XOR

Examples (we assume that the expression is represented on a byte):

<code>~11110000b</code>	<code>; output result is 0000111b</code>
<code>01010101b &amp; 11110000b</code>	<code>; output result is 01010000b</code>
<code>01010101b   11110000b</code>	<code>; output result is 11110101b</code>
<code>01010101b ^ 11110000b</code>	<code>; output result is 10100101b</code>
<code>! – logical negation (similar with C) ; !0 = 1 ; !(anything different from zero) = 0</code>	

### 3.2.2.6. The segment specification operator

The *segment specifier operator* (`:`) performs the FAR address computation of a variable or label relative to a certain segment. Its syntax is:

**segment:expression**

[ss: ebx+4] ; offset relative to SS;  
[es:082h] ; offset relative to ES;  
10h:var ; the segment address is specified by the 10h selector,  
the offset being the value of the *var* label.

### 3.2.2.7. Type operators

They specify the types of some expressions or operands stored in memory. Their syntax is:

*type expression*

where the type specifier is one of the following: **BYTE, WORD, DWORD, QWORD or TWORD**

This syntactic form causes *expression* to be treated temporarily (limited to that particular instruction) as having „*type*” sizeof without destructively modifying its initial value. That is why these type operators are also called „non-destructive temporary conversion operators”. For memory stored operators, *type* may be **BYTE, WORD, DWORD, QWORD or TWORD** having the size of 1, 2, 4, 8 and 10 bytes respectively. For code labels *type* is either **NEAR** (4 bytes address) or **FAR** (6 bytes address).

For example, **byte** [A] takes only the first byte from the memory location designated by A. Similar, **dword** [A] will consider the doubleword starting at address A.

BYTE / WORD / DWORD / QWORD specifiers have always only the task of clarifying an ambiguity (inclusive when we talk about a memory variable, writing **mov BYTE [v], 0** or **mov WORD [v], 0** is also a way of eliminating an ambiguity, because NASM does not associate a DATA TYPE to a variable !! - v is NEVER a byte/ word / dword, it is just a label without an associated data type).

**mov [v],0 ; syntax error – operation size not specified**

**QWORD specifier is NEVER explicitly present in any 32 bits code !!.**

Examples where we need a data size specifier (type operator) for the given operands:

- **mov [mem], 12**

- **(i)div [mem] ; (i)mul [mem]**

- **push [mem] ; pop [mem]**

- **push 15** – here is an inconsistency of NASM, the assembler will never issue error or warning, but instead it will generate **push DWORD 15**

Examples of IMPLICIT operands on 64 bits (in 32 bits code):

- **mul dword [v]** ; multiplies eax by the dword from the address v and the result will be obtained in EDX:EAX

- **div dword [v]** ; division of EDX:EAX by v

### 3.3. DIRECTIVES

Directives direct the way in which code and data are generated during assembling.

#### 3.3.1.1. The SEGMENT directive

SEGMENT directive allows targeting the bytes of code or of data emitted by an assembler to a given segment, having a name and some specific characteristics.

**SEGMENT** *name* [*type*] [**ALIGN**=*alignment*] [*combination*] [**usage**] [**CLASS**=*class*]

The numeric value assigned to the segment name is the segment address (32 bits) corresponding to the memory segment's position during run-time. For this purpose, NASM offers the special symbol \$\$ which is equal with the current segment's address, this having the advantage that can be used in any context, without knowing the current segment's name.

Except the name, all the other fields are optional both regarding their presence or the order in which they are specified.

The optional arguments *alignment*, *combination*, *usage* and '*class*' give to the link-editor and the assembler the necessary information regarding the way in which segments must be loaded and combined in memory.

The type allows selecting the usage mode of the segment, having the following possible values:

- **code** (or **text**) - the segment will contain code, meaning that the content cannot be written but it can be executed
- **data** (or **bss**) - data segment allowing reading and writing but not execution (implicit value).
- **rdata** - the segment that it can only be read, containing definitions of constant data

The optional argument *alignment* specifies the multiple of the bytes number from which that segment may start. The accepted alignments are powers of 2, between 1 and 4096.

If *alignment* is missing, then it is considered implicitly that ALIGN=1, i.e. the segment can start from any address.

The optional argument *combination* controls the way in which similar named segments from other modules will be combined with the current segment at linking time. The possible values are:

- **PUBLIC** - indicates to the link editor to concatenate this segment with other segments with the same name, obtaining a single segment having the length the sum of concatenated segments' lengths.
- **COMMON** - specifies that the beginning of this segment must overlap with the beginning of all segments with the same name, obtaining a segment having the length equal to the length of the larger segment with the same name.
- **PRIVATE** - indicates to the link editor that this segment cannot be combined with others with the same name.
- **STACK** - the segments with the same name will be concatenated. During run time the resulted segment will be the stack segment.

Implicitly, if no combination method is specified, any segment is PUBLIC.

The argument *usage* allows choosing another word size than the default 16 bits one.

The argument 'class' has the task to allow choosing the order in which the link editor puts the segments in memory. All the segments that have the same class will be placed in a contiguous block of memory whatever their order in the source code. No implicit value exists, it being undefined when its specification is missing, leading though to NOT concatenating all the program's segments defined so in a continuous memory block.

segment code use32 class=CODE

segment data use32 class=DATA

### **3.3.2. Data definition directives**

*Data definition = declaration* (attributes specification) + *allocation* (reserving required mem. space).  
**(UNIQUE !!!)**                            **(it is NOT unique !!!)**            **(UNIQUE !!!!)**

In C – 17 modules (separate files) ; A1- global variable (`int A1` + 16 data declarations `extern int A1`)  
LINKER is responsible for checking the DEPENDENCIES between the modules !

The structure of a Variable = ([name], set\_of\_attributes, [address/reference, value])

Dynamic variable DOES NOT HAVE A NAME !!!!!

P=new(...); p=malloc(...); ...free... (Diferenta between POINTER and DYNAMIC variables !!!!)

(Name, set\_of\_attributes) = Formal parameters !!!!

Set\_of\_attributes = (type, Domeniu\_de\_vizibilitate (scope), lifetime (extent), memory class)  
Memory class (in C) = (auto, register, static, extern)

*data type* = *size of representation* – byte, word, doubleword or quadword

The general form of a data definition source line is:

[name] *data\_type* *expression\_list* [;*comment*]

or

[name] allocation\_type factor [;comment]

or

[name] **TIMES** factor *data\_type* *expression\_list* [;*comment*]

where *name* is a label for data referral. The data type is the size of representation and its value will be the address of its first byte.

*factor* is a number which shows how many times the *expression\_list* is repeated.

*Data\_type* is a data definition directive, one of the following:

**DB** - byte data type (BYTE)

**DW** - word data type (WORD)

**DD** - doubleword data type (pointer - DWORD)

**DQ** - 8 bytes data type (QWORD – 64 bits)

**DT** - 10 bytes data type (TWORD – used to store BCD constants or real constants for extended precision)

For example, the following sequence defines and initializes 5 memory variables:

```
segment data
    var1 DB  'd' ;1 byte
          .a DW  101b ;2 bytes
    var2 DD  2bfh ;4 bytes
          .a DQ  307o ;8 bytes (1 quadword)
          .b DT  100  ;10 bytes
```

Var1 and var2 variables are defined using common labels, visible in the entire source code, while .a and .b are local labels, the access to these local variables being restricted in the sense that:

- these variables can be accessed with the local name, i.e. .a or .b, until another common label is defined (they are local to preceding label);
- they can be accessed from anywhere by their complete name: var1.a, var2.a or var2.b.

The initialization value may be also an expression, as for example var1 DW (1002/4+1)

After a data definition directive may appear more than one value, thereby allowing declaration and initialization of arrays. For example, the declaration:

Tablou DW 1,2,3,4,5

creates an array with 5 integers represented as words and having their values 1,2,3,4,5. If the values supplied after the directive don't fit on a single line, we can add as many lines as necessary, which shall contain only the directive and the desired values. Example:

```
Tabpatrate DD 0, 1, 4, 9, 16, 25, 36  
          DD 49, 64, 81  
          DD 100, 121, 144, 169
```

*allocation\_type* is a uninitialized data reservation directive:

- RESB** - byte data type (BYTE)
- RESW** - word data type (WORD)
- RESD** - doubleword data type (DWORD)
- RESQ** - 8 bytes data type (QWORD - 64 bits)
- REST** - 10 bytes data type (TWORD – 80 bits)

*factor* is a number showing how many times the specified data type allocation is repeated.  
For example Tabzero RESW 100h reserves 256 words for *Tabzero* array.

NASM does not support the MASM/TASM syntax of reserving uninitialized space by writing DW ?. The operand to a RESB-type pseudo-instruction is a **critical expression (all operands involved in computations must be known at expression evaluation time)**. Ex:

```
buffer:    resb 64 ; reserve 64 bytes  
wordvar:   resw 1  ; reserve a word  
realarray: resq 10 ; array of ten reals
```

**TIMES directive** allows repeated assembly of an instruction or data definition.

**TIMES** *factor data\_type expression*

For example

Tabchar    TIMES 80 DB 'a'

creates an "array" of 80 bytes, every one of them being initialized with the ASCII code of 'a'.

matrice10x10        times 10\*10 dd 0

will provide 100 doublewords stored continuously in memory starting from address associated with *matrice10x10* label.

TIMES can also be applied to instructions:

TIMES 32 add eax, edx ; having as effect EAX = EAX + 32\*EDX

### **3.3.3. EQU directive**

***EQU directive*** allows assigning a numeric value or a string during assembly time to a label without allocating any memory space or bytes generation. The EQU directive syntax is:

*name EQU expression*

Examples:

END_OF_DATA	EQU '!"
BUFFER_SIZE	EQU 1000h
INDEX_START	EQU (1000/4 + 2)
VAR_CICLARE	EQU i

By use of such equivalence, the source code may become more readable.

You can see the similarity between the labels defined by the EQU directive and the symbolic constants defined in high level programming languages.

The expressions used when defining labels by EQU may also contain labels defined by EQU:

TABLE_OFFSET	EQU 1000h
INDEX_START	EQU (TABLE_OFFSET + 2)
DICTIONAR_STAR	EQU (TABLE_OFFSET + 100h)

## Type operators and operands data types

**Operators** can *perform computations only* with *constant values* determinable at assembly time. The *single exception* to this rule is *the offset specification/computation formula*. (we have there the operator '+' which handles registers contents !)

The specifiers BYTE / WORD / DWORD / QWORD always have the task to clarify an ambiguity

v d? ....

a d?...

b d?...

Push v – stack ← offset v

Push [v] - Syntax error ! – Operation size not specified !! (a PUSH on a 32 bits programming stack accepts both 16 and 32 bits values as stack operands) ;

Push dword [v] - ok

Push word [v] - ok

Mov eax,[v] - ok ; EAX = dword ptr [v], in Olly dbg “mov eax, dword ptr [DS:v]”

Push [eax] - Syntax error ! – Operation size not specified !!

Push word/dword [eax]

Push 15 – PUSH DWORD 15

Pop [v] - Syntax error ! – Operation size not specified !! (a POP from the stack accepts both 16 and 32 bits values as stack operands) ;

Pop word/dword [v];

Pop v ; The syntax is POP destination, where destination is a L-value !!

“Invalid combination of opcode and operands”, because v is an offset (R-value) and a R-value CANNOT be the destination of an assignment ! (like attempting 2=3)

Pop dword b ; syntax error !

Pop [eax] – Op size not specified !

Pop (d)word [eax] ; ok!

Pop 15 - Invalid combination of opcode and operands , because v is an offset (R-value) and a R-value CANNOT be the destination of an assignment ! (like attempting 2=3); 15 is NOT a L-value !

Pop [15] ; syntax error - Op size not specified

Pop dword [15] ; syntactic ok , cel mai probabil run-time error deoarece probabil [DS:15] va provoca Access violation !!

Mov [v],0 - op size not spec.

Mov byte [v],0 ; ok !!!

Mov [v], byte 0 ; ok !!!!

Div [v] – Op. size not spec. – 3 possibilities ...

Div word [v]; ok!

Imul [v+2] - Op. size not spec

Imul word [v+2]; DX:AX = AX\*word de la adresa v+2

a d?...

b d?...

Mov a,b – Invalid combination of opcode and operands , because a is NOT a L-value, but an offset (R-value) and a R-value CANNOT be the destination of an assignment ! (like attempting 2=3)

Mov [a], b – Op. size not spec.

Mov word [a], b or mov [a], word b - the lower word from the offset of b will be transferred into the first 2 bytes starting at offset a !

Mov dword [a], b or mov [a], dword b - the offset of b will be transferred into the first 4 bytes starting at offset a !

Mov byte [a], b or mov [a], byte b – SYNTAX ERROR ! because AN OFFSET is EITHER a 16 bits value or a 32 bits value, NEVER an 8 bit value !!!!! (the same effect as mov ah, v)

Mov a,[b] - Invalid combination of opcode and operands , because a is an offset (R-value) and a R-value CANNOT be the destination of an assignment ! (like attempting 2=3)

Mov [a], [b] - Invalid combination of opcode and operands, BECAUSE asm doesn't allow both explicit operands to be from memory !!!

Mul v – Invalid combination of opcode and operands, BECAUSE syntax is MUL reg/mem

Mul word v - syntax error – MUL reg/mem

Mul [v] – op size not spec.

Mul dword [v]; ok !

Mul eax ; ok !

Mul [eax] ; op. size not specified

Mul byte [eax] ; ok !!!

MUL 15 ; Invalid combination of opcode and operands, BECAUSE syntax is MUL reg/mem

Pop byte [v] - Invalid combination of opcode and operands

Pop qword [v] – Instruction not supported in 32 bit mode !

## Error types in Computer Science

- **Syntax error – diagnosed by assembler/compiler !**
- **Run-time error (execution error) – program crashes – it stops executing**
- **Logical error = program runs until its end or remains blocked in an infinite loop ... if it functions until its end, it functions LOGICALLY WRONG obtaining totally different results/output then the envisioned ones**
- **Fatal: Linking Error !!! (for example in the case of a variable defined multiple times in a multimodule program ... if we have 17 modules, a variable must be defined ONLY in a SINGLE module ! If it is defined in 2 or more modules , a “Fatal: Linking Error !!! – Duplicate definition for symbol ....” Will be obtained.**

**The steps followed by a program from source code to run-time:**

- Syntactic checking (done by assembler/compiler/interpreter)
- OBJ files are generated by the assembler/compiler
- Linking phase (performed by a LINKER = a tool provided by the OS, which checks the possible DEPENDENCIES between this OBJ files/modules); The result → .EXE file !!!

- You (the user) are activating your exe file by clicking or entering...
- The LOADER of the OS is looking for the required RAM memory space for your EXE file. When finding it, it loads the EXE file AND performs ADDRESS RELOCATION !!!!
- In the end the loader gives control to the processor by specifying THE PROGRAM's ENTRY POINT (ex: the start label) !!! The run-time phase begins NOW...

Mark Zbirkowski – semnatura EXE = 'MZ'

## Operands data types

Data definition directives in NASM are NOT data types definition mechanisms !!

a db ...  
b dw...  
c dd....

The task of the data definition directives in NASM is NOT to specify an associated data type for the defined variables, but ONLY to generate the corresponding bytes to those memory areas designated by the variables accordingly to the chosen data definition directive and following the little-endian representation order.

So, a is NOT a byte – but only an offset and that is all... a symbol representing the start of a memory area WITHOUT HAVING AN ASSOCIATED DATA TYPE !

So, b is NOT a word – but only an offset and that is all... a symbol representing the start of a memory area WITHOUT HAVING AN ASSOCIATED DATA TYPE !

So, c is NOT a doubleword – but only an offset and that is all... a symbol representing the start of a memory area WITHOUT HAVING AN ASSOCIATED DATA TYPE !

- their task is only to allocate the required space AND to specify TO THE ASSEMBLER the way in which they have to be initialized !!!!

Known things, but good to be remembered:

The **name of a variable** is **associated** in assembly language **with its offset relative to the segment** in which its **definition appears**. The **offsets of the variables** defined in a program are **always constant** values, determinable at assembly/compiling time.

**Assembly language** and **C** are **value oriented languages**, meaning that everything is reduced in the end to a numeric value, this is a low level feature.

In a **high-level programming language**, the **programmer can access the memory only** by using **variable names**, in contrast, in **assembly language**, the **memory is/can/must be accessed ONLY** by using the **offset computation formula** ("formula de la doua noaptea") where **pointer arithmetic** is also used (pointer arithmetic is also used in C !).

**mov ax, [ebx]** – the source operand **doesn't** have an **associated data type** (it represents only a start of a memory area) and because of that, in the case of our MOV instruction the **destination operand** is the one that **decides the data type of the transfer (a word in this case)**, and the transfer will be made accordingly to the little endian representation.

## Conversions classification

a). **Destructive – cbw, cwd, cwde, cdq, movzx, movsx, mov ah,0; mov dx,0; mov edx,0**

**Non-destructive – Type operators: byte, word, dword, qword**

b). **Signed - cbw, cwd, cwde, cdq, movsx**

**Unsigned – movzx, mov ah,0; mov dx,0; mov edx,0, byte, word, dword, qword**

c). **by enlargement – all the destructive ones ! + word, dword, qword**

**by narrowing – byte, word, dword**

d). **implicit vs explicit conversions**

e = a+b+c e,b = float , a,c – integer

i=c //only in C NOT in C++

float → integer ? How can you do this conversion ?

**YOU CAN NOT CONVERT ANYTHING !!!!!**

- Alternatively you must ASSUME THE RESPONSIBILITY OF CUTTING OUT INFORMATION by using predefined special functions (floor, ceil, round, trunc)

e = a+b+c – integer to float = implicit conversions

- Float to integer – NOT by conversions but by applying predefined functions of the language (floor, ceil, trunc etc).

## Bitwise operators and instructions

In computer programming, a bitwise operation operates on a bit string, a bit array or a binary numeral at the level of its individual bits. It is a fast and simple action, basic to the higher-level arithmetic operations and directly supported by the processor.

Pay attention to the difference between operators and instructions !!!

Mov ah, 01110111b << 3 ; AH := 10111000b

Vs.

Mov ah, 01110111b

Shl ah, 3

---

& - bitwise AND operator

AND – instruction

x AND 0 = 0

x AND 1 = x

; x AND x = x

; x AND ~x = 0

Operation useful for FORCING the values of certain bits to 0 !!!!

| - bitwise OR operator

OR – instruction

x OR 0 = x

x OR 1 = 1

; x OR x = x

; x OR ~x = 1

Operation useful for FORCING the values of certain bits to 1 !!!!

^ - bitwise EXCLUSIVE OR operator;

XOR – instruction

x XOR 0 = x

x XOR 1 = ~x

x XOR x = 0

x XOR ~x = 1

Operation useful for COMPLEMENTING the value of some bits !!!

XOR ax, ax ; AX=0 !!! = 00000000 0000000b

## Operators ! and ~ usage

In C - !0 = 1 (0 = false, anything different from 0 = TRUE, but a predefined function will set TRUE =1)

In ASM - !0 = same as in C, so ! - Logic Negation: !X = 0 when X ≠ 0, otherwise = 1

~ 1's Complement: mov al, ~0 => mov AL, 0ffh (bitwise operator !)

(because a 0 in asm is a binary ZERO represented on 8, 16, 32 or 64 bits the logical BITWISE negation – 1's complement - will issue a binary 8 of 1's, 16 of 1's, 32 of 1's or 64 of 1's... )

a d?....

b d?...

Mov eax, ![a] - because [a] is not something computable/determinable at assembly time, this instruction will issue a syntax error ! – (expression syntax error)

Mov eax, ![a] - ! can only be applied to SCALAR values !! (a = pointer data type ≠ scalar !)

Mov eax, !a - ! can only be applied to SCALAR values !!

Mov eax, !(a+7) - ! can only be applied to SCALAR values

Mov eax, !(b-a) – ok ! because a,b – pointers, but b-a = SCALAR !

Mov eax, ![a+7] - expression syntax error

Mov eax, !7 - EAX = 0

Mov eax, !0 – EAX = 1

Mov eax, ~7 ; 7 = 00000111b , so ~7 = 11111000b = f8h,  
EAX=ff ff ff f8h

Mov eax, !ebx ; syntax error !

aa equ 2

mov ah, !aa ; AH=0

Mov AH, 17^(~17) ; AH = 11111111b = 0ffh = -1

Mov ax, value ^ ~value ax=11111111 11111111 = 0ffffh

value ^ ~value ax=0ffffh

## Data definition directives

Always your data segment starts at offset 00401000 in OllyDbg

Segment data

a1 db 0,1,2,'xyz' ; 00 01 02 'x' 'y' 'z' ; offset(a1) – computed at OllyDbg loading time = 00401000; offset(a1) determined at assembly time by NASM = 0 !!!

78 79 7A

db 300, "F"+3 ; 2C ascii code for 'F' + 3 = 49 ; Warning – byte data (300) exceeds bounds!

a2 TIMES 3 db 44h ; 44 44 44 ; offset(a2) = 00401008, assembly time offset = 8 !

a3 TIMES 11 db 5,1,3 ; 05 01 03...11 times (total 33 bytes)

a41 db a2+1 – syntax err. – OBJ format can only handle 16 or 32 bits relocation !

a4 dw a2+1, 'bc' ; offset(a2)=00401008h; a2+1=...1009h; 09 10 'b' 'c' = 09 10 62 63  
; 09 10 (correct, BUT... this particular 10h value it is only finally computable after LOADING !!!)  
– so the offset of the beginning of segments is computable only at LOADING TIME !!!)  
The variables offset relative to the beginning of segments in which they are defined are constant POINTERS (so POINTER data types !, NOT scalar !) determinable at assembly time !!

a42 dw a2+1, 'bc' ; offset(a2)=00401008h; a2+1=1009h; 09 10 'b' 'c' = 09 10 62 63  
'b', 'c' ; 'b' 00 'c' 00 = 09 10 62 00 63 00

a44 dw 1009h ; 09 10

a5 dd a2+1, 'bcd' ; 09 10 40 00| 62 63 64 00

a6 TIMES 4 db '13' ; equiv with a6 TIMES 4 db '1','3' ; 31 33 31 33 31 33 31 33

a6bis TIMES 4 dw '13' ; 31 33 31 33 31 33 31 33 !!!!!!!!!!!!!!!

a7 db a2 ; syntax err. – OBJ format can only handle 16 or 32 bits relocation (equiv. mov ah,a2)

a8 dw a2 ; 08 10

a9 dd a2 ; 08 10 40 00

a10 dq a2 ; 08 10 40 00 00 00 00 00

a11 db [a2] ; syntax error ! A CONTENTS of a memory area or the contents of a register are NOT values accessible or determinable at assembly time ! These are accessible and determinable ONLY at run-time !!

a12 dw [a2] ; syntax error !

a13 dd dword [a2] ; syntax error !

a14 dq [a2] ; syntax error !

a15 dd eax; expression syntax error

a16 dd [eax]; expression syntax error

mov ax, v ; Warning – 32 bit offset in 16 bit field !!!

### The steps followed by a program from source code to run-time:

- Syntactic checking (done by assembler/compiler/interpreter)
- OBJ files are generated by the assembler/compiler
- Linking phase (performed by a LINKER = a tool provided by the OS, which checks the possible DEPENDENCIES between this OBJ files/modules); The result → .EXE file !!!
- You (the user) are activating your exe file by clicking or enter-ing...
- The LOADER of the OS is looking for the required RAM memory space for your EXE file. When finding it, it loads the EXE file AND performs ADDRESS RELOCATION !!!!
- In the end the loader gives control to the processor by specifying THE PROGRAM's ENTRY POINT (ex: the start label) !!! The run-time phase begins NOW...

Mark Zbirkowski – semnatura EXE = 'MZ'

Segment code (starts always at offset 00402000 – WHO DECIDES THAT ?)

The linker makes such decisions. The base address for loading PEs, at least the default one (set by the Microsoft linkeditor and not only) is 0x400000 for executables (respectively 0x10000000 for libraries). Alink complies with this convention and fills in the ImageBase field of the IMAGE\_OPTIONAL\_HEADER structure in the P.E. newly built value 0x400000. As each "segment" / section of the program can provide different access rights (the code is executable, we can have read-only segments etc ...), these are planned to start each one at the address of a new memory page (4KiB, so multiple of 0x1000), each memory page can be configured with specific rights by the program loader. In the case of small programs, the implication is that you will get the following map of the program in memory (at run time):

- the program is planned to be loaded into memory at exactly the address 0x400000 (but here will reach the metadata structures of the file, not the code or the data of the program itself)
- the first "segment" will be loaded at 0x401000 (quotation marks because it is not a segment itself but only a logical division of the program, the "segment" of a segment register is not directly associated - for this reason the name is often preferred section instead of segment)

- the second "segment" will be loaded at 0x402000 (the segment that the processor will use for segmentation starts at address 0 and has a limit of 4GiB, regardless of the addresses and section sizes)

- will be prepared "segment" (section) of imports, "segment" of exports and "segment" of stack in the order decided by the likeditor (and of dimensions also provided by him), segments that will be loaded from 0x403000, 0x404000 and so on (increments of 0x1000 as long as they are small enough, otherwise need to be used for increment the smallest multiple of 0x1000 which allows enough space for the contents of the entire segment)

According to the decision logic of the start addresses of the sections, we can conclude that here we have a section (probably data) before the code, containing less than 0x1000 bytes, which is why the code starts immediately after, from 0x402000, the program map being at the end : metadata (headers) from 0x400000, data to 0x401000 and code to 0x402000 (followed of course by other "segments" for stack, imports and, optionally, exports).

---

**Linkeditorul** ia deciziile de acest tip. Adresa de baza pentru incarcarea PE-urilor, cel putin cea implicita (setata de catre linkeditorul de la Microsoft si nu numai) este 0x400000 in cazul executabilelor (respectiv 0x10000000 pentru biblioteci). Alink respecta aceasta **conventie** si completeaza in campul ImageBase al structurii IMAGE\_OPTIONAL\_HEADER din fisierul P.E. nou construit valoarea 0x400000. Cum fiecare "segment"/sectiune din program poate prevedea drepturi diferite de acces (codul este executabil, putem avea segmente read-only etc...), acestea sunt planificate sa inceapa fiecare la adresa cate unei noi pagini de memorie (4KiB, deci multiplu de 0x1000), fiecare pagina de memorie putand fi configurata cu drepturi specifice de catre incarcatorul de programe. In cazul unor programe de mici dimensiuni, implicatia este ca se va obtine urmatoarea harta a programului in memorie (la executare):

- programul este planificat a fi incarcat in memorie la exact adresa 0x400000 (insa aici vor ajunge structurile de metadate ale fisierului, nu codul sau datele programului in sine)
- primul "segment" va fi incarcat la 0x401000 (pun ghilimele deoarece nu este un segment propriu-zis ci doar o diviziune logica a programului, nu este asociat direct "segmentul" unui registru de segment – din aceasta pricina se prefera de multe ori denumirea de sectiune in loc de cea de segment)
- al doilea "segment" va fi incarcat la 0x402000 (segmentul pe care il va folosi procesorul pentru segmentare incepe la adresa 0 si are limita de 4GiB, indiferent de adresele si dimensiunile sectiunilor)
- va fi pregatit "segment" (sectiune) de importuri, "segment" de exporturi si "segment" de stack in ordinea decisa de catre likeditor (si de dimensiuni prevazute tot de catre acesta), sectiuni ce vor fi incarcate de la 0x403000, 0x404000 si asa mai departe (incremente de 0x1000 cat timp au dimensiune suficient de mica, in caz contrar fiind nevoie a se folosi pentru increment cel mai mic multiplu de 0x1000 care permite suficient spatiu pentru continutul intregului segment)

Conform logicii de decizie a adreselor de inceput ale sectiunilor, putem concluziona ca aici avem o sectiune (de date probabil) inaintea celei de cod, continand sub 0x1000 octeti, motiv pentru care codul porneste imediat dupa, de la 0x402000, harta programului fiind la final: metadate (antete) de la 0x400000, date la 0x401000 si cod la 0x402000 (urmat bineintele de alte "segmente" pentru stiva, importuri si, optional, exporturi).

Segment code (starts always at offset 00402000)

Start:

Jmp Real_start	(2 bytes)	- 00402000
a db 17		- 00402002
b dw 1234h		- 00402003
c dd 12345678h		- 00402005

Real\_start:

.....

Mov eax, c ; eax = 402005

Mov edx, [c] ; mov edx, DWORD PTR DS:[402005]; in mod normal asta inseamna ca in EDX will be assigned with the doubleword of offset 00402005 taken from DS !!!!

.....

Mov edx, [CS:c] ; mov edx, DWORD PTR CS:[402005]

Mov edx, [DS:c] ; mov edx, DWORD PTR DS:[402005]

Mov edx, [SS:c] ; mov edx, DWORD PTR SS:[402005]

Mov edx, [ES:c] ; mov edx, DWORD PTR ES:[402005]

The output will be in all of the 5 cases the same **EDX:=12345678h** WHY ??

The explanation is directly related to the **flat memory model** - all segments actually describe the entire memory, from 0 to the end of the first 4GiB of memory. As such, [CS: c] or [DS: c] or [SS: c] or [ES: c] will access the same memory location but with different access rights. Although all selectors indicate identical segments in address and size, they may differ in how other control and access fields of the segment descriptors indicated by them are completed.

The flat model assures us that the segmentation mechanism is transparent to us, we do not notice differences between segments and, as such, we completely get rid of the segmentation worry, but we are interested in the logical division into segments of the program, which is why we use separate **sections** / "segments". for data code). This is true but only as long as we limit ourselves to CS / DS / ES and SS! The FS and GS selectors point to special segments that do not follow the flat pattern (reserved for the interaction of the program with the S.O.), more precisely, [FS: c] does not indicate the same memory as [CS: c]!

---

Explicatia este direct legata de **modelul de memorie flat** – toate segmentele descriu in realitate intreaga memorie, incepand de la 0 si pana la capatul primilor 4GiB ai memoriei. Ca atare, [CS:c] sau [DS:c] sau [SS:c] sau [ES:c] vor accesa aceeasi locatie de memorie insa cu drepturi de acces potential diferite. Desi toti selectorii indica segmente identice ca adresa si dimensiune, acestia pot avea diferente in cum le sunt completate alte campuri de control si de acces ale descriptorilor de segment indicati de catre ei.

Modelul flat ne asigura ca mecanismul de segmentare este transparent pentru noi, noi nu sesizam diferente intre segmente si, ca atare, scapam complet de grija segmentarii (insa ne intereseaza impartirea logica in segmente a programului, motiv pentru care folosim sectiuni/"segmente" separate pentru cod date). Acest lucru este valabil insa doar cat timp ne limitam la CS/DS/ES si SS! Selectorii FS si GS indica inspre segmente speciale care nu respecta modelul flat (rezervate interactiunii programului cu S.O-ul), mai precis, [FS:c] sau [GS:c] NU indica aceeasi memorie ca si [CS:c]!

## 24. x86 Instruction Prefix Bytes

---

- x86 [instruction](#) can have up to 4 prefixes.
- Each prefix adjusts interpretation of the opcode:

**String manipulation** instruction prefixes (prefixes provided EXPLICITLY by the programmer !)

**F3h = REP, REPE**

**F2h = REPNE**

where

- **REP** repeats instruction the number of times specified by *iteration count ECX*.
- **REPE** and **REPNE** prefixes allow to terminate loop on the value of **ZF** CPU flag.
- 0xF3 is called REP when used with MOVS/LODS/STOS/INS/OUTS (instructions which don't affect flags)  
0xF3 is called REPE or REPZ when used with CMPS/SCAS  
0xF2 is called REPNE or REPNZ when used with CMPS/SCAS, and is not documented for other instructions.  
Intel's insn reference manual REP entry only documents F3 REP for MOVS, not the F2 prefix.

Related string manipulation instructions are:

- **MOVS**, move string
- **STOS**, store string
- **SCAS**, scan string
- **CMPS**, compare string, etc.

See also string manipulation sample program: [rep\\_movsb.asm](#)

---

**Segment override** prefix causes memory access to use *specified segment* instead of *default segment* designated for instruction operand. (provided EXPLICITLY by the programmer).

**2Eh = CS**

**36h = SS**

**3Eh = DS**

**26h = ES**

**64h = FS**

**65h = GS**

---

**Operand override, 66h.** Changes size of **data** **expected by default mode of the instruction** e.g. 16-bit to 32-bit and vice versa.

---

**Address override, 67h.** Changes size of **address** **expected by the default mode of the instruction**. 32-bit address could switch to 16-bit and vice versa.

These two last prefix types appear as a result of some particular ways of using the instructions (examples below), which will cause the generation of these prefixes by the assembler in the internal format of the instruction. These prefixes are NOT provided EXPLICITLY by the programmer by keywords or reserved words of the assembly language.

**Instruction prefix - REP MOVSB**

**Segment override prefix - ES xlat or mov ax, [cs:ebx]  
(ES:EBX)**

**mov ax, DS:[ebx] – implicit prefix**

**mov ax, [cs:ebx] – explicit prefix given by the programmer**

**Operand size prefix –**

**Bits 32 - default mode of the below code**

.....

cbw ; 66:98 - because rez is on 16 bits (AX)  
 cwd ; 66:99 - because rez is composed by 2 reg on 16 bits (DX:AX)  
 cwde ; 98 - because we follow the default mode on 32 biti –  
 rez in EAX  
 push ax ; 66:50 – because a 16 bits value is loaded onto the stack, the  
 stack being organized on 32 bits  
 push eax ; 50 - ok – consistent usage with default mode  
 mov ax, a ; 66:B8 0010 – because rez is on 16 bits

### Address size prefix – 0x67

Bits 32

mov eax, [bx] ; 67:8B07 - because DS:[BX] is 16 bits addressing

Bits 16

mov BX, [EAX] ; 67:8B18 – because DS:[EAX] is 32 bits addressing

Bits 16

push dword[ebx] ; 66:67:FF33 – Here the default mode is Bits 16;  
because the addressing [EBX] is on 32 bits 67 will be generated and  
because a push is made to a DWORD operand instead of one on 16 bits  
66 will be generated as a prefix

67:8B07 mov eax, [bx] ; Offset\_16\_bits = [BX|BP] + [SI|DI] + [const]

Bits 16 - default mode of the below code

.....

cbw ; 98 - ok, because result is on 16 bits (AX)  
 cwd ; 99 - ok, because result is composed by a combination of 2  
 registers on 16 bits (DX:AX)  
 cwde ; 66:98 - because here the 16 bits default mode is not followed  
 – result in EAX

## String constants. Memory layout and using them in data transfer instructions.

When initializing a memory area with string type constants (sizeof > 1), the data type used in definition (dw, dd, dq) does only the reservation of the required space, **the “filling” order of that memory area being the order in which the characters (bytes) appear in that string constant:**

a6 dd '123', '345','abcd' ; 3 doublewords are defined, their contents being  
31 32 33 00|33 34 35 00|61 62 63 64|

a6 dd '1234' ; 31 32 33 34

a6 dd '12345' ; 31 32 33 34|35 00 00 00|

a71 dw '23','45' |32 33| 34 35| - 2 words = 1 doubleword

a72 dw '2345' - 2 words - 32 33|34 35|

a73 dw '23456' - 3 words - 32 33|34 35|36 00|

mov eax, [a73] ; EAX = 35 34 33 32

mov ah, [a73] ; AH = 32

mov ax, [a73] ; AX = 33 32

The same happens for a71 and a72.

'...' = "..." in NASM ; In C, '...' ≠ "..."

In C, ASCII<sub>Z</sub> implies that 'x' = ASCII code for x (1 byte) – character ;  
"x" = 'x','\0' (2 bytes) – string;

a8 dw '1', '2', '3' - 3 words - 31 00|32 00|33 00

a9 dw '123' - 2 words - 31 32|33 00

The following definitions provide the same memory configuration:

dd 'ninechars' ; doubleword string constant

dd 'nine','char','s' ; 3 doublewords

db 'ninechars',0,0,0 ; “filling” memory area by a bytes sequence

From official documentation we have:

A character constant with more than one byte will be arranged (WHERE ???) with little-endian order in mind: if you code

```
mov eax, 'abcd' (EAX = 0x64636261)
```

then the constant generated is not 0x61626364, but 0x64636261 so that if you were then to store the value into memory, it would read abcd rather than dcba. This is also the sense of character constants understood by the Pentium's CPUID instruction.

---

The main idea of this definition is that THE CHARACTER REPRESENTATION VALUE associated to a string constant 'abcd' is in fact 'dcba' (this being the STORAGE format in the CONSTANTS TABLE).

Mov dword [a], '2345' will be in OllyDBG mov dword ptr DS:[401000],35343332

And the effect on the memory area reserved for a is |32 33 34 35|

....but if you code a data definition like a7 dd '2345' the corresponding memory layout will be NO little-endian representation, but |32 33 34 35|

So, comparatively and in short (string type constants vs. numeric constants):

```
a7 dd '2345' ; |32 33 34 35|
a8 dd 12345678h ; |78 56 34 12|
```

.....

```
mov eax, '2345' → EAX = '5432' = 35 34 33 32 (in OllyDbg you will find
mov eax, 35343332)
```

```
mov ebx, [a7] → EBX = '5432' = 35 34 33 32
```

```
mov ecx, 12345678h ; ECX = 12345678h (sizeof <12345678h> = 4 bytes)
mov dword [var1], '12345678' ; var1 = '1234' (31 32 33 34)
    ( sizeof '12345678' = 8 bytes)
```

```
mov edx, [a8] → EDX = 12345678h
```

In the case when DB is used as a data definition directive it is normal that the bytes order given in the constant to be also kept in memory in similar way (little-endian representation being applied only to data types bigger than a byte!), so this case doesn't need an extra analysis.

```
a66 TIMES 4 db '13' ; 31 33 31 33 31 33 31 33
```

a67 TIMES 4 dw '13' ; 31 33 31 33 31 33 31 33 - those two DIFFERENT definitions provide the same output result !!!

```
a68 TIMES 4 dw '1','3' ; 31 00 33 00 31 00 33 00 31 00 33 00 31 00 33 00
```

```
a69 TIMES 4 dd '13' ; 31 33 00 00 | 31 33 00 00 | 31 33 00 00 | 31 33 00 00
```

So, a constant string in NASM behaves as there is a previously allocated “memory area” (IT IS AND IT IS CALLED CONSTANT TABLE) to these constants, where these are stored using the little-endian representation !!

From a REPRESENTATION point of view the value associated with a string constant IS ITS INVERSE !!!! (see the official definition above)

Basically, if we initialize a memory area with a string constant (either through data definition directives, or through mov [memory\_area], string\_constant) the order in which the characters will be stored in memory is the order in which they appear when writing the string constant on paper !!!

If we initialize the content of a register with a string constant, the characters will be placed in the register in the reverse order of their appearance in the “paper writing” of that string constant!

From a NUMERIC VALUE point of view ??? (true both in C and assembler ???)

“abcd” = THE ADDRESS FROM MEMORY OF THIS CONSTANT (in C)

“abcd”[1] = ‘b’

“abcd”[251] = ??

# Pointer arithmetic

In the addressing system operations with pointers are performed. Which are the ARITHMETIC operations allowed with pointers in COMPUTER SCIENCE ?...

**Answer:** Any operation that makes sense... meaning any operation that expresses as a result a correct location in memory useful as an information for the programmer/processor.

- adding a constant value to a pointer  $a[7] = *(a+7)$  – useful for going into memory forth and back relative to a starting address
- subtracting .....  $a[-4]$  ,  $a(-4)$  ...
- multiplying 2 pointers ? – No way ... no practical usage !
- dividing 2 pointers ? - No way ... no practical usage !
- adding/subtracting 2 pointers ?
- ADDING 2 pointers doesn't make sense !! – it is not allowed
- SUBTRACTING 2 pointers !! does makes sense...  $q-p$  = nr. of elements (in C) = nr. of bytes between these 2 addresses in assembly (this can be very useful for determine the length of a memory area).

$$a[7] = *(a+7) = *(7+a) = 7[a] \quad - \text{both in C and assembly !}$$

**POINTER ARITHMETIC OPERATIONS** - *Pointer arithmetic* represents the set of arithmetic operations allowed to be performed with pointers, this meaning using arithmetic expressions which have addresses as operands.

Pointer arithmetic contains ONLY 3 operations that are possible:

1). Subtracting two addresses

Adress – adress = ok ( $q-p$  = subtraction of 2 pointers = `sizeof(array)` in C, the number of bytes between these 2 addresses in assembly)

Address - offset = address – address

2). Adding a numerical constant to a pointer

Address + numerical constant (identification of an element by indexing –  $a[7]$ ) ,  $q+9$

3). Subtracting a numerical constant from a pointer

Adress - numerical constant -  $a[-4]$  ,  $p-7$ ;  
 $*(a-4)$  - useful for reffering array elements

- subtraction of 2 pointers = SCALAR VALUE (constant)
- adding a constant to a pointer → a POINTER !!
- subtracting a constant from a pointer → a POINTER !!

ADDING TWO POINTERS IS NOT ALLOWED !!!

$p+q = ????$  (allowed in NASM...sometimes...) – but it doesn't mean in the end as we shall see that this is “a pointer addition” !!!

How do I make the difference between the address of a variable and its contents ?

Var – invoked like that it is an address (offset) ; [var] – is its contents

[ ] = the dereferencing operator !! (like  $*p$  in C)

V db 17

add edx, [EBX+ECX\*2 + v -7] – OK !!!!

mov ebx, [EBX+ECX\*2 - v-7] – Syntax error !!!! invalid effective address – impossible segment base multiplier

mov [EBX+ECX\*2 + a+b-7], bx – not allowed ! syntax error ! because of “a+b” invalid effective address – impossible segment base multiplier

sub [EBX+ECX\*2 + a-b-7], eax – ok, because a-b is a correct pointers operation !!!

[EBX+ECX\*2 + v -7] – ok  
SIB      dep. const.

[EBX+ECX\*2 + a-b-7]  
SIB      const.

mov eax, [EBX+ECX\*2+(-7)] – ok.

## L-value vs. R-value. LHS vs. RHS of an assignment.

Assignment:  $i := i + 1$       LHS vs. RHS

Address of I  $\leftarrow$  value of I + 1

LHS(i) = Address of I := RHS(i) = (the contents from the address i) + 1

LHS (Left Hand Side of an assignment = L-value = address) := RHS  
(Right Hand Side of an assignment = R-Value = CONTENTS !!)

---

Symbol := expression\_value

Identifier := expression      (usually in 99% of the cases)

Address\_computation\_expression := expression      (the most general)

Dereferencing is usually implicit depending on the context ! in 99% of the cases. Exception: BLISS language, where dereferencing must always be explicitly specified;  $i \leftarrow *i + 1$  (also we have some similar situations in Algol68)

---

Symbol := expression\_value (99% of the cases...)

Address\_computation\_Expression := expression\_value

In C++    $f(a, b, 2) = x + y + z$

Int&  $f(i, \dots) \{ \dots \text{return } v[i]; \}$  – f is a function that will return an L-value !!  
 $f(88, \dots) = 79;$  it means that  $v[88] = 79 !!!$

Int&  $j = i;$  // j becomes ALIAS for i

$(a + 2?b:c) = x + y + z;$  - correct

$(a + 2?1:c) = x + y + z;$  - syntax error !!!       $1 := n !!!$

---

## Segment data

```
A db 17,-2  
B dw -20345, "x"  
Start2:  
C dd 12345678h  
.....
```

## Segment code

```
.....  
Jmp start2 ; example of a jump in a data segment, so code labels are accepted in  
; data segments !  
.....
```

---

# Location counter and

# pointer arithmetic

## Location counter and pointer arithmetic

SEGMENT data

a db 1,2,3,4 ; 01 02 03 04

lg db \$-a ; 04

lg0 db \$-data ; syntax error – expression is not simple or relocatable

in TASM will be the same effect as above because in TASM, MASM

offset(segment\_name)=0 !!!; in NASM NO WAY, offset(data) = 00401000 !!!

lg1 db a-data ; syntax error – expression is not simple or relocatable

lg2 dw data-a; the assembler allows it but we obtain a linking error – “Error in file at 00129 – Invalid fixup recordname count....”

db a-\$ ; = -5 = FB

c equ a-\$ ; 0-6 = -6 = FA

d equ a-\$ ; 0-6 = -6 = FA

e db a-\$ ; 0-6 = -6 = FA

x dw x ; 07 10 !!!!!

x db x ; syntax error !

x1 dw x1 ; x1 = offset(x1) 09 00 at assembly time and 09 10 in the end...

db lg-a ; 04

db a-lg ; = -4 = FC

db [\$-a] ; expression syntax error – a memory contents is not a constant computable at assembly time

db [lg-a] ; expression syntax error – a memory contents is not a constant computable at assembly time

lg1 EQU lg1 ; lg1 = 0 ! (BUG NASM !!!!) – it considers that an uninitialized constant = 0

lg1 EQU lg1-a ; lg1 = 0 – WHY ????? It's a BUG !!! It works like that only because offset(a) = 0; if we put something else before a in data segment, offset(a) ≠ 0 and we will obtain a syntax error : “Recursive EQUs, macro abuse”

g34 dw c-2 ; -8

b dd a-start ; expression is not simple or relocatable !!! syntax error  
(a – defined here, start – defined somewhere else)

dd start-a ; OK !!!!!!! - (start – defined somewhere else, a – defined here)  
POINTER DATA TYPE!!!!!! (considered as FAR pointers subtraction !!!!)

dd start-start1 ; OK !!! – because they are 2 labels defined in the same segment! –  
Result will be a SCALAR DTyPe !!!!

### segment code use32

start:

mov ah, lg1 ; AH = 0  
mov bh, c ; BH = -6 = FA

mov ch, lg ; OBJ format can handle only 16 or 32 byte relocation  
mov ch, lg-a ; CH = 04  
mov ch, [lg-a] ; mov byte ptr DS:[4] – Access violation – most probably...

mov cx, lg-a ; CX = 4  
mov cx, [lg-a] ; mov WORD ptr DS:[4] – Access violation – most probably...

mov cx, \$-a ; invalid operand type !!!!! (\$ – defined here, a – somewhere else)  
mov cx, \$\$-a ; invalid operand type !! ; \$\$ from code segm and a from data segm !!

mov cx, a-\$ ; OK !!!!! (a – defined somewhere else, \$ – defined here)

mov ch, \$-a ; invalid operand type !!!!! (\$ – defined here, a – somewhere else)  
mov ch, a-\$ ; OBJ format can handle only 16 or 32 byte relocation  
(a-\$ is OK, but a-\$ = POINTER !! – syntax error ! – because offset doesn't fit 1 byte !!)

mov cx, \$-start ; ok !!!  
mov cx, start-\$ ; ok !!! (both ok – the labels are defined in the same segment !!!)

mov ch, \$-start ; ok !!! because RESULT is scalar ! (if it were pointer – syntax error !)  
mov ch, start-\$ ; ok !!!

`mov cx, a-start ; ok !!!` (a – defined somewhere else, start – defined here)

`mov cx, start-a ; invalid operand type !!!` (start – defined here, a – somewhere else)

**start1:**

`mov ah, a+b ; NO syntax error !!!!!!! BUT ... It is NO pointer arithmetic, NO  
pointers addition ; it is SCALAR addition - a+b = (a-$) + (b-$)`

`mov ax, b+a ; AX = (b-$) + (a-$) – SCALARS ADDITION !!!  
(somewhere else – here)`

`mov ax, [a+b] ; INVALID EFFECTIVE ADDRESS !!! – THIS represents REALLY a  
pointers addition which is FORBIDDEN !!!`

`var1 dd a+b ; syntax error ! - expression is not simple or relocatable`

(so NASM doesn't allow "a+b" to appear in a DATA DEFINITION initialization, but  
ONLY as an INSTRUCTION OPERAND like above !!!)

## Conclusion:

Expressions of type et1 – et2 (where et1 and et2 are labels – either code or data) are  
syntactically accepted by NASM,

- Either if both of them are defined in the same segment
- Either if et1 belongs to a different segment from the one in which the expression  
appears and et2 is defined in this latter one. In such a case, the expression is  
accepted and the data type associated to the expression et1-et2 is POINTER and  
NOT SCALAR (numeric constant) as in the case of an expression composed of  
labels belonging to the same segment. (So SOMEWHERE ELSE – HERE OK !, but  
HERE – SOMEWHERE ELSE NO !!!)

Subtracting offsets specified relative to the same segment = SCALAR

Subtracting pointers belonging to different segments = POINTER

The name of a segment is associated with "Segment's address in memory at run-time", but this value  
isn't accessible to us, this being decided only at loading-time by the OS loader. That is why, if we try to  
use the name of a segment explicitly in our programs we will get either a syntax error (in situations like

`$/a-data` – “HERE – SOMEWHERE ELSE”) either a linking error (in situations like `data-a - SOMEWHERE ELSE – HERE`) because practically the name of a segment is associated with its FAR address (which will be known only at loading time, so it will be available only at run-time; we notice though that `segment_address` is considered to be “SOMEWHERE ELSE”) and it is NOT associated to “The Offset of a segment is a constant determinable at assembly time” (like it is in 16 bits programming for example, where `segment_name` at assembly time = its offset = 0). In 32 bits programming, the offset of a segment is NOT a constant computable at assembly time and that is why we cannot use it in pointer arithmetic expressions !

`Mov eax, data ; Segment selector relocations are not supported in PE files (relocation error occurred)`

You can check for instance that NASM and OllyDbg always provide for start offset (DATA) = 00401000, and offset(CODE) = 00402000. So here the offsets aren't zero as in 16 bits programming !! So from this point of view there is a big difference between VARIABLES NAMES (which offsets can be determined at assembly time) and SEGMENTS NAMES (which offsets can NOT be determined at assembly time as a constant, this value being known exactly like the segment's address ONLY at loading time).

If we have multiple pointer operands, the assembler will try to fit the expression into a valid combination of pointer arithmetic operations:

`Mov bx, [(v3-v2) ± (v1-v)] – OK !!! (adding and subtracting immediate values is correct !!)`

... but we must not forget that in the case of INDIRECT ADDRESSING the final result of the expression with pointer operands in parentheses must finally provide A POINTER !!! from this reason in the case of indirect addressing operands in the form “a + b” will never be accepted !

If not, we will obtain “Invalid effective address ”syntax error”:

`Mov bx, [v2-v1-v] ; Invalid effective address !`

`Mov bx, v2-v1-v ; Invalid operand type !      mov bx, v2-(v1+v) – so we conclude that v1+v` is accepted as a SCALAR in interpretation `a+b = (a-$) + (b-$)`, ONLY IF a+b appears AS ITS OWN or besides other SCALAR expressions ! but NOT in combination with POINTER expressions !!

`Mov bx, v2+v1-v ; ok = v2+scalar`

`Mov bx, [v3-v2-v1-v] ; Invalid effective address !`

`Mov bx, v3-v2-v1-v ; OK !!! – because... Mov bx, v3-v2-v1-v = Mov bx, (v3-v2)-(v1+v) = subtracting immediate values (SCALARS !!!)`

The direct vs. indirect addressing variant is more permissive as arithmetic operations in NASM (due to the acceptance of "a + b" type expressions) but this does not mean that it is more permissive IN POINTER OPERATIONS !!!

Mov bx, (v3±v2) ± (v1±v) – OK !!! (adding and subtracting immediate values is correct!!)

The expressions in parentheses (in both yellow and green variants) MUST BE SCALARS !!!!!!!

### Varianta in limba romana a textului de dupa concluzii

Numele unui segment este asociat cu "Adresa segmentului in memorie in faza de execuție" însă aceasta nu ne este disponibilă/accesibilă, fiind decisă la momentul încărcării programului pt execuție de către încărcătorul de programe al SO. De aceea, dacă folosim nume de segmente în expresii din program în mod explicit vom obține fie eroare de sintaxă (în situații de tipul \$/a-data - "AICI – ALTUNDEVA") fie de link-editare (în situații de tipul data-a - ALTUNDEVA – AICI), deoarece practic numele unui segment este asociat cu adresa FAR al acestuia (adresă care nu va fi cunoscută decât la momentul încărcării programului, deci va fi disponibilă doar la run-time; observăm astfel că adresă\_segment este considerată ca "ALTUNDEVA") și NU este asociat cu "Offset-ul segmentului în faza de asamblare, fiind o constantă determinată la momentul asamblării" (așa cum este în programarea sub 16 biți de exemplu, unde nume\_segment în faza de asamblare = offset-ul său = 0). Ca urmare, se constată că în programarea sub 32 de biți numele de segmente NU pot fi folosite in expresii !!

Mov eax, data ; Segment selector relocations are not supported in PE files (relocation error occurred)

Sub 32 biți offset (data) = vezi OllyDbg – întotdeauna DATA segment începe la offset-ul 00401000, iar CODE segment la offset 00402000. Deci offset-urile începuturilor de segment nu sunt 0 la fel ca și la programarea sub 16 biți. Din acest punct de vedere sub 32 biți este o mare diferență între numele de variabile (al căror offset poate fi determinat la asamblare) și numele de segmente (al căror offset NU poate fi determinat la momentul asamblării ca și o constantă, această valoare fiind cunoscută la fel ca și adresa de segment doar la momentul încărcării programului pt execuție - loading time).

Dacă avem mai mulți operanzi pointeri, asamblorul va încerca să încadreze expresia într-o combinație validă de operații cu pointeri:

**Mov bx, [(v3-v2) ± (v1-v)] – OK !!! (adunarea și scăderea de valori imediate este corectă !!)**

...însă nu trebuie să uităm că fiind vorba despre ADRESARE INDIRECTĂ rezultatul final al expresiei cu operanzi pointeri din paranteze trebuie să furnizeze în final UN POINTER !!!... din această cauză în cazul adresării indirecte nu vor fi niciodată acceptate expresii cu operanzi adrese de forma “a+b”

Dacă expresia nu va putea fi încadrată într-o combinație validă de operații cu pointeri, vom obține eroarea de sintaxă “Invalid effective address”:

Mov bx, [v2-v1-v] ; Invalid effective address !

Mov bx, v2-v1-v ; Invalid operand type !

Mov bx, v2-v1-v ; Invalid operand type !    mov bx, v2-(v1+v) – de unde concluzionăm că v1+v este acceptată ca și SCALAR în interpretarea **a+b = (a-\$)+ (b-\$)**, doar dacă apare DE SINE STATATOR sau în combinație cu alți SCALARI , dar NU și nu în combinație cu expresii de tip POINTER !!!

Mov bx, v2+v1-v ; ok = v2+scalar

Mov bx, [v3-v2-v1-v] ; Invalid effective address !

Mov bx, v3-v2-v1-v ; OK !!! – deoarece ?... Mov bx, v3-v2-v1-v = Mov bx, (v3-v2)-(v1+v) = scădere de valori **imediate** (SCALARE!)

Varianta de **adresare directă** vs.**indirectă** este mai permisivă ca operații aritmetice în NASM (din cauza acceptării expresiilor de tip “a+b”) însă asta nu înseamnă că este mai permisivă IN OPERAȚIILE CU POINTERI !!!

**Mov bx, (v3±v2) ± (v1±v) – OK !!! (adunarea și scăderea de valori imediate este corectă !!)**

## Location Counter

### Segment data

a db 17, -2, 0ffh, 'xyz',...

db ....

db....

;lga db \$-a (mov [lga],...); ok //pointer arithmetic – subtracting 2 pointers = scalar value (numerical constant) – lga = memory variable (mov [lga],...)

;lga dw \$\$ ; the same correct length, but ONLY IF a is the first element allocated in the data segment !!!!

;lga EQU \$-a ; ok ! but mov [lga],... will issue a syntax error !!! because lga is NOT an allocated variable... so it doesn't have a memory address to be deref.

;lga dw \$-data ; correct in TASM/MASM, INCORRECT in NASM on 32 bits !!! syntax error – “Expression is not simple or relocatable”

;lga dw lga-a !!!! ok !

b EQU 27 ; b is NOT an offset !!!!

c dd 12345678h

;lga dw b-a ; syntax error !!!!! b is NOT an address !!!

;lga dw c-a ; ok !!!!

lga dw \$-a-4 ; ok !!!

lg dw \$-a ; length (a) + 4 !!!

---

If no section directive is explicitly used, the symbol \$\$ will be implicitly evaluated to the offset of the beginning of the current segment.

“:” is mandatory when we define code labels (ex: “start:”) but must not be present when we define a data label (ex: a variable definition “a db 17”)

## SHORT JMP vs. LONG JMP

Dinnou:

```
Mov eax, 89
```

```
.....  
Jmp Maideparte ; JMP is not restricted to any “distance”
```

Resd 1000h; The distance between LOOP and the label Dinnou is > 127 bytes so it is not a short jump !

Maideparte:

```
Mov ebx, 17
```

```
.....
```

Loop Dinnou ; syntax error: short jump is out of range + warning: byte data exceeds bounds

If we replace **Loop Dinnou** with the equivalent

```
dec ecx  
jnz Dinnou
```

we will NOT obtain an error anymore because

In TASM and MASM the short jump condition (ie maximum 127 bytes distance) is imposed both at the level of LOOP type instructions and at the level of conditional jump instructions.

In NASM the restriction is valid only for LOOP type instructions, the conditional jump instructions are no longer subject to this restriction.

Although, there is a very important difference between these 2 variants: Loop does NOT affect the flags, but DEC DOES that !!

If we need a similar effect without affecting the flags, we could do:

Dinnou:

```
Mov eax, 89
```

```
.....
```

```
Jmp Maideparte
```

Resd 1000h; The distance between LOOP and the label Dinnou is > 127 bytes so it is not a short jump !

MaiAproape:

```
Jmp Dinnou
```

Maideparte:

```
Mov ebx, 17
```

```
.....
```

Loop MaiAproape ; short jump

MNEMONICA	SEMNIFICATIE (salt dacă..<<relație>>)	Condiția verificată
<b>JB</b> <b>JNAE</b> <b>JC</b>	este inferior nu este superior sau egal există transport	CF=1
<b>JAE</b> <b>JNB</b> <b>JNC</b>	este superior sau egal nu este inferior nu există transport	CF=0
<b>JBE</b> <b>JNA</b>	este inferior sau egal nu este superior	CF=1 sau ZF=1
<b>JA</b> <b>JNBE</b>	este superior nu este inferior sau egal	CF=0 și ZF=0
<b>JE</b> <b>JZ</b>	este egal este zero	ZF=1
<b>JNE</b> <b>JNZ</b>	nu este egal nu este zero	ZF=0
<b>JL</b> <b>JNGE</b>	este mai mic decât nu este mai mare sau egal	SF $\neq$ OF
<b>JGE</b> <b>JNL</b>	este mai mare sau egal nu este mai mic decât	SF=OF
<b>JLE</b> <b>JNG</b>	este mai mic sau egal nu este mai mare decât	ZF=1 sau SF $\neq$ OF
<b>JG</b> <b>JNLE</b>	este mai mare decât nu este mai mic sau egal	ZF=0 și SF=OF
<b>JP</b> <b>JPE</b>	are paritate paritatea este pară	PF=1
<b>JNP</b> <b>JPO</b>	nu are paritate paritatea este impară	PF=0
<b>JS</b>	are semn negativ	SF=1
<b>JNS</b>	nu are semn negativ	SF=0
<b>JO</b>	există depășire	OF=1
<b>JNO</b>	nu există depășire	OF=0

**Tabelul 4.1.** Instrucțiunile de salt condiționat

## CHAPTER 4

# ASSEMBLY LANGUAGE INSTRUCTIONS

General form of an ASM program in NASM + short example:

```
global start ; we ask the assembler to give global visibility to the symbol called start  
;(the start label will be the entry point in the program)
```

```
extern ExitProcess, printf ; we inform the assembler that the ExitProcess and printf symbols are foreign  
;(they exist even if we won't be defining them),  
; there will be no errors reported due to the lack of their definition
```

```
import ExitProcess kernel32.dll ;we specify the external libraries that define the two symbols:  
; ExitProcess is part of kernel32.dll library (standard operating system library)
```

```
import printf msrvct.dll ;printf is a standard C function from msrvct.dll library (OS)
```

```
bits 32 ; assembling for the 32 bits architecture
```

```
segment code use32 class=CODE ; the program code will be part of a segment called code  
start:
```

```
; call printf("Hello from ASM")  
push dword string ; we send the printf parameter (string address) to the stack (as printf requires)  
call [printf] ; printf is a function (label = address, so it must be indirected [])
```

```
; call ExitProcess(0), 0 represents status code: SUCCESS  
push dword 0  
call [ExitProcess]
```

```
segment data use32 class=DATA ; our variables are declared here (the segment is called data)  
string: db "Hello from ASMI!", 0
```

## 4.1. DATA MANAGEMENT / 4.1.1. Data transfer instructions

### 4.1.1.1. General use transfer instructions

<b>MOV d,s</b>	<d> <-> <s> (b-b, w-w, d-d)	-
<b>PUSH s</b>	ESP = ESP - 4 and transfers („pushes”) <s> in the stack (s – doubleword)	-
<b>POP d</b>	Eliminates („pops”) the current element from the top of the stack and transfers it to d (d – doubleword) ; ESP = ESP + 4	-
<b>XCHG d,s</b>	<d> ↔ <s> ; s,d – have to be L-values !!!	-
<b>[reg_segment] XLAT</b>	AL ← < DS:[EBX+AL] > or AL ← < segment:[EBX+AL] >	-
<b>CMOVcc d, s</b>	<d> ← <s> if cc (conditional move) is true	-
<b>PUSHA / PUSHAD</b>	Pushes in the stack EAX, ECX, EDX, EBX, ESP, EBP, ESI and EDI	-
<b>POPA / POPAD</b>	Pops EDI, ESI, EBP, ESP, EBX, EDX, ECX and EAX from stack	-
<b>PUSHF</b>	Pushes EFlags in the stack	-
<b>POPF</b>	Pops the top of the stack and transfers it to Eflags	-
<b>SETcc d</b>	<d> ← 1 if cc is true, otherwise <d> ← 0 (byte set on condition code)	-

If the destination operand of the MOV instruction is one of the 6 segment registers, then the source must be one of the eight 16 bits EU general registers or a memory variable. The loader of the operating system initializes automatically all segment registers and changing their values, although possible from the processor point of view, does not bring any utility (a program is limited to load only selector values which indicates to OS preconfigured segments without being able to define additional segments).

**PUSH** and **POP** instructions have the syntax      **PUSH s**    and    **POP d**

Operands d and s MUST be doublewords, because the stack is organized on doublewords. The stack grows from big addresses to small addresses, 4 bytes at a time, ESP pointing always to the doubleword from the top of the stack.

We can illustrate the way in which these instructions works, by using an equivalent sequence of MOV and ADD or SUB instructions:

push eax	$\Leftrightarrow$	sub esp, 4 ; prepare (allocate) space in order to store the value mov [esp], eax ; store the value in the allocated space
pop eax	$\Leftrightarrow$	mov eax, [esp] ; load in eax the value from the top of the stack add esp, 4 ; clear the location

In the perspective of evaluating the effect of instructions such as **PUSH ESP** or **POP dword [ESP]**, the order in which the component (sub)operations of the PUSH and POP instructions are performed should be specified even more clearly:

- a). The operand of the instruction is evaluated (ESP or respectively dword [ESP] for example above)
- b). ESP is updated accordingly (ESP := ESP-4 for PUSH and ESP := ESP+4 for POP respectively)
- c). The assignment involved in the effect of the instruction is performed

Assuming that the initial situation is  $ESP = 0019FF74$ , after **PUSH ESP** we will have  $ESP = 0019FF70$  and the contents of the top of the stack will now be  $0019FF74$ .

Assuming that the initial situation is  $ESP = 0019FF74$  and that in this location is the value  $7741FA29$  (the top of the stack), after **POP dword [ESP]** we will have  $ESP = 0019FF78$  and the content of this location (the content of the location at the top of the stack) will be  $7741FA29$  (so we could say that "the top of the stack moves one position lower"!!).

PUSH and POP only allow you to deposit and extract values represented by word and doubleword. Thus, PUSH AL is not a valid instruction (syntax error), because the operand is not allowed to be a byte value. On the other hand, the sequence of instructions

```
PUSH    ax ; push ax in the stack  
PUSH    ebx ; push ebx in the stack  
POP  ecx ; ecx <- the doubleword from the top of the stack (the value of ebx)  
POP  dx  ; dx <- the word from the stack (the value of ax)
```

is a valid sequence of instructions and is equivalent as an effect with:

```
MOV ecx, ebx  
MOV dx, ax
```

In addition to this constraint (which is inherent in all x86 processors), the operating system requires that stack operations be made only through doublewords or multiple of doublewords accesses, for reasons of compatibility between user programs and the kernel and system libraries. The implication of this constraint is that the PUSH operand16 or POP operand16 instructions (for example, PUSH word 10), although supported by the processor and assembled successfully by the assembler, is not allowed by the operating system, might causing what is named the incorrectly aligned stack error: the stack is correctly aligned if and only if the value in the ESP register is permanently divisible by 4!

The XCHG instruction allows interchanging the contents of two operands having the same size (byte, word or doubleword), at least one of them having to be a register (the other one being either a register or a memory address). This restriction comes from the fact that both operands must be L-values !! Its syntax is

**XCHG** *operand1, operand2*

XLAT "translates" the byte from AL to another byte, using for that purpose a user-defined correspondence table called *translation table*. The syntax of the XLAT instruction is

[reg\_segment] XLAT

*translation\_table* is the **direct address** of a string of bytes. The instruction requires at entry the far address of the translation table provided in one of the following two ways:

- DS:EBX (implicit, if the segment register is missing)
- segment\_register:EBX, if the segment register is explicitly specified.

The effect of **XLAT** is the replacement of the byte from AL with the byte from the translation table having the index the initial value from AL (the first byte from the table has index 0). EXAMPLE: pag.111-112 (course book).

For example, the sequence

```
    mov ebx, Table
    mov al,6
    ES xlat           AL ← < ES:[EBX+6] >
```

transfers the content of the 7th memory location (having the index 6) from *Table* into AL.

The following example translates a decimal value “number” between 0 and 15 into the ASCII code of the corresponding hexadecimal digit :

```
segment data use32
.
.
.
TabHexa  db  '0123456789ABCDEF'
.
.
.
segment code use32
mov ebx, TabHexa
.
.
.
mov al, numar
xlat          ; AL ← < DS:[EBX+AL] >
ES xlat        ; AL ← < ES:[EBX+AL] >
```

This strategy is commonly used and proves useful in preparing an integer numerical value for printing (it represents a conversion *register numerical value – string to print*).

How many ACTIVE code segments can we have ?... 1 – CS

How many ACTIVE stack segments can we have ?... 1 - SS

How many ACTIVE data segments can we have ?... 2 – DS and ES BOTH are reffering to DATA segments

#### **4.1.1.3. Address transfer instruction - LEA**

<b>LEA</b> general_reg, contents of a memory_operand	general_reg $\leftarrow$ offset(mem_operand)	-
--	--	---

**LEA (Load Effective Address)** transfers the offset of the *mem* operand into the destination register. For example

**lea eax,[v]**

loads into EAX the offset of the variable v, the instruction equivalent to **mov eax, v**

But **LEA** has the advantage that the source operand may be an addressing expression (unlike the **mov** instruction which allows as a source operand only a variable with direct addressing in such a case). For example, the instruction:

**lea eax,[ebx+v-6]**

is not equivalent to a single **MOV** instruction. The instruction

**mov eax, ebx+v-6**

is syntactically incorrect, because the expression ebx+v-6 cannot be determined at assembly time.

By using the values of offsets that result from address computations directly (in contrast to using the memory pointed by them), **LEA** provides more versatility and increased efficiency: versatility by combining a multiplication with additions of registers and/or constant values and increased efficiency because the whole computation is performed in a single

instruction, without occupying the ALU circuits, which remain available for other operations (while the address computation is performed by specialized circuits in BIU)

Example: multiplying a number with 10

```
mov eax, [number]           ; eax <- the value of the variable number  
lea eax, [eax * 2]         ; eax <- number * 2  
lea eax, [eax * 4 + eax]   ; eax <- (eax * 4) + eax = eax * 5 = (number * 2) * 5
```

#### **4.1.1.4. Flag instructions**

The following four instructions are *flags transfer instructions*:

**LAHF** (*Load register AH from Flags*) copies SF, ZF, AF, PF and CF from FLAGS register in the bits 7, 6, 4, 2 and 0, respectively, of register AH. The contents of bits 5, 3 and 1 are undefined. Other flags are not affected (meaning that LAHF does not generate itself other effects on some other flags – it just transfers the flags values and that's all).

**SAHF** (*Store register AH into Flags*) transfers the bits 7, 6, 4, 2 and 0 of register AH in SF, ZF, AF, PF and CF respectively, replacing the previous values of these flags.

**PUSHF** transfers all the flags on top of the stack (the contents of the EFLAGS register is transferred onto the stack). The values of the flags are not affected by this instruction. The **POPF** instruction extracts the word from top of the stack and transfer its contents into the EFLAGS register.

The assembly language provides the programmer with some instructions to set the value of the flags (the condition indicators) so that the programmer can influence the operation mode of the instructions which exploits these flags as desired.

<b>CLC</b>	CF=0	CF
<b>CMC</b>	CF = ~CF	CF
<b>STC</b>	CF=1	CF
<b>CLD</b>	DF=0	DF
<b>STD</b>	DF=1	DF

**CLI, STI** – they are used on the Interrupt Flag. They have effect only on 16 bits programming, on 32 bits the OS blocking the programmer's access to this flag.

## Responsabilities for generating the call code, entry code and exit code

		Function/proc call	{	}
CALLER	CALLEE	Call code	Entry code	Exit code
C	C	C compiler	C compiler	C compiler
C	asm	C compiler	ASM programmer	ASM programmer
asm	C	ASM programmer	C compiler	C compiler
asm	asm	Call (saving the return address)	NOTHING mandatory	RET (grab the returning address and jmp)

### Call code (THE CALLER):

- a). Saving the volatile resources (EAX, ECX, EDX, EFLAGS)
- b). Passing parameters
- c). Saving the returning address and performing the call

### Entry code (THE CALLEE – called subroutine):

- a). Building the new stackframe                   PUSH EBP,  
   MOV EBP, ESP
- b). Allocating space for local variables     SUB ESP, nr\_bytes
- c). Saving non-volatile resources exposed to be modified

### Exit code (THE CALLEE):

- a). Restoring non-volatile resources
- b). Freeing the space allocated for local variables [ADD ESP, nr\_bytes\_locals] – mentioned here just as a reverse for the above b) from the entry code, but not really necessary because deallocating the stackframe (mov esp, ebp) includes this action anyway from a practically point of view.
- c). Deallocating the stackframe     MOV ESP, EBP (if we know exactly the size of the stackframe , ADD ESP, sizeof(stackframe) solves similarly...) and restoring the base of the     POP EBP caller stackframe (old EBP)       (a, b c – the reverse of the entry code)
- d). Returning from the subroutine (RET) and deallocating passed parameters (if we have a STDCALL function)    - (reverse of b + c from the call code)

It is still to be done the reverse of a) from call code. It is the task of the CALLER to do it together with a possible parameters take out from the stack (if it is a CDECL function).

## Volatile vs. non-volatile resources

- **volatile** resources are represented by those registers that **the calling convention is defining them as belonging to the called subroutine**, thus, the caller being responsible **as part of the call code** to save their values (if the called subroutine is using them) and after that, at the end of the call to restore the initial (old) values. So: who is saving the volatile resources ? **The caller** (as part of the call code) . Who is restoring in the end those values ? Also **the caller but NOT as part of a certain call/entry or exit code**. Just restore them after the call in the regular code as a mandatory responsibility.
- **non-volatile** resources are any memory addresses or registers which do not belong explicitly to the called subroutine, but if this one needs to modify those resources, it is necessary that the called subroutine to save them at the entry as part of the entry code and restore them back at exit, as part of the exit code. So: who is saving the non-volatile resources ? **The callee** (apelatul = the **called** subroutine, as part of the entry code) . Who is restoring in the end these values ? Also **the callee** (as part of the exit code).



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Multi-module programming

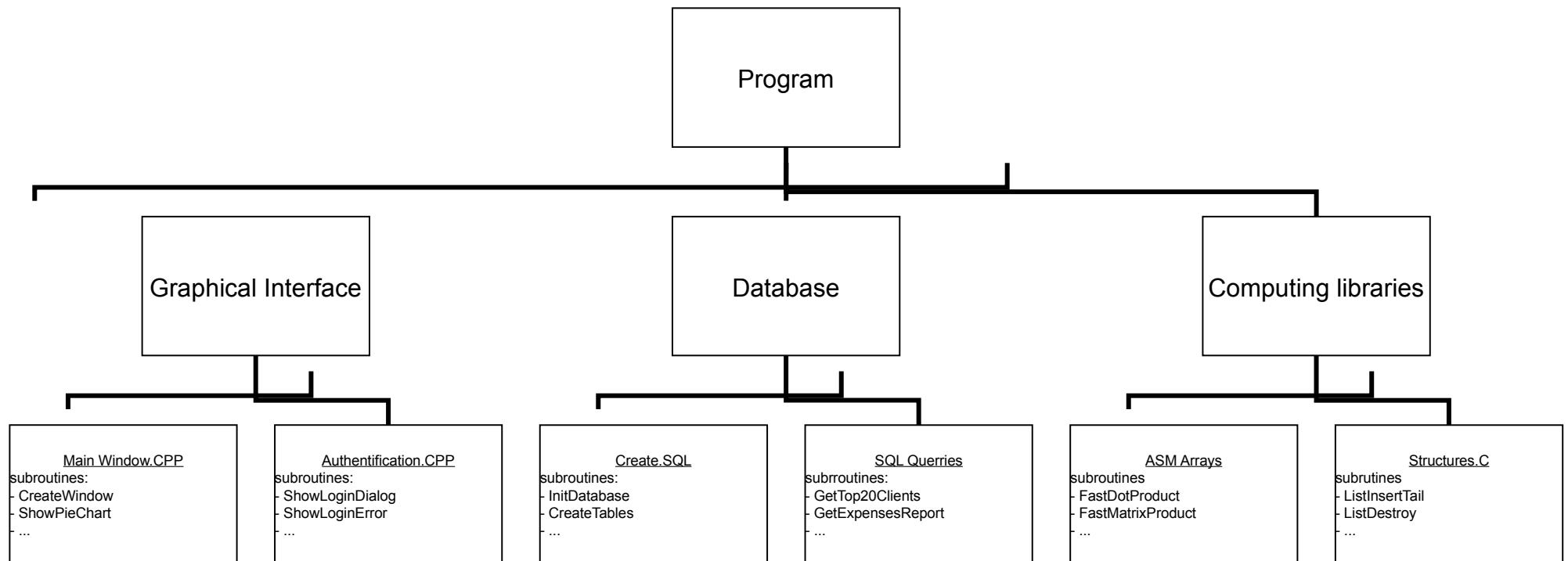
Marius Vanță

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# 1. Modular Architectures

# Modular programming

- How to split a problem in sub-problems?
  - Modularization
  - program -> logic units
  - code (of units) -> distinct files
  - Files -> subroutines



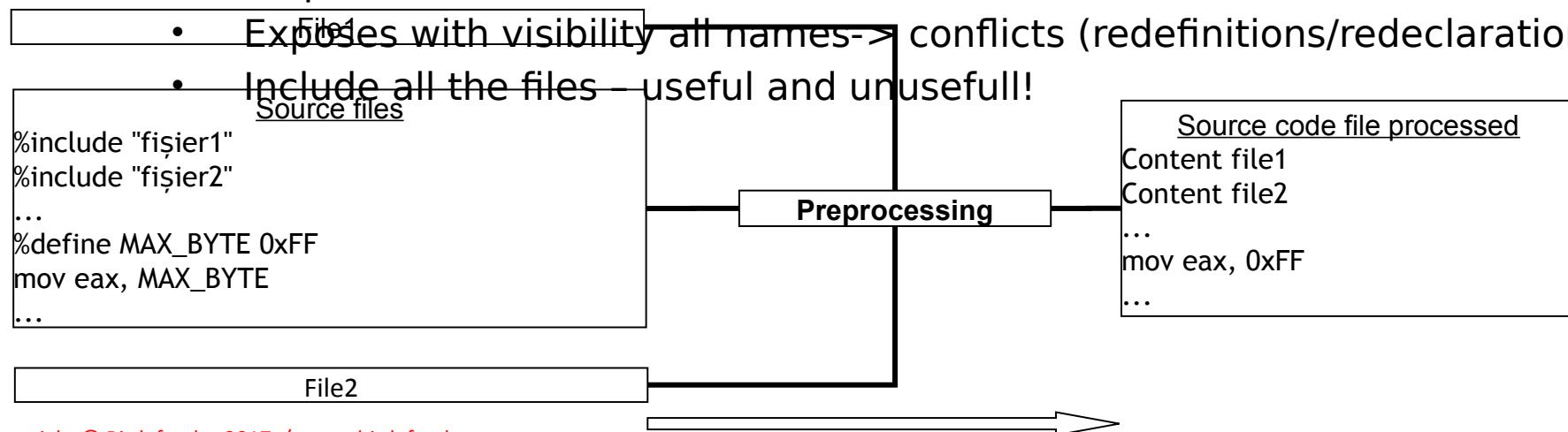
# Modular programming

- Exist already some available solutions for some sub-problems?
- Reusability
  - Code files
    - *Code reusability and dates from assembly*
      - %include directive
    - Binary files
      - *Code reuse and și dates from assembly*
      - *Codes and dates from high level languages*
      - *Libraries*
  - Existence of separate binary files implies  
SEPARATE COMPILATION !!!

# 2. Techniques and tools

# Techniques and tools

- **Static inclusion at compilation/assembly:** directive **%include**
  - Realise the specificity of language (but has equivalent also in other languages)
  - Modularization: allows only code division for the code written in the same language!
    - It is NOT multimodule programming !(this requires SEPARATE COMPIRATION !!!)
  - Reusability: display the source code!
  - Dangerous and problematic:
    - Preprocessor mechanism -> textual concatenation of files
    - ~~Exposes with visibility all names -> conflicts (redefinitions/redeclarations)~~
    - ~~Include all the files - useful and unusefull!~~



# Tools and techniques

- How to use %include

```
; files constante.inc

; double inclusion
#ifndef      _CONSTANTE_INC_ ; at first inclusion, _CONSTANTE_INC_ is not defined
#define      _CONSTANTE_INC_ ; definim _CONSTANTE_INC_ -> fake condition for next
inclusions

; it is recommended that this type of files (included by other files) contain only
declarations

MAX_BYTE    equ 0xFF
MAX_WORD    equ 0xFFFF
MAX_DWORD   equ 0xFFFFFFFF
MAX_QWORD   equ 0xFFFFFFFFFFFFFFFF

#endif ; _CONSTANTE_INC_
```

# Techniques and tools

- **%include** usage example

```
; file constants.inc

; protect against double inclusion
#ifndef      _CONSTANTS_INC_ ; at the first inclusion, _CONSTANTE_INC_ is not defined
#define      _CONSTANTS_INC_ ; we define _CONSTANTE_INC_ -> the condition will be
false for future inclusions

; it is recommended that files included by other files should (only) consist of
declarations!
MAX_BYTE    equ 0xFF
MAX_WORD    equ 0xFFFF
MAX_DWORD   equ 0xFFFFFFFF
MAX_QWORD   equ 0xFFFFFFFFFFFFFFFF

#endif ; _CONSTANTS_INC_
```

# Techniques and tools

- **%include** usage example – “moving” the contents of eax in a BYTE/WORD/DWORD, according to the actual size of its value

```
; file program.asm
%include "constants.inc"
    cmp     eax, MAX_BYTE
    ja      .no_fit_in_byte          ; the value in eax fits in a BYTE?

.fits_in_byte:
    mov     [result_byte], al        ; if yes, save AL in result_byte
    jmp     .done

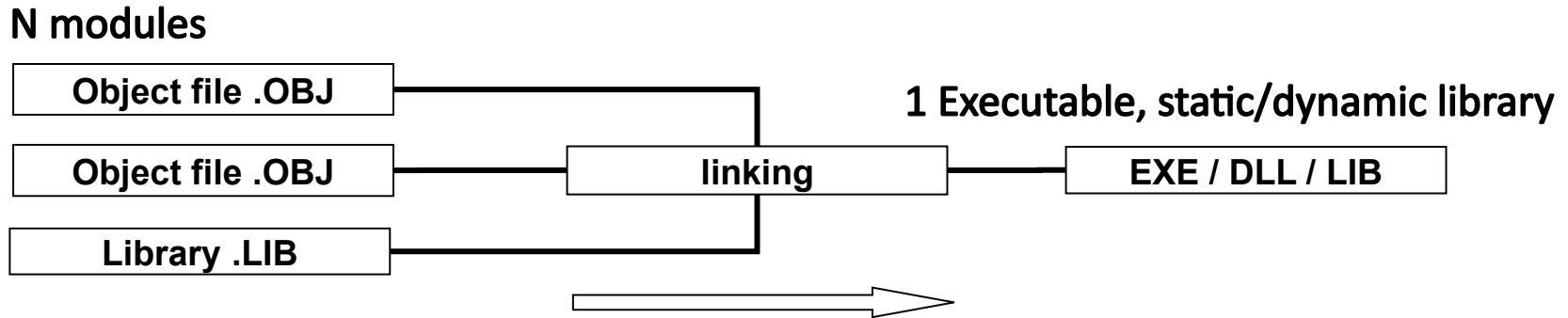
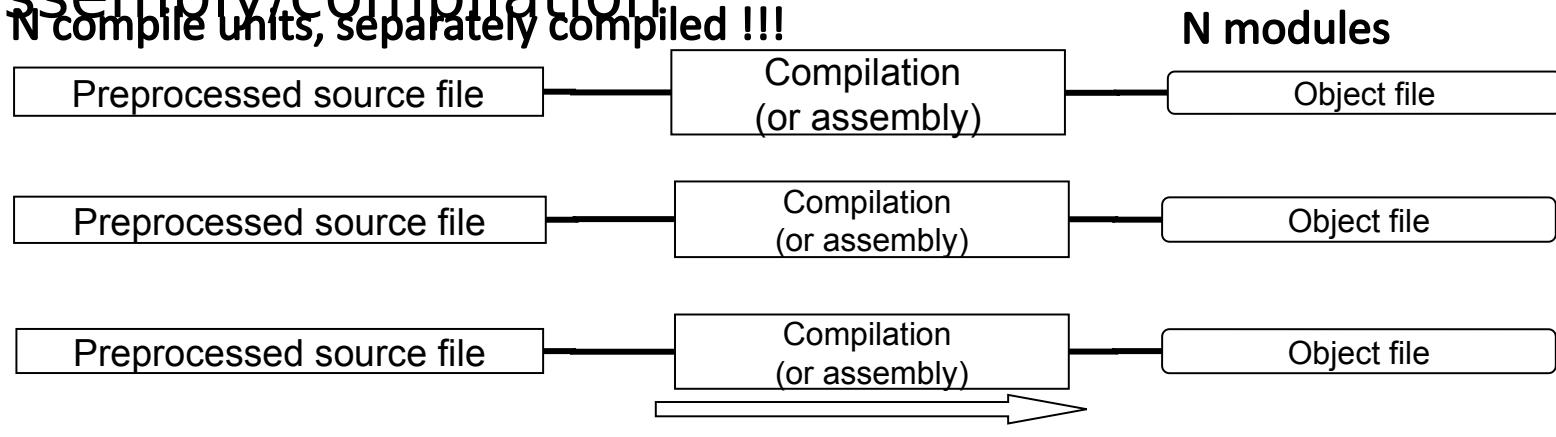
.no_fit_in_byte:
    cmp     eax, MAX_WORD
    ja      .no_fit_in_word         ; otherwise check if it fits in a
WORD

.fits_in_word:
    mov     [resultat_word], ax       ; if yes, save AX in resultat_word
    jmp     .done

.no_fit_in_word:
    mov     [resultat_dword], eax     ; if a WORD is not enough, save all
of eax
```

# Techniques and tools

- **Static linking at link-time**
  - a step performed by the **linker** after assembly/compilation



# Techniques and tools

- Static **linking** at **link-time** – summary of responsibilities Preprocessor: **text => text**

- Performs a processing of the source text, resulting a intermediary text source
- Can be imagined as a component of the compiler or assembler
- May be missing, many languages do not have a preprocessor.

- Assembler: **instructions (text) => binary encoding (object file)**

- Encodes the instructions and data (variables) from the preprocessed text source and builds an object file that consists of machine code and variable values, along with information about the content (variable names, subroutines, information about their type and visibility etc.)

- Compiler: **instructions (text) => binary encoding (object file)**

- Identifies sequences of processor instructions through which the functionalities described in the text source can be obtained, *then, like an assembler*, generates an object file that contains the binary codification of those instructions and the variables from the program
- Assembling is a special case of compilation, where the processor instructions are provided directly in the text of the program and therefore the compiler does not need to select them!

- Linking: **object file => library or program**

- Constructs the final result, specifically a program (.exe) or a library (.dll or .lib) in which it *links together* (includes) the code and binary data from the object file
- It has no regard for which compilers or languages were used! Linking only requires that the input file follow the standard format of object files!

# Techniques and tools

## • Static linking at link-time

- Allows joining multiple **binary modules** (object files or static libraries) in a single file
  - Input: any number of object files (**.OBJ**) and/or static libraries (**.LIB**)
    - *Attention: not all .LIB files are static libraries!*
  - Output: .EXE or .LIB or .DLL (Dynamic-Link Library)
- Multimodule: any number of files may be compiled separately and linked together
  - Step performed by the linker *after* compilation/assembly -> **language independent**
- Reuse:
  - In binary form – does not expose the source code!
  - Allows inter-operability between different languages!
- Other advantages and disadvantages:
  - The linker *can* identify and remove unused resources or perform other optimizations
  - Large program size: the program incorporates reused external resources
  - Large program size: popular libraries duplicated in most programs
- NASM: **global** and **extern** directives
  - *global name* – allows the possibility of external reuse of this resource through its name
  - *extern name* – requests access to the specified resource; it needs to be public!

# Techniques and tools

- Static **linking** at **link-time** - nasm requirements
  - Resources are shared based on a mutual agreement
  - *Export* through **global** name1, name2, ...
    - It makes the resources available to any interested file
  - *Import* through **extern** name1, name2, ...
    - Request access, no matter from which file the source is provided
  - Request without availability = error!
    - Only resources that are exported somewhere can be imported
  - Availability without request is allowed. Why?
    - Answer: even if none of the program's modules does not request/use a resource, it may be used in a future version or by a different program
  - High level programming languages also offer syntactical constructions with an equivalent purpose!
    - Example: in C
      - *Availability is automatic/implicit, however access may be restricted by using the keyword **static***
      - *Access request is (also) done through the keyword **extern***

# Techniques and tools

- Static **linking** at **link-time** - nasm requirements
    - Practical example for global and extern directives
- ~~; FILE1.ASM~~      ~~; FILE2.ASM~~
- global Var1, Subroutine2 → extern Var1, Subroutine2
- extern Var3, Subroutine3 ← global Subroutine3, Var3
- Subroutine1:  
....  
call(Subroutine3)  
....  
operations(Var3)  
....
- Subroutine2:  
....  
Var1 dd ...  
Var2 db ...
- Subroutine3:  
....  
call(Subroutine2)  
....  
operations (Var1)  
....
- Subroutine1:  
....  
Var2 db ...  
Var3 dd ...

# Techniques and tools

- Static linking at **linkediting** - nasm requirements

; FILE1.ASM

```
global Var1, Subroutine2
extern Var3, Subroutine3
Subroutine1:
```

....

call (Subroutine3)

....

operations(Var3)

....

Subroutine2:

....

Var1 dd ...

Var2 db ...

; FILE2.ASM

```
extern Var1, Subroutine2
global Subroutine3, Var3
Subroutine3:
```

....

call (Subroutine2)

....

operations(Var1)

....

Subroutine1:

....

Var2 db ...

Var3 dd ...

*Can reuse names  
as long as they  
are not global!*

# Techniques and tools

- Example of a multimodule program nasm + nasm

; MODULE MAIN.ASM

```
global SirFinal
extern Concatenare
```

```
import printf msvcrt.dll
import exit msvcrt.dll
extern printf, exit
global start
```

```
segment code use32 public code class='code'
start:
```

```
    mov eax, Sir1
    mov ebx, Sir2
    call Concatenare
    push dword SirFinal
    call [printf]
    add esp, 1*4
    push dword 0
    call [exit]
```

```
segment data use32
```

```
    Sir1 db 'Buna ', 0
    Sir2 db 'dimineata!', 0
    SirFinal resb 1000 ; space for result
```

; MODULE SUB.ASM

```
extern SirFinal
global Concatenare
```

```
segment code use32 public code class='code'
```

```
; eax = address of the first array,
; ebx = address of the second array
```

Concatenare:

```
    mov edi, SirFinal ; destination = SirFinal
    mov esi, eax      ; source = first array
.sir1Loop:
    lodsb
    test al, al
    jz .sir2
    stosb
    jmp .sir1Loop ; next byte
; array terminator (=0)?
; if yes, go to second array
; (otherwise) copy in destination
; continue to nul
```

.sir2:

```
    mov esi, ebx      ; source = second array
.sir2Loop:
    lodsb
    test al, al
    jz .gata
    stosb
    jmp .sir2Loop ; same process for the new array
```

.gata:

```
    stosb
    ret ; add array terminator from al
```

# Techniques and tools

- Example of a multimodule program nasm + nasm
  - Necessary steps to build the final executable program
    - Assemble file main.asm
      - *nasm.exe -fobj main.asm*
    - Assemble file sub.asm
      - *nasm.exe -fobj sub.asm*
    - Edit links between the two modules
      - *alink.exe main.obj sub.obj -oPE -entry:start - subsys:console*
  - Notice: the two modules can be assembled in any order! Only at linkediting is necessary that the referred symbols to have all implementations available in one of the object files offered by the linker
  - Linkediting, of course, is possible only after assembly/compilation!

# Techniques and tools

- Static linkage at **linkediting**: nasm + high level languages
  - Requirements of the linkeditor
    - global directive to allow access to other languages to our labels
    - extern directive to allow access in NASM of resources implemented in other languages
    - Declaration of variables and subroutines written in NASM in high level languages
      - *Example C: extern declarator!*
  - Entering the procedure
  - Keeping register values unaltered
  - Transmission and accessing parameters
  - Space allocation for local data (optional)
  - Returning a result (optional)
- The last aspects are discussed in detail in the call convention section!
  - See interface with high level languages: call conventions

# Techniques and tools

- Example of a multimodule program asm + C

```
//  
// AFISARE.C  
  
// requests the C preprocessor to include file stdio.h  
// stdio.h declares the header (return type and parameters) of the C function printf  
#include <stdio.h>  
  
// we declare the function from the asm file so that the C compiler knows the type of the parameters and the return var  
// linkeditor will handle the function implementation, the compiler needs to know only the header  
void asm_start(void); //equivalent with extern void asm_start(void) ! Any function declared at the most  
exterior level  
                                // of a C module belongs to the extern memory class  
  
// print function called by asm code  
void afisare(int *vector, int numar_elemente) //any function defined at the most exterior level of a C module  
{  
    automatically exported  
    //is implicitly "global" – meaning it is  
    {  
        int index;  
        for (index = 0; index < numar_elemente; index++)  
        {  
            printf("%d", vector[index]);  
        }  
        printf("\n");  
    }  
  
    // main program, calls asm_start function written in assembly  
    void main(void) // here starts the execution of the final program  
    {  
        asm_start(); // we call the function from the asm file  
    }  
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```

# Techniques and tools

- Example of a multimodule program asm + C

```
; VECTOR.NASM
;

; inform the assembler on the existence of the printing function
extern _afisare           ; add _ as prefix to names from C!

; inform the assembler that we want asm_start to be available to other compiling units
global _asm_start           ; add _ as prefix to names referred by C!

; asm code is available in a public segment, and can be shared with an other extern code
segment code public code use32

_asm_start:
    push dword elemente ; parameter by value (write in stack value 5)
    push dword vector   ; vector given by reference (write in stack its address)
    call _afisare        ; call C function, again with prefix _
    add esp, 4*2         ; afisare is a C function (cdecl) -> we need to free arguments!
    ret                 ; back to C code that called this code

; the linkeditor can use the public data segment even for outside data
segment data public data use32
    vector dd 1, 2, 3, 4, 5      ; the vector we will print using the C routine
    elemente equ ($ - vector) / 4 ; constant equal to 5 (number of elements from the vector)
```

# Techniques and tools

- Example of a multimodule program asm + C
  - Why \_ ?
  - Build executable:
    1. Compile/assembly :
      - *afisare.c can be compiled with any C compiler (as desired) -> afisare.obj*
        - Visual C: `cl /c afisare.c`
        - `nasm.exe vector.asm -fwin32 -o vector.obj`
      - 2. Link-editing :
        - *Call any linkeditor compatible with C, using:*
          - Input: afişare.obj and vector.obj
          - Output: console application
        - `link vector.obj afisare.obj /OUT:afisare.exe /MACHINE:X86 /SUBSYSTEM:CONSOLE`
  - Alternatively, files can be bundled into one Visual Studio ‘solution’, configuring the IDE to:
    1. Assemble the asm file: specifying for example as **Pre-Build Event** the above assembly command (`nasm.exe vector.asm -fwin32 -o vector.obj`)
    2. Include afisare.obj as additional input to linkediting
    3. There are Visual Studio extensions that solve this automatically and transparently!



# Bitdefender® Awake.

## Multi-modules programming

**Marius Vanta**  
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# 3. Interfacing with high-level languages

# Interfacing with high-level languages

- Passing parameters by value (Call by value)
  - The values of data bytes are copied
  - Wasteful and slow when data take up a lot of memory!
  - From caller perspective, data is constant
- Passing parameters by reference (address(pointer)) (Call by reference)
  - The data address (and sometimes data size) is specified
  - Ineffective when data take up less memory space
    - additional 32 bits for address storage + need to read the pointer prior to data access
  - Data may undergo changes
- Call by value or call by reference decision
  - Performance criterion: data size in bytes
    - Is there any risk to exceed the available memory? Call by reference!
  - Accessibility criterion: Do data need to be changed?
    - Must data be constant? Call by value!

# Interfacing with high-level

## languages

### • Calling conventions

- How do we pass parameters to subroutines?
  - Which types of parameters can we pass?
  - In what order?
  - How many parameters? Any number of parameters?
- What resources are volatile (may be altered by the callee)?
- Where is the result stored?
- What cleanup actions are required after the call?
  - Who is responsible to make them?
- Conventions
  - Commonly used: **CDECL**, **STDCALL**
  - Less commonly used or obsolete: PASCAL, FORTRAN, SYSCALL, etc...

# Interfacing with high-level languages

- Calling conventions – C convention (**CDECL**)

- Specific to the C programming language
- How do we pass parameters to subroutines? By pushing them on the stack
  - Which types of parameters can we pass? Any type, but extended at least to DWORD
  - In what order? From right to the left, that is in the reverse order of declaration
  - How many parameters? Any? Yes, in C is allowed functions with any parameters (ex: printf)
- What resources are volatile? EAX, ECX, EDX, EFlags
- Where is the result stored? EAX, EDX:EAX or ST0 (FPU)
- What cleanup actions are required? Freeing up the arguments

Parameters			Volatile resources	Results	Cleanup
Storage	Order	Number			
Stack	Reverse	<u>Any</u>	EAX, ECX, EDX, EFlags	EAX / EDX:EAX / ST0 (FPU)	<u>Caller</u>

# Interfacing with high-level languages

- Calling conventions – **STDCALL** convention
  - Specific to Windows operating system
    - Also called **WINAPI**
    - Used by Windows system libraries
  - Very similar to the CDECL convention
    - Differences:
      - A fixed number of parameters*
      - The cleanup is performed by callee*

Parameters			Volatile resources	Results	Cleanup
Storage	Order	Number			
Stack	Reverse	<u>Fixed</u>	EAX, ECX, EDX, Flags*	EAX / EDX:EAX / ST0 (FPU)	<u>Callee</u>

# Interfacing with high-level languages

- Subroutine call

- Steps:
  1. **Call code**: call preparation and execution
  2. **Entry code**: procedure entry and preparation of execution
  3. **Exit code**: returning and freeing up out-of-date resources
- The actions depend by calling convention of called subroutine - but the steps remain the same!
- The steps are handled/implemented automatically in the code generated by compilers of high-level languages
  - In assembly language, everything is our responsibility!

# Interfacing with high-level languages

- Subroutine call - call code

- Tasks:
  1. Save the volatile resources in use: *push register*
  2. Assure the compliance with constraints (aligned ESP, DF=0, ...)
  3. Prepare the arguments (stack, by convention): *push*
  4. Call execution: *call*
    - *call subroutine* - if subroutine is statically linked
    - *call [subroutine]* - if subroutine is dynamically linked (at link-time)
    - *call register or call [variable]* - for run-time dynamic linking
- ASM subroutines used only from assembly language can avoid (for simplicity or efficiency) these tasks

# Interfacing with high-level languages

- Subroutine call - call code

- Example: call printf from asm to display digits from 0 to 9
- ```

import exit msvcrt.dll
import printf msvcrt.dll
extern exit, printf
global start

segment code use32
start:
    mov ecx, 10
    xor eax, eax
.next:
    push eax
    push ecx
    push eax
    push dword format_string
    call [printf]
    add esp, 2*4
    pop ecx
    pop eax
    inc eax
loop .next
push dword 0
call [exit]

segment data use32
format_string db "%d", 10, 13, 0

```
- If the call was made from C, the compiler would have generated by itself the call code!  
 But the call is made from assembly, so the call code must be written by us!

(1) Save the volatile resources

(2) DF=0, stack is aligned (only DWORDs were pushed)

(3) Prepare the arguments for CDECL call

(4) Call execution

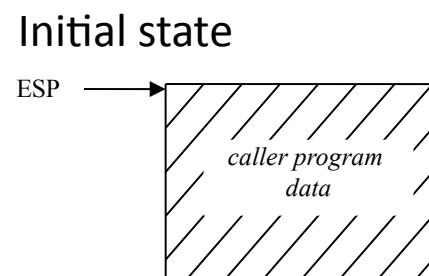
Recover the volatile resources (the caller)

## Communicating with high level languages

- Calling subroutines – call code
  - Effect of the call code on the stack

```
push eax  
push ecx
```

```
push eax  
push dword format_string  
call [printf]  
add esp, 2*4
```



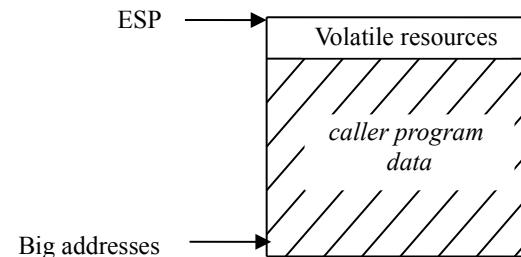
## Communicating with high level languages

- Calling subroutines – call code
  - Effect of the call code on the stack

```
push eax → (1) Saving volatile resources  
push ecx
```

```
push eax  
push dword  
format_string  
call [printf]  
add esp, 2*4
```

(1) Saving volatile resources



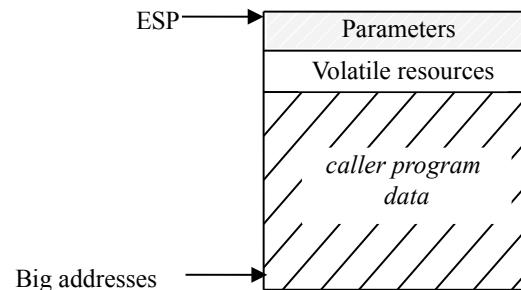
## Communicating with high level languages

- Calling subroutines – call code
  - Effect of the call code on the stack

```

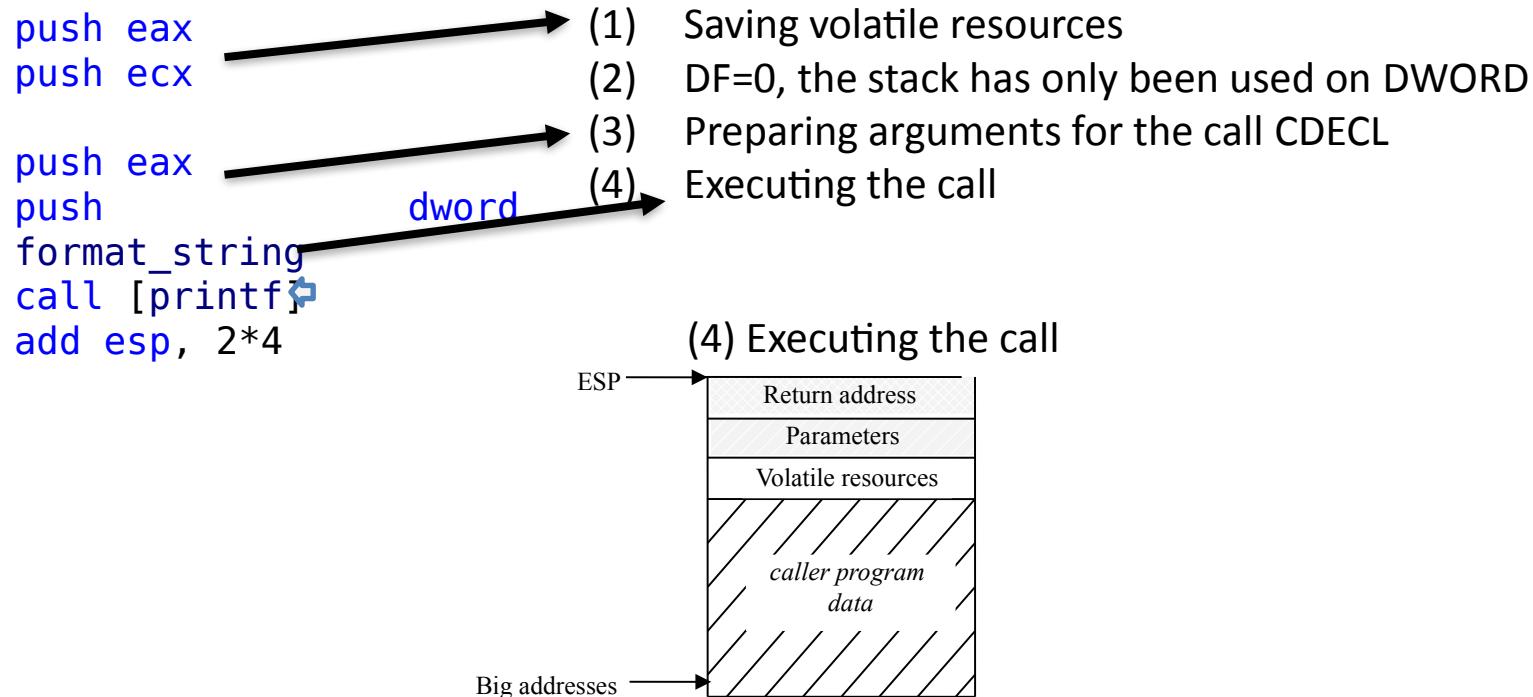
push eax          → (1) Saving volatile resources
push ecx          → (2) DF=0, the stack has only been used on DWORD
push eax          → (3) Preparing arguments for the call CDECL
push
      dword
format_string
call [printf]
add esp, 2*4
    
```

(3) Preparing arguments for the call CDECL



## Communicating with high level languages

- Calling subroutines – call code
  - Effect of the call code on the stack



# Communicating with high level languages



- Calling subroutines - entry code
  - Tasks:
    1. Configuring a **stack frame**: taking ebp or esp into account?
    2. Preparing local variables of the function: sub esp, nr\_bytes
    3. Saving a copy of the *non-volatile* resources that are modified: push register
      - *Any registers except the volatile ones*
  - Stack frame: data structure stored in the stack, of fixed dimension (for a given subroutine) and containing:
    - *The parameters prepared by the caller*
    - *Return address (to the instruction that follows the call instruction)*
    - *Copies of the non-volatile resources used by the subroutine*
    - *Local variables*
  - Asm subroutines used only from asm can avoid this tasks (for simplicity or efficiency)

# Communicating with high level languages



- Calling subroutines - entry code
  - Example: entry code to the function CDECL **chdir**, generated by the C compiler

; disassembled with IDA - **The Interactive Disassembler**  
; syntax corresponds to the MASM assembler  
; int \_\_cdecl chdir(const char \*)

chdir:

allows modification!

|      |                         |
|------|-------------------------|
| mov  | edi, edi ; useless, but |
| push | ebp                     |
| sub  | ebp, esp                |
|      | esp, 118h               |
| mov  | eax, __security_cookie  |
| xor  | eax, ebp                |
| mov  | [ebp+var_4], eax        |
| mov  | eax, [ebp+lpPathName]   |
| and  | [ebp+var_110], 0        |
| push | ebx                     |
| or   | ebx, 0xFFFFFFFF         |
| push | esi                     |

- (1) Configuring the stack frame  
(2) Local variables  
(3) Saving non-volatile registers

The entry code has been  
automatically generated by the  
compiler!

# Communicating with high level languages

## Calling subroutines – entry code



- Example: entry code to a function STDCALL written in asm by us

(1) Configuring the stack frame → push ebp  
(2) Local variables → mov ebp, esp ; define a stack frame with EBP pivot/reference  
(3) Saving non-volatile registers → sub esp, 4 ; allocate space on the stack for a temporary DWORD  
variable

```
factorial://in the caller C module we declare - extern int __stdcall factorial(int n)

int factorial (int n)
{ if (n==1) return 1;
  else
    return n * factorial (n-1);
}

factorial:
    push ebp
    mov ebp, esp
    sub esp, 4
    push ebx
    push eax, [ebp + 8]
    cmp eax, 2
    jae .recursiv
    mov eax, 1
    jmp .gata

.recursiv:
    push eax
    recursive call
    dec eax
    push eax
    call factorial
    mov [ebp - 4], eax
    pop eax
    mov ebx, [ebp - 4]
    variable
    mul ebx
    .gata:
    pop ebx
    add esp, 4
    pop ebp
    ret 4
```

; save ebx in order to restore it later  
; load the value of the argument from the stack frame  
; test the termination condition ( $n < 2$ )  
; return 1 when  $n < 2$   
; holding the value of  $n$  for not to be lost in the  
; call factorial( $n-1$ ), push  $n-1$  on the stack  
; recursive call (STDCALL)  
; save the value of factorial( $n-1$ ) in the temporary DWORD  
; restore the value of  $n$   
; ebx <- factorial( $n-1$ ), taken from the temporary  
; compute  $(edx:)eax = (EAX=)n * (EBX=)factorial(n-1)$   
; restore EBX to its initial value  
; free the memory where the temporary variable was stored  
; restore ebp to its initial value  
; STDCALL : return and free the memory where the parameters are

# Comunicating with high level languages subroutines - entry code

- Example: entry code to a function STDCALL written in asm - stackframe

```

factorial:
    push ebp ←
    mov ebp, esp      ; define a stack frame with EBP pivot/reference
    sub esp, 4        ; allocate space on the stack for a temporary DWORD
variable
    push ebx          ; save ebx in order to restore it later

    mov eax, [ebp + 8] ; load the value of the argument from the stack frame

    cmp eax, 2         ; test the termination condition (n < 2)
    jae .recursiv
    mov eax, 1          ; return 1 when n < 2
    jmp .gata

.recursiv:
    push eax          ; hold the value of n so that it is not lost in the
recursive call

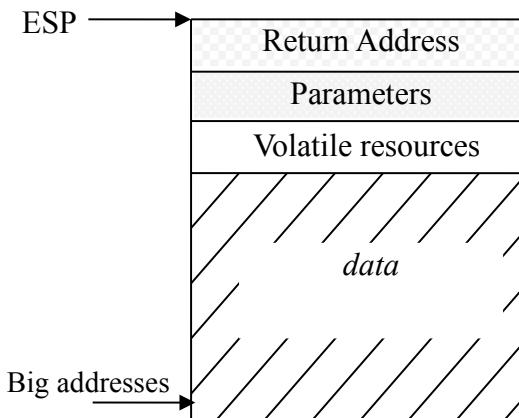
    dec eax
    push eax
    call factorial     ; call factorial(n-1), push n-1 on the stack
                        ; recursive call (STDCALL)

    mov [ebp - 4], eax ; save the value of factorial(n-1) in the temporary
DWWORD
    pop eax
    mov ebx, [ebp - 4] ; ebx <- factorial(n-1), taken from the temporary
variable
    mul ebx            ; compute (edx:)eax = (EAX=)n * (EBX=)factorial(n-1)

.gata:
    pop ebx
    ; restore EBX to its initial value
    ; for the next iteration

```

Entry state



# Communicating with high level languages

## Calling subroutines - entry code

- Example: entry code to a function STDCALL written in asm - stackframe

(1) Configuring the stack frame

```

factorial:
    push ebp
    mov ebp, esp          ; define a stack frame with EBP pivot/reference
    sub esp, 4             ; allocate space on the stack for a temporary DWORD
    push ebx              ; save ebx in order to restore it later
    mov eax, [ebp + 8]     ; load the value of the argument from the stack frame
    cmp eax, 2             ; test the termination condition (n < 2)
    jae .recursiv
    mov eax, 1             ; return 1 when n < 2
    jmp .gata

.recursiv:
    push eax              ; hold the value of n so that it is not lost in the
    recursive call         

    dec eax
    push eax
    call factorial          ; call factorial(n-1), push n-1 on the stack
    call factorial          ; recursive call (STDCALL)

    mov [ebp - 4], eax      ; save the value of factorial(n-1) in the temporary
    DWORD
    pop eax                ; restore the value of n
    mov ebx, [ebp - 4]       ; ebx <- factorial(n-1), taken from the temporary
    variable
    mul ebx                ; compute (edx:)eax = (EAX=)n * (EBX=)factorial(n-1)

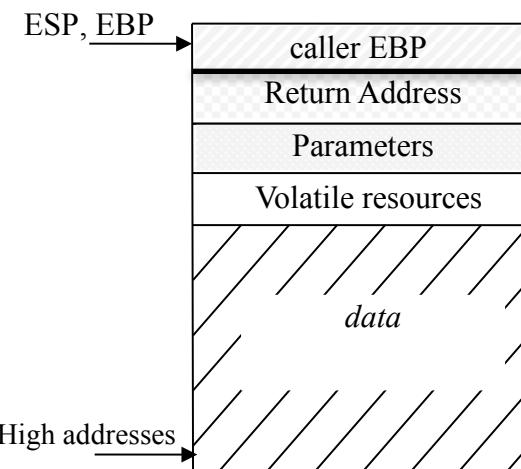
```

(1) Configuring the stack frame

```

.gata:
    pop ebx
    add esp, 4
    ; restore EBX to its initial value
    ; free the memory where the temporary variable was

```



# Comunicating with high level languages

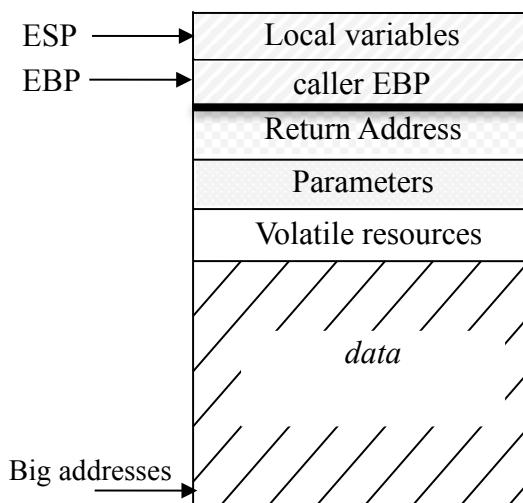
## Calling subroutines - entry code

- Example: entry code to a function STDCALL written in asm - stackframe

(1) Configuring the stack frame

(2) Local variables

(2) Local variables



```

factorial:
    push ebp
    mov ebp, esp
    sub esp, 4
    push ebx             ; save ebx in order to restore it later
    mov eax, [ebp + 8]   ; load the value of the argument from the stack frame
    cmp eax, 2           ; test the termination condition (n < 2)
    jae .recursiv
    mov eax, 1           ; return 1 when n < 2
    jmp .gata

.recursiv:
    push eax             ; stores the value of n for not being lost in the
    recursive call

    dec eax
    push eax
    call factorial        ; call factorial(n-1), push n-1 on the stack
                           ; recursive call (STDCALL)

    mov [ebp - 4], eax   ; save the value of factorial(n-1) in the temporary DWORD
    pop eax
    mov ebx, [ebp - 4]    ; ebx <- factorial(n-1), taken from the temporary
                           ; variable

    mul ebx              ; compute (edx:)eax = (EAX=)n * (EBX=)factorial(n-1)

.gata:
    pop ebx              ; restore EBX to its initial value
    add esp, 4            ; free the memory where the temporary variable was stored
  
```

# Communicating with high level languages

- Calling subroutines - entry code

- Example: entry code to a function STDCALL written in asm - stackframe

- (1) Stack frame configuration
- (2) Local variables
- (3) Saving Non-volatile registers

```
factorial:
    push ebp
    mov ebp, esp
    sub esp, 4
    variable
    push ebx
```

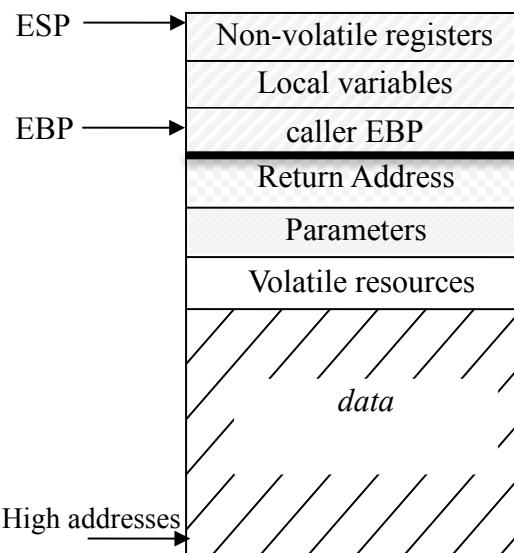
; define a stack frame with EBP pivot/reference  
; allocate space on the stack for a temporary DWORD

; save ebx in order to restore it later

```
    mov eax, [ebp + 8]
    cmp eax, 2
    jae .recursiv
    mov eax, 1
    jmp .gata
```

; load the value of the argument from the stack frame  
; test the termination condition ( $n < 2$ )  
; return 1 when  $n < 2$

## (3) Saving Non-volatile registers



.recursiv:  
push eax  
in the recursive call

; stores the value of n for not being lost

**ENTRY CODE IS GENERATED HERE FOR THE**

**NEXT RECURSIVE CALL !!**

```
dec eax
push eax
call factorial
```

; call factorial( $n-1$ ), push  $n-1$  on the stack  
; recursive call (STDCALL)

```
mov [ebp - 4], eax
pop eax
mov ebx, [ebp - 4]
mul ebx
```

; save the value of factorial( $n-1$ ) in the temporary DWORD  
; restore the value of n  
; ebx <- factorial( $n-1$ ), taken from the temporary variable  
; compute  $(edx:)eax = (EAX=)n * (EBX=)factorial(n-1)$

```
.gata:
pop ebx
add esp, 4
pop ebp
ret 4
stord
```

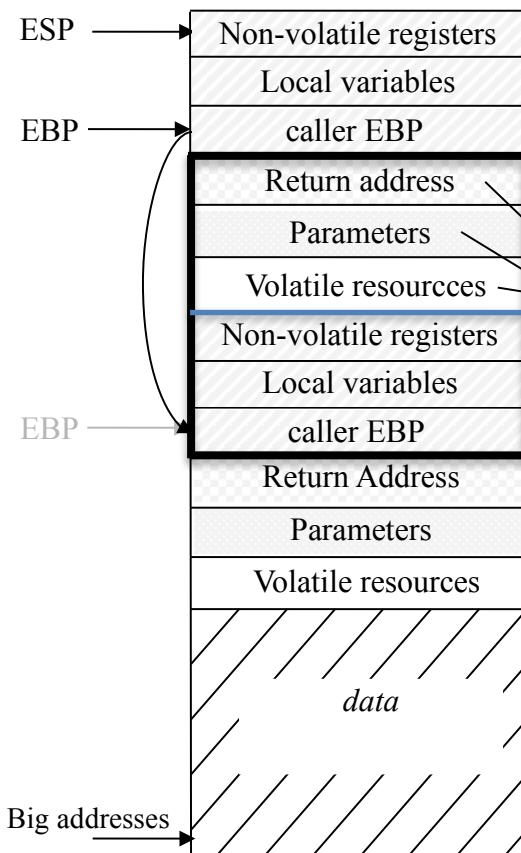
; restore EBX to its initial value  
; free the memory where the temporary variable was stored  
; restore ebp to its initial value  
; STDCALL: return and free the memory where the parameters are stored

# Communicating with high level languages

- Calling subroutines - entry code

- Example: entry code to a function STDCALL written in asm - stackframe

## Stack evolution to recursive call



```

factorial:
    push ebp
    mov ebp, esp
    sub esp, 4
    ; define a stack frame with EBP pivot/reference
    ; allocate space on the stack for a temporary DWORD

variable
    push ebx
    ; save ebx in order to restore it later

    mov eax, [ebp + 8] ← ; load the value of the argument from the stack frame

    cmp eax, 2
    jae .recursiv
    mov eax, 1
    jmp .gata
    ; test the termination condition (n < 2)
    ; return 1 when n < 2

.recursiv:
    push eax
    ; holding the value of n for not to be lost in the

    recursive call ← ; NEXT RECURSIVE CALL !!
    dec eax
    push eax
    call factorial ← ; call factorial(n-1), push n-1 on the stack
    ; recursive call (STDCALL)

    mov [ebp - 4], eax ; save the value of factorial(n-1) in the temporary DWORD
    pop eax
    mov ebx, [ebp - 4]
    mul ebx
    ; restore the value of n
    ; ebx <- factorial(n-1), taken from the temporary variable
    ; compute (edx:)eax = (EAX=)n * (EBX=)factorial(n-1)

.gata:
    pop ebx
    add esp, 4
    pop ebp
    ret 4
    ; restore EBX to its initial value
    ; free the memory where the temporary variable was stored
    ; restore ebp to its initial value
    ; STDCALL: return and free the memory for the stored

```

**ENTRY CODE IS GENERATED HERE FOR THE**

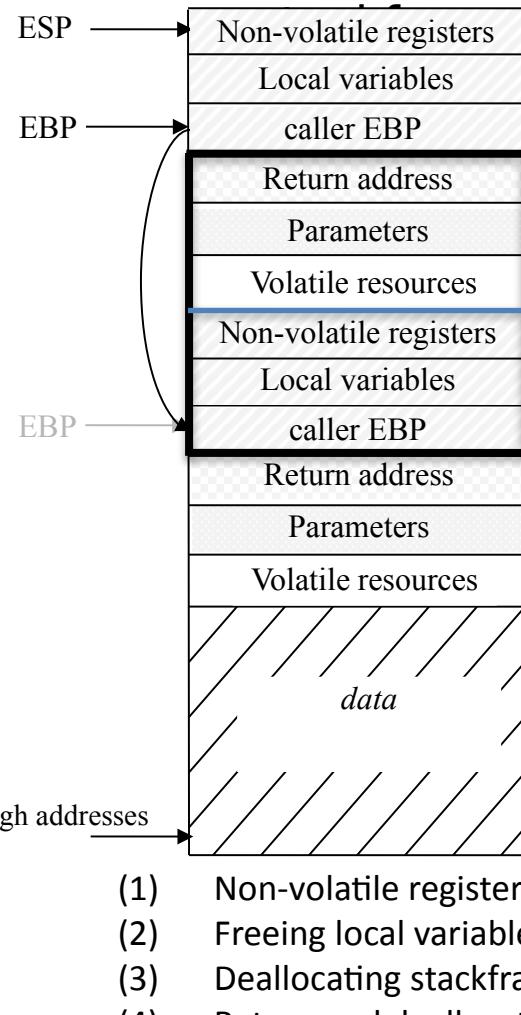
# Communicating with high level languages

- Calling subroutines - exit code
  - Tasks:
    1. Restore altered non-volatile resource
    2. Release the local variables of the function
    3. Deallocating the stack frame
    4. Returning from the function and releasing arguments
      - *CDECL:*
        - Called subroutine: *ret*
        - Calling procedure: *add esp, size\_of\_arguments*
      - *STDCALL:*
        - *ret size\_of\_arguments*
  - Except for the volatile resources and direct results of the function, **the status of the program after these steps must reflect the initial, pre-call state!**

# Communicating with high level languages

- Calling subroutines - exit code

- Example: exit code from a STDCALL asm function (recursive call) -



```

factorial:
    push ebp
    mov ebp, esp
    sub esp, 4
; define a stack frame with EBP pivot/reference
; allocate space on the stack for a temporary DWORD

variable
    push ebx
; save ebx in order to restore it later

    mov eax, [ebp + 8] ; load the value of the argument from the stack frame

    cmp eax, 2
    jae .recursiv
    mov eax, 1
    jmp .gata
; test the termination condition (n < 2)
; return 1 when n < 2

.recursiv:
    push eax
; holding the value of n for not to be lost in the
; recursive call

    dec eax
    push eax
    call factorial
; call factorial(n-1), push n-1 on the stack
; recursive call (STDCALL)

    mov [ebp - 4], eax
    pop eax
    mov ebx, [ebp - 4]
    mul ebx
; save the value of factorial(n-1) in the temporary DWORD
; restore the value of n
; ebx <- factorial(n-1), taken from the temporary variable
; compute (edx:)eax = (EAX=)n * (EBX=)factorial(n-1)

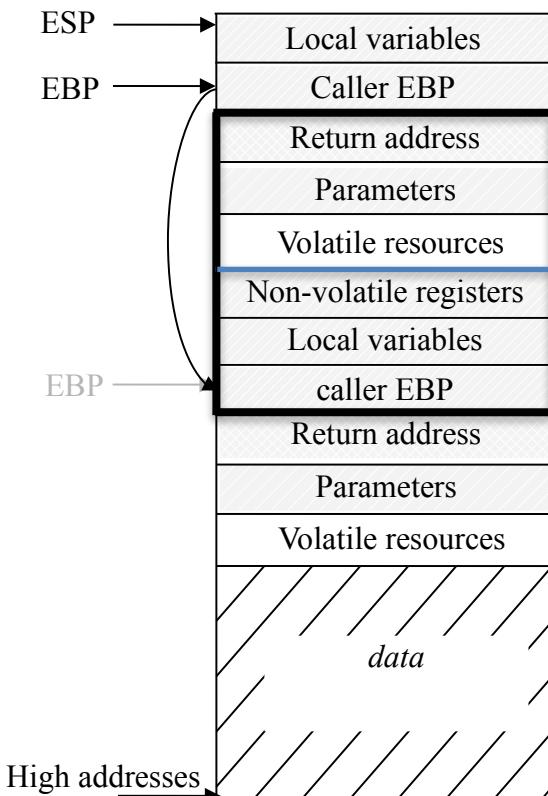
.gata:
    pop ebx
    add esp, 4
    pop ebp
    ret 4
; restore EBX to its initial value
; free the memory where the temporary variable was stored
; restore ebp to its initial value
; STDCALL: return and free the memory where the parameters are
; stored

```

# Interfacing with high-level languages

- Calling subroutines - exit code

- Example: exit code from a STDCALL asm function (recursive call) - stackframe



(1) Non-volatile registers

```

factorial:
    push ebp
    mov ebp, esp
    sub esp, 4
; define a stack frame with EBP pivot/reference
; allocate space on the stack for a temporary DWORD

variable
    push ebx
; save ebx in order to restore it later

    mov eax, [ebp + 8] ; load the value of the argument from the stack frame

    cmp eax, 2
    jae .recursiv
    mov eax, 1
; test the termination condition (n < 2)
; return 1 when n < 2

    jmp .gata

.recursiv:
    push eax
; holding the value of n for not to be lost
in the recursive call

    dec eax
    push eax
    call factorial
; call factorial(n-1), push n-1 on the stack
; recursive call (STDCALL)

    mov [ebp - 4], eax
    pop eax
    mov ebx, [ebp - 4]
    mul ebx
; save the value of factorial(n-1) in the temporary DWORD
; restore the value of n
; ebx <- factorial(n-1), taken from the temporary variable
; compute (edx:)eax = (EAX=)n * (EBX=)factorial(n-1)

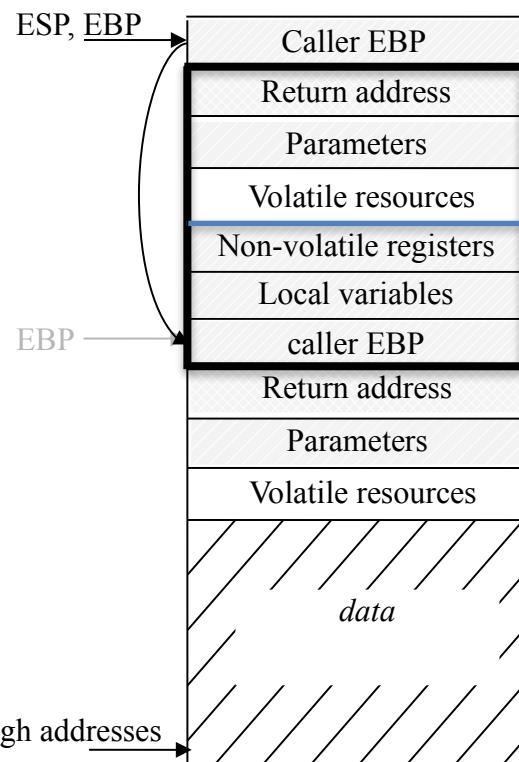
.gata:
    pop ebx
    add esp, 4
    pop ebp
    ret 4
; restore EBX to its initial value
; free the memory where the temporary variable was stored
; restore ebp to its initial value
; STDCALL: return and free the memory where the parameters are
stored

```

# Interfacing with high-level languages

- Calling subroutines - exit code

- Example: exit code from a STDCALL asm function (recursive call) - stackframe



(2) Freeing local variables

```

factorial:
    push ebp
    mov ebp, esp      ; define a stack frame with EBP pivot/reference
    sub esp, 4        ; allocate space on the stack for a temporary DWORD
variable
    push ebx          ; save ebx in order to restore it later
    mov eax, [ebp + 8] ; load the value of the argument from the stack frame
    cmp eax, 2        ; test the termination condition (n < 2)
    jae .recursiv
    mov eax, 1        ; return 1 when n < 2
    jmp .gata

.recursiv:
    push eax          ; holding the value of n for not to be lost in the
    recursive call

    dec eax
    push eax
    call factorial    ; call factorial(n-1), push n-1 on the stack
                      ; recursive call (STDCALL)

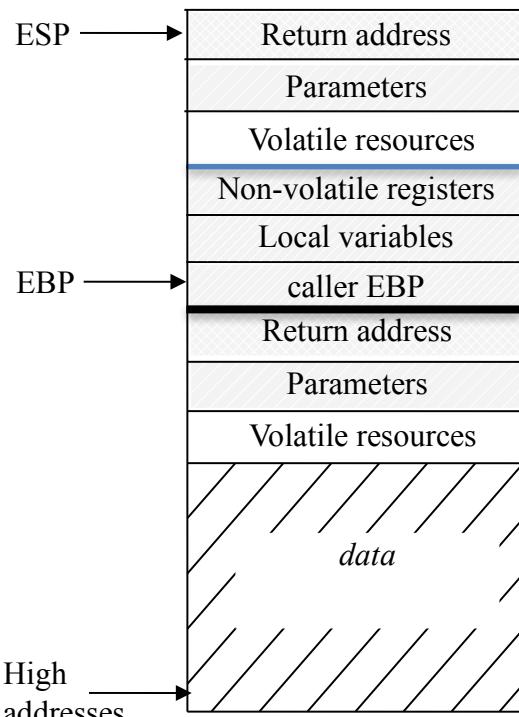
    mov [ebp - 4], eax ; save the value of factorial(n-1) in the temporary DWORD
    pop eax
    mov ebx, [ebp - 4] ; ebx <- factorial(n-1), taken from the temporary
variable
    mul ebx           ; compute (edx:)eax = (EAX=)n * (EBX=)factorial(n-1)

.gata:
    pop ebx           ; restore EBX to its initial value
    add esp, 4         ; free the memory where the temporary variable was stored
    pop ebp           ; restore ebp to its initial value

```

# Interfacing with High Level Languages

- Calling subprograms - exit code
  - Example: asm exit code from a STDCALL function (recursive call) - stackframe



(3) Deallocating stackframe

```

factorial:
    push ebp
    mov ebp, esp      ; define a stackframe with EBP as pivot/reference
    sub esp, 4        ; reserve space on the stack for a temporary DWORD variable
    push ebx          ; save EBX so we can restore its value

    mov eax, [ebp + 8] ; load the value of the argument from the stackframe

    cmp eax, 2        ; check the terminating condition (n < 2)
    jae .recursive
    mov eax, 1        ; return 1 when n < 2
    jmp .finish

.recursive:
    push eax          ; holding the value of n for not to be lost in the recursive
    call factorial

    dec eax
    push eax
    call factorial    ; call factorial(n-1), save on the stack the value of n-1
                      ; recursive call (STDCALL)

    mov [ebp - 4], eax ; save in the temporary DWORD variable the value of
.factorial(n-1)      ; factorial(n-1)
    pop eax
    mov ebx, [ebp - 4] ; restore the value of n
                      ; ebx <- factorial(n-1), taken from the temporary DWORD
variable
    mul ebx            ; compute (edx:)eax = (EAX=)n * (EBX=)factorial(n-1)

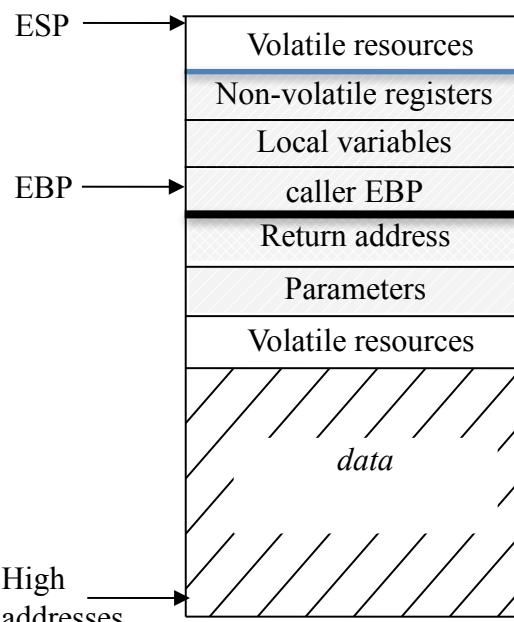
.finish:
    pop ebx            ; restore EBX to its initial value
    add esp, 4          ; free the memory occupied by the temporary variable
    pop ebp            ; restore EBP to its initial value
    ret 4              ; STDCALL: return and free the reserved memory
  
```

# Interfacing with High Level Languages



## • Calling subprograms - exit code

- Example: asm exit code from a STDCALL function (recursive call) - stackframe



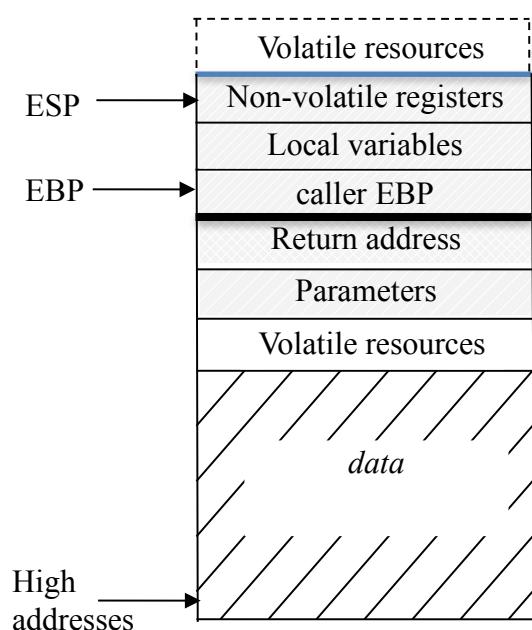
```
factorial:  
    push ebp  
    mov ebp, esp      ; define a stackframe with EBP as pivot/reference  
    sub esp, 4        ; reserve space on the stack for a temporary DWORD variable  
    push ebx          ; save EBX so we can restore its value  
  
    mov eax, [ebp + 8] ; load the value of the argument from the stackframe  
  
    cmp eax, 2        ; check the terminating condition (n < 2)  
    jae .recursive  
    mov eax, 1        ; return 1 when n < 2  
    jmp .finish  
  
.recursive:  
    push eax          ; holding the value of n for not to be lost in the recursive  
    call factorial  
  
    dec eax  
    push eax  
    call factorial    ; call factorial(n-1), save on the stack the value of n-1  
    ; recursive call (STDCALL)  
  
    mov [ebp - 4], eax ; save in the temporary DWORD variable the value of  
factorial(n-1)           ; factorial(n-1)  
    pop eax            ; restore the value of n  
    mov ebx, [ebp - 4]  ; ebx <- factorial(n-1), taken from the temporary DWORD  
variable  
    mul ebx            ; compute (edx:)eax = (EAX=)n * (EBX=)factorial(n-1)  
  
.finish:  
    pop ebx  
    add esp, 4         ; restore EBX to its initial value  
    pop ebp            ; free the memory occupied by the temporary variable  
    ret 4              ; restore EBP to its initial value  
                      ; STDCALL: return and free the reserved memory
```

(4) Return and deallocating params

# Interfacing with High Level Languages

## • Calling subprograms - exit code

- Example: asm exit code from a STDCALL function (recursive call) - stackframe



```

factorial:
    push ebp
    mov ebp, esp           ; define a stackframe with EBP as pivot/reference
    sub esp, 4              ; reserve space on the stack for a temporary DWORD variable
    push ebx               ; save EBX so we can restore its value

    mov eax, [ebp + 8]      ; load the value of the argument from the stackframe

    cmp eax, 2              ; check the terminating condition (n < 2)
    jae .recursive
    mov eax, 1              ; return 1 when n < 2
    jmp .finish

.recursive:
    push eax               ; holding the value of n for not to be lost in the recursive
    call factorial          ; call factorial(n-1), save on the stack the value of n-1
                            ; recursive call (STDCALL)

    mov [ebp - 4], eax      ; save in the temporary DWORD variable the value of n-1
    factorial(n-1)          ; factorial(n-1) ←
    pop eax                ; restore the value of n
    mov ebx, [ebp - 4]       ; ebx <- factorial(n-1), taken from the temporary DWORD
                            ; variable
    mul ebx                ; compute (edx:)eax = (EAX=)n * (EBX=)factorial(n-1)

.finish:
    pop ebx                ; restore EBX to its initial value
    add esp, 4              ; free the memory occupied by the temporary variable
    pop ebp                ; restore EBP to its initial value
    ret 4                  ; STDCALL: return and free the reserved memory

```

# Interfacing with High Level Languages

## Calling subprograms - exit code

- Example: asm exit code from a STDCALL function (recursive call) - stackframe

```

factorial:
    push ebp
    mov ebp, esp      ; define a stackframe with EBP as pivot/reference
    sub esp, 4        ; reserve space on the stack for a temporary DWORD variable
    push ebx          ; save EBX so we can restore its value

    mov eax, [ebp + 8] ; load the value of the argument from the stackframe

    cmp eax, 2        ; check the terminating condition (n < 2)
    jae .recursive
    mov eax, 1        ; return 1 when n < 2
    jmp .finish

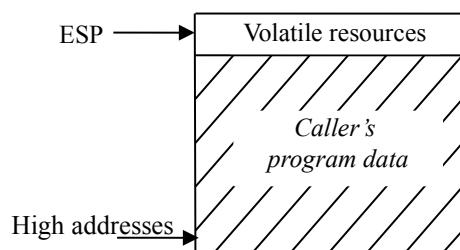
.recursive:
    push eax          ; retain the value of n so we don't lose it in the recursive
call

    dec eax
    push eax          ; call factorial(n-1), save on the stack the value of
                     ; factorial(n-1)
    call factorial    ; recursive call (STDCALL)

    mov [ebp - 4], eax ; save in the temporary variable the value of
                     ; factorial(n-1)
    pop eax
    mov ebx, [ebp - 4] ; ebx <- factorial(n-1), taken from the temporary
                     ; DWORD var
    mul ebx           ; compute (edx:)eax = (EAX=)n * (EBX=)factorial(n-1)

.finish:
    pop ebx            ; restore EBX to its initial value
    add esp, 4          ; free the memory occupied by the temporary variable
    pop ebp            ; restore EBP to its initial value

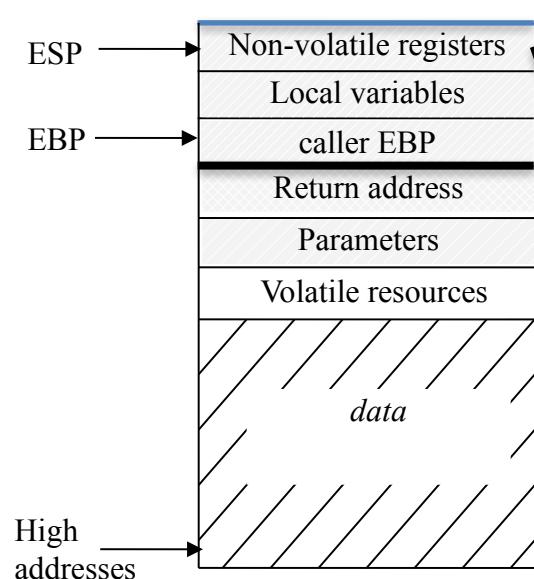
```



# Interfacing with High Level Languages

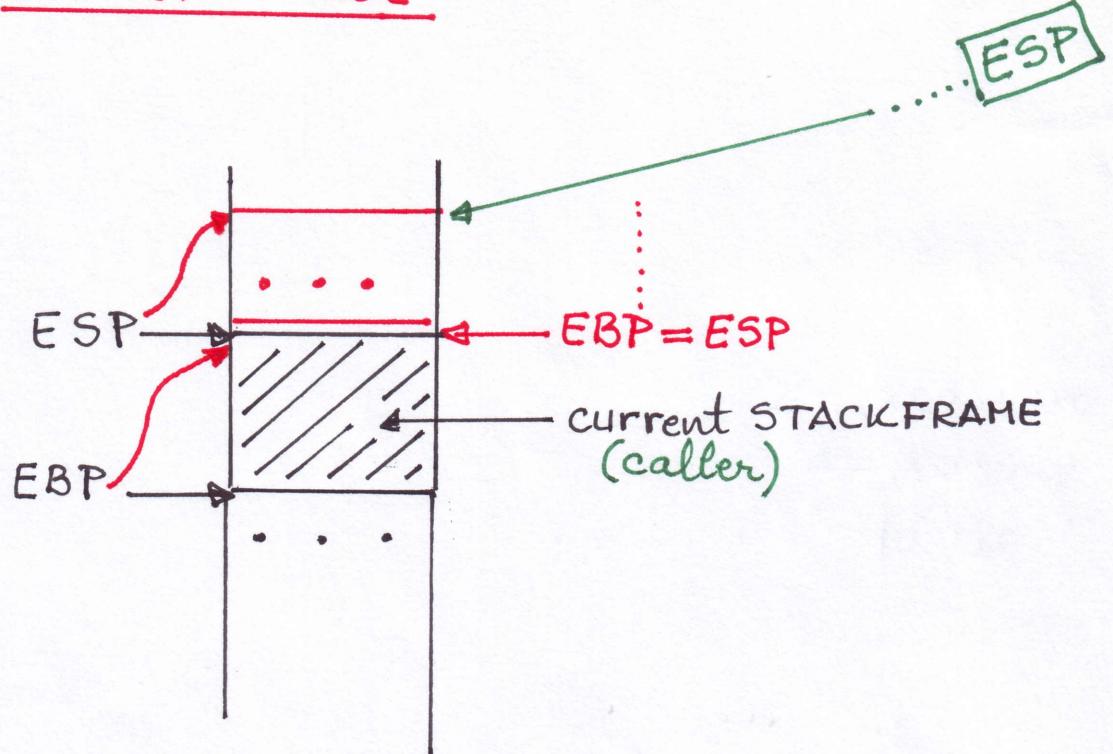


- Calling subprograms - exit code
  - Example: asm exit code from a STDCALL function (recursive call) - stackframe



```
factorial:  
    push ebp  
    mov ebp, esp      ; define a stackframe with EBP as pivot/reference  
    sub esp, 4        ; reserve space on the stack for a temporary DWORD variable  
    push ebx          ; save EBX so we can restore its value  
  
    mov eax, [ebp + 8] ; load the value of the argument from the stackframe  
  
    cmp eax, 2        ; check the terminating condition (n < 2)  
    jae .recursive  
    mov eax, 1        ; return 1 when n < 2  
    jmp .finish  
  
.recursive:  
    push eax          ; holding the value of n for not to be lost in the recursive  
    call factorial  
  
    dec eax  
    push eax  
    call factorial    ; call factorial(n-1), save on the stack the value of n-1  
    ; recursive call (STDCALL)  
  
    mov [ebp - 4], eax ; save in the temporary DWORD variable the value of  
factorial(n-1)  
    pop eax           ; restore the value of n  
    mov ebx, [ebp - 4] ; ebx <- factorial(n-1), taken from the temporary DWORD  
variable  
    mul ebx           ; compute (edx:)eax = (EAX=)n * (EBX=)factorial(n-1)  
  
.finish:  
    pop ebx  
    add esp, 4        ; restore EBX to its initial value  
    ; free the memory occupied by the temporary variable  
    pop ebp          ; restore EBP to its initial value  
    ret 4             ; STDCALL: return and free the reserved memory
```

## ENTRY PHASE



- involves the creation of a NEW STACKFRAME for the CALLED subroutine:

push EBP ; for restoring the base of the CURRENT STACKFRAME when returning

MOV EBP,ESP ; This is the BIRTH of the NEW STACKFRAME (sizeof initial = 0)  
... - - - - - [ESP] will start to "grow" by currently performed PUSHES