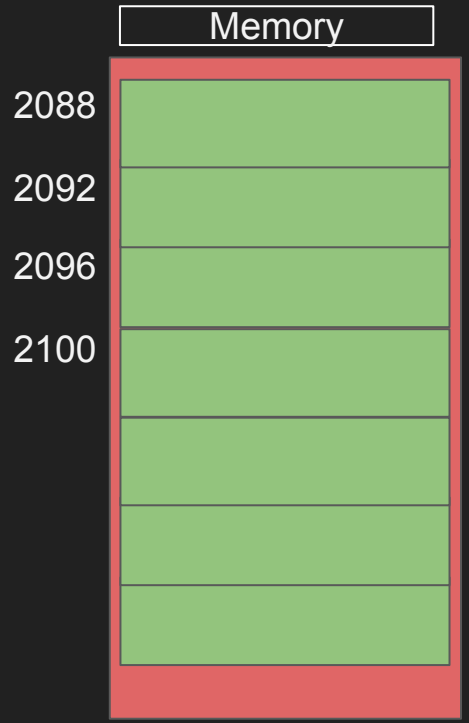
Introduction to 8086 Assembly

Lecture 16

Implementing Arrays

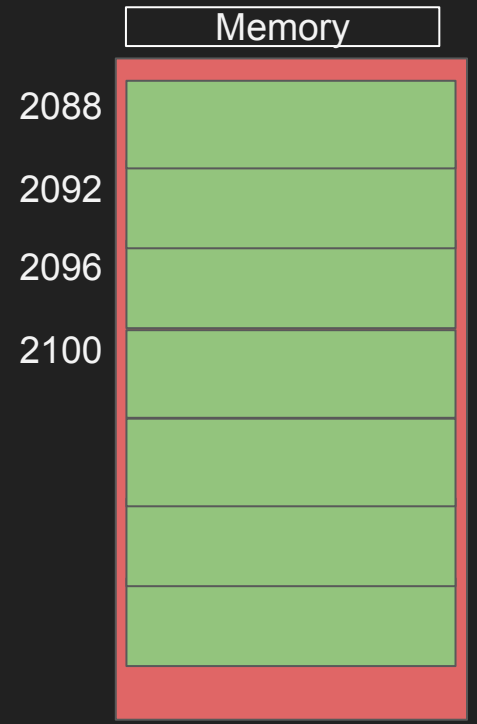
Arrays

- A list of elements all of same size (and type)
- Accessing array element `a[i]`



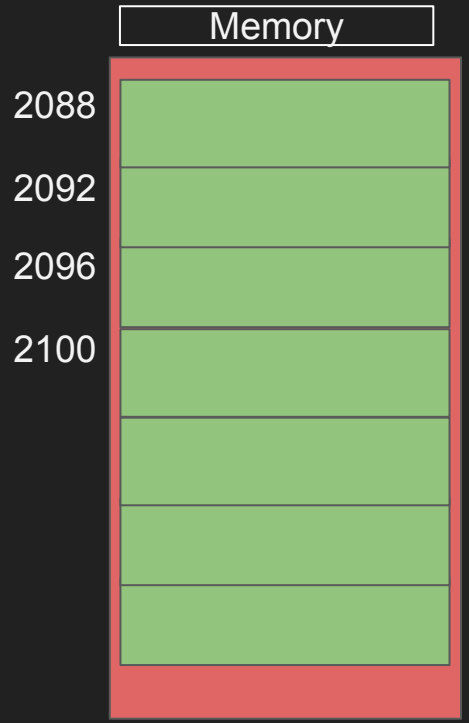
Arrays

- A list of elements all of same size (and type)
- Accessing array element `a[i]`
  - **starting address in memory**
  - **element size**
  - **index**
  - **index of first element** (0 or 1?)
  - **no. of elements (array size)?**



Defining arrays

- Define arrays
  - In data segment (e.g. global arrays)
    - absolute address (global label)
  - In stack (e.g. local arrays)
    - relative address (relative to esp or ebp)



Global labels

```
segment .data

arr1:   db    1,3,6,10, 15, 21, 28
arr2:   dw    0, 0, 0, 0, 0, 0
arr3:   dd    10, 100, 1000, 10000, 100000
arr4:   times 64 dd 20

segment .bss

arr5:   resb  100
arr6:   resw  200
arr7:   resd  50
arr8:   resq  400
```

start address: `arr1`
element size: 1 byte
array size: 7 elements (7 bytes)

start address: `arr2`
element size: 2 bytes
array size: 6 elements (12 bytes)

start address: `arr3`
element size: 4 bytes
array size: 5 elements (20 bytes)

start address: `arr4`
element size: 4 bytes
array size: 64 elements (256 bytes)

start address: `arr8`
element size: 8 bytes
array size: 400 elements (3200 bytes)

Arrays on stack (as local variable)


```
func:
    push ebp
    mov  ebp, esp

    ;; just a single
    ;; local variable (array)
    sub esp, 400
```

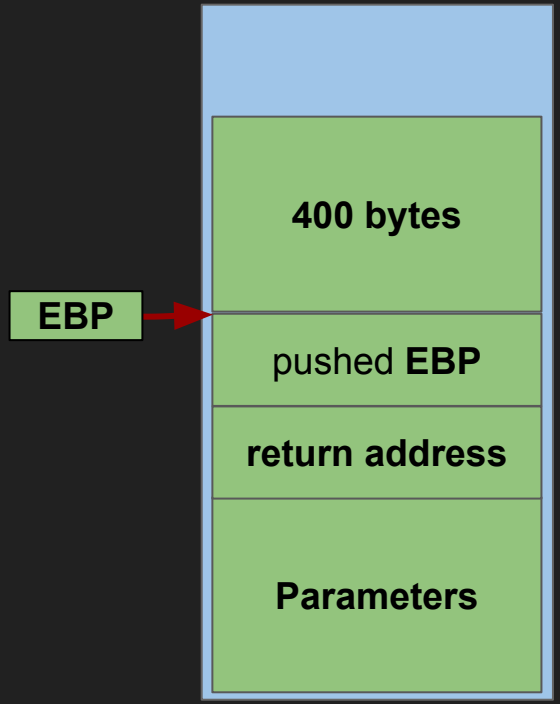
start address: ebp-400
element size: 1 byte
array size: 400 elements

OR

start address: ebp-400
element size: 2 bytes
array size: 200 elements

OR

start address: ebp-400
element size: 4 bytes
array size: 100 elements



Access array elements

- Use indirect addressing

```
segment .data

arr1:   db   1,3,6,10, 15, 21, 28
arr2:   dw   0, 0, 0, 0, 0, 0
arr3:   dd   10, 100, 1000, 10000, 100000
arr4:   times 64 dd 20

segment .bss

arr5:   resb  100
arr6:   resw  200
arr7:   resd  50
arr8:   resq  400
```

```
mov al, [arr1+3]

mov ax, [arr2+2]

mov eax, [arr3+8]

mov eax, [arr3+3]

mov ecx, 12

mov dword [arr7+ecx], -200
```

Access array elements


```
segment .data

array1: dd   1, 2, 4, 8, 16, 32

segment .text
        global asm_main
        extern print_int, print_nl

asm_main:
        pusha

        mov ecx, 6 ; array size
        mov ebx, 0
loop1:
        mov eax, [array1+ebx]
        call print_int
        call print_nl

        add ebx, 4
        loop loop1


        popa
        ret
```

array2.asm

Access array elements


```
segment .data

array1: dd   1, 2, 4, 8, 16, 32

segment .text
        global asm_main
        extern print_int, print_nl

asm_main:
        pusha

        mov ecx, 6 ; array size
        mov ebx, 0
loop1:
        mov eax, [array1+ebx]
        call print_int
        call print_nl

        add ebx, 4
        loop loop1


        popa
        ret
```

array2.asm

```
segment .data

array1: dd   1, 2, 4, 8, 16, 32

segment .text
        global asm_main
        extern print_int, print_nl

asm_main:
        pusha

        mov ecx, 6 ; array size
        mov ebx, array1
loop1:
        mov eax, [ebx]
        call print_int
        call print_nl

        add ebx, 4
        loop loop1

        popa
        ret
```

array3.asm

Exercise

- Write a function to print an array of double word integers.

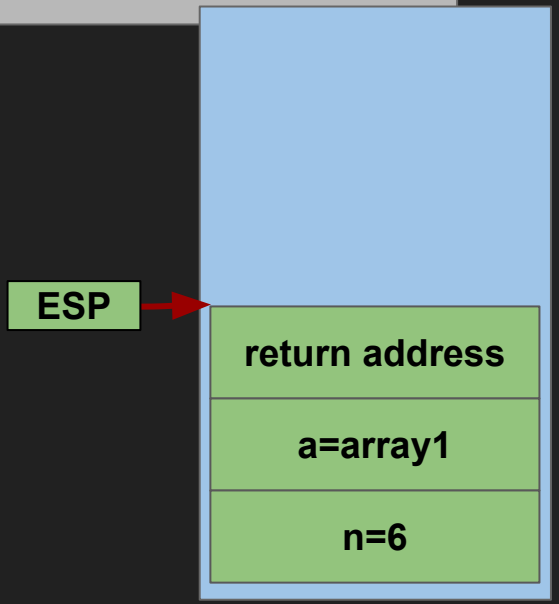
```
void printArray(const int a[], int n) {
  for (int i = 0; i < n; i++)
    printf("%d, ", a[i]);
  putchar('\n');
}
```

array4.asm

```
%include "asm_io.inc"

segment .data

array1: dd   1, 2, 4, 8, 16, 32

segment .text
        global asm_main

asm_main:
        pusha

        push 6
        push array1
        call printArray

        popa
        ret
```

Exercise

```
void printArray(const int a[], int n) {
  for (int i = 0; i < n; i++)
    printf("%d, ", a[i]);
  putchar('\n');
}
```



array4.asm

```
%include "asm_io.inc"

segment .data

array1: dd   1, 2, 4, 8, 16, 32

segment .text
        global asm_main

asm_main:
        pusha

        push 6
        push array1
        call printArray

        popa
        ret
```

Exercise

```
; printArray(int ARRAY[], int SIZE)
%define ARRAY  [ebp+8]
%define SIZE   [ebp+12]

printArray:
        push ebp
        mov ebp, esp

        mov ebx, ARRAY
        mov ecx, SIZE
loop1:
        mov eax, [ebx]
        call print_int
        mov al, ','
        call print_char
        mov al, ' '
        call print_char

        add ebx, 4
        loop loop1

        mov  al, 10
        call print_char

        mov esp, ebp
        pop ebp
        ret 8
```

array4.asm

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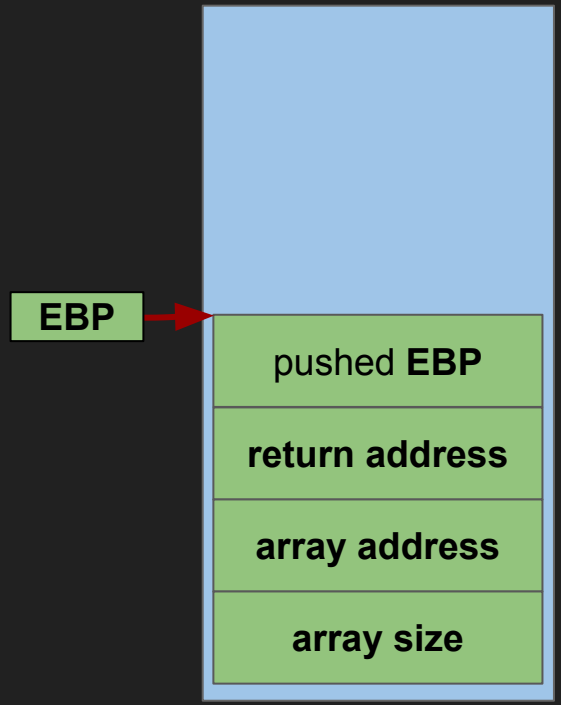

Advanced indirect addressing


```
mov eax, [ecx]

mov eax, [ecx + constant]

mov eax, [4 * ecx + constant]

mov eax, [ ebx + 4 * ecx + constant]
```

Advanced indirect addressing

Intel Syntax	AT&T Syntax
mov eax, [ecx]	mov (%ecx), %eax
mov eax, [ecx + const]	mov const(%ecx), %eax
mov eax, [4 * ecx + const]	mov const(,%ecx,4), %eax
mov eax, [ebx + 4 * ecx + const]	mov const(%ebx,%ecx,4), %eax

Advanced indirect addressing

Intel Syntax	AT&T Syntax
mov eax, [ecx]	mov (%ecx), %eax
mov eax, [ecx + const]	mov const(%ecx), %eax
mov eax, [4 * ecx + const]	mov const(,%ecx,4), %eax
mov eax, [ebx + 4 * ecx + const]	mov const(%ebx,%ecx,4), %eax

MYMOV eax, ebx, ecx, 4, const

Advanced indirect addressing


```
[ base-reg + scale * index-reg + constant ]
```

scale: 1,2,4,8

base-reg: EAX, EBX, ECX, EDX, EBP, ESP, ESI, EDI

index-reg: EAX, EBX, ECX, EDX, EBP, ESI, EDI (not ESP)

constant: label or integer (positive/negative)

Advanced indirect addressing


```
[ base-reg + scale * index-reg + constant ]
```

effective address

scale: 1,2,4,8

base-reg: EAX, EBX, ECX, EDX, EBP, ESP, ESI, EDI

index-reg: EAX, EBX, ECX, EDX, EBP, ESI, EDI (not ESP)

constant: label or integer (positive/negative)

Advanced indirect addressing


```
Intel Syntax: [base-reg + scale*index-reg + constant]

AT&T Syntax: constant(base-reg, index-reg , scale)
```

scale: 1,2,4,8

base-reg: EAX, EBX, ECX, EDX, EBP, ESP, ESI, EDI

index-reg: EAX, EBX, ECX, EDX, EBP, ESI, EDI (not ESP)

constant: label or integer (positive/negative)

Advanced indirect addressing

array3.asm

```
segment .data

array1: dd   1, 2, 4, 8, 16, 32

segment .text
        global asm_main
        extern print_int, print_nl

asm_main:
        pusha

        mov ecx, 6   ; array size
        mov ebx, 0
loop1:
        mov eax, [ebx+array1]
        call print_int
        call print_nl

        add ebx, 4
        loop loop1

        popa
        ret
```

array5.asm

```
segment .data

array1: dd   1, 2, 4, 8, 16, 32

segment .text
        global asm_main
        extern print_int, print_nl

asm_main:
        pusha

        mov ecx, 6   ; array size
        mov ebx, 0
loop1:
        mov eax, [4*ebx+array1]
        call print_int
        call print_nl

        inc  ebx
        loop loop1

        popa
        ret
```

local variables/arrays


```
void myfunc() {
  int k;
  int j;
  int a[100];

  for (int i = 0; i < 100; i++) {
    a[i] = i*i;
  }

  printArray(a,100);
}
```

local variables/arrays


```
void myfunc() {
  int k;
  int j;
  int a[100];

  for (int i = 0; i < 100; i++) {
    a[i] = i*i;
  }

  printArray(a,100);
}
```

```
myfunc:
        push ebp
        mov  ebp, esp
        sub  esp, 4+4+100*4




        mov esp, ebp
        pop ebp
        ret
```

local variables/arrays


```
void myfunc() {
  int k;
  int j;
  int a[100];

  for (int i = 0; i < 100; i++) {
    a[i] = i*i;
  }

  printArray(a,100);
}
```

```
myfunc:
        push ebp
        mov  ebp, esp
        sub  esp, 4+4+100*4
                  immediate




        mov esp, ebp
        pop ebp
        ret
```

local variables/arrays


```
void myfunc() {
  int k;
  int j;
  int a[100];

  for (int i = 0; i < 100; i++) {
    a[i] = i*i;
  }

  printArray(a,100);
}
```

```
myfunc:
        push ebp
        mov  ebp, esp
        sub  esp, 4+4+100*4

                  immediate
                  (evaluated at
                  assemble time)

        mov esp, ebp
        pop ebp
        ret
```

local variables/arrays

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```
void myfunc() {
  int k;
  int j;
  int a[100];

  for (int i = 0; i < 100; i++) {
    a[i] = i*i;
  }

  printArray(a,100);
}
```

array6.asm

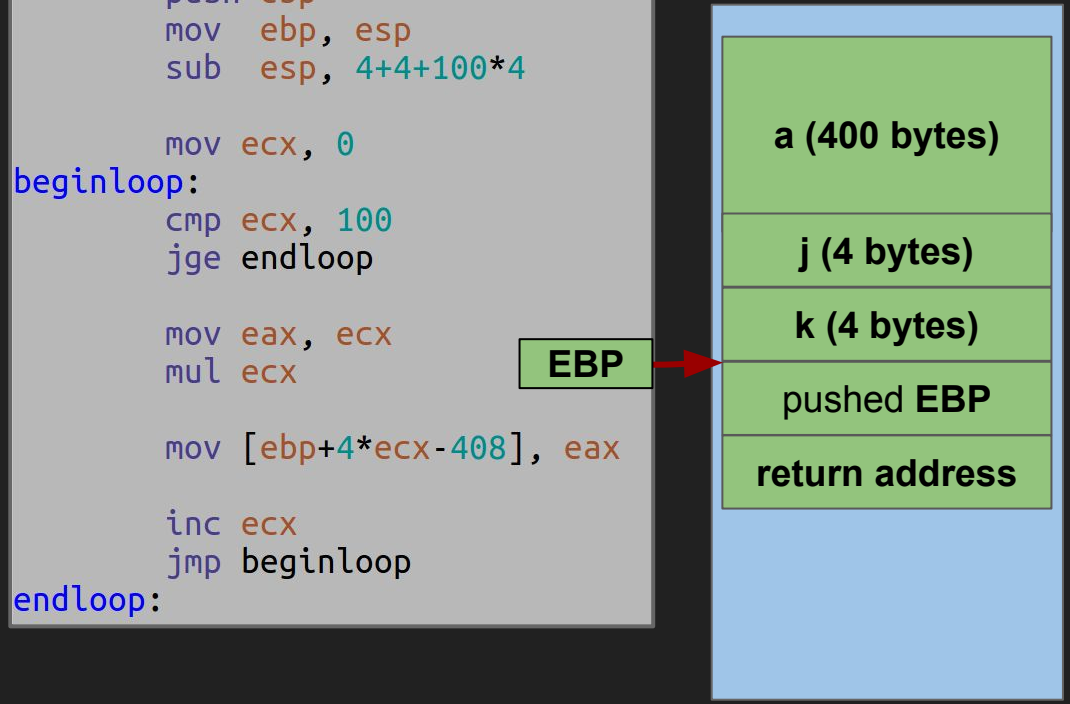
```
myfunc:
        push ebp
        mov  ebp, esp
        sub  esp, 4+4+100*4

        mov ecx, 0
beginloop:
        cmp ecx, 100
        jge endloop

        mov eax, ecx
        mul ecx

        mov [ebp+4*ecx-408], eax

        inc ecx
        jmp beginloop
endloop:
```



local variables/arrays

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```
void myfunc() {
  int k;
  int j;
  int a[100];

  for (int i = 0; i < 100; i++) {
    a[i] = i*i;
  }

  printArray(a,100);
}
```

array6.asm

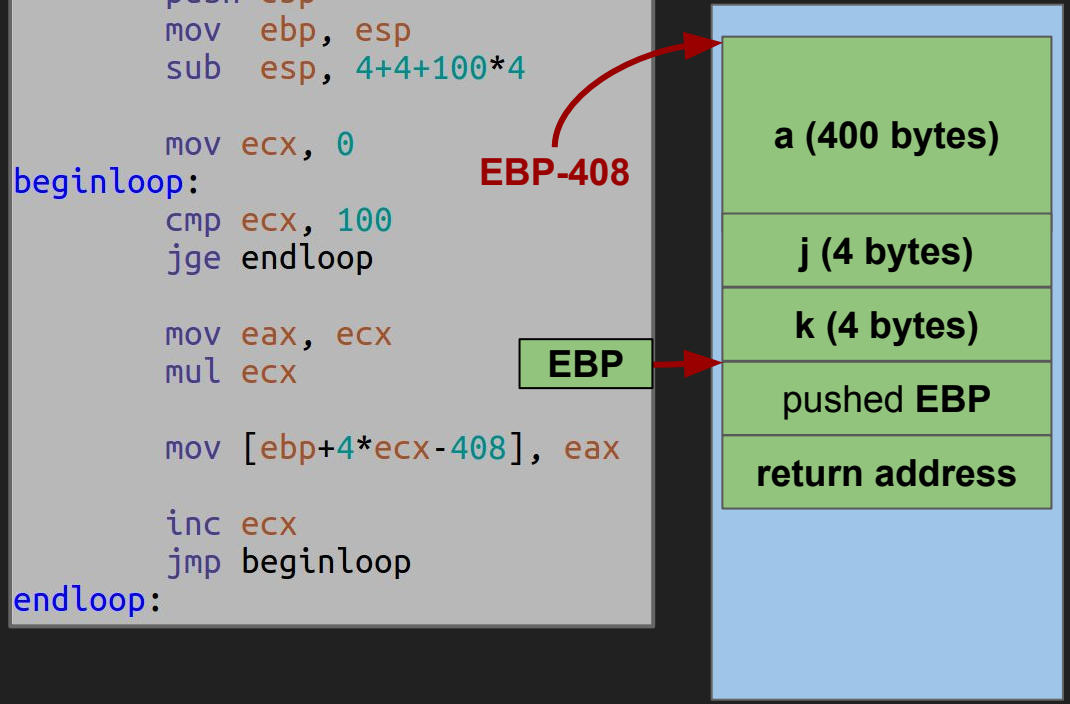
```
myfunc:
        push ebp
        mov  ebp, esp
        sub  esp, 4+4+100*4

        mov ecx, 0
beginloop:
        cmp ecx, 100
        jge endloop

        mov eax, ecx
        mul ecx

        mov [ebp+4*ecx-408], eax

        inc ecx
        jmp beginloop
endloop:
```



local variables/arrays

```
void myfunc() {
  int k;
  int j;
  int a[100];

  for (int i = 0; i < 100; i++) {
    a[i] = i*i;
  }

  printArray(a,100);
}
```

array6.asm

```
myfunc:
        push ebp
        mov  ebp, esp
        sub  esp, 4+4+100*4

        mov ecx, 0
beginloop:
        cmp ecx, 100
        jge endloop

        mov eax, ecx
        mul ecx

        mov [ebp+4*ecx-408], eax

        inc ecx
        jmp beginloop
endloop:

        mov  eax, ebp
        sub  eax, 408
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

local variables/arrays


```
void myfunc() {
  int k;
  int j;
  int a[100];

  for (int i = 0; i < 100; i++) {
    a[i] = i*i;
  }

  printArray(a,100);
}
```

array6.asm

```
endloop:

        mov  eax, ebp
        sub  eax, 408
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

local variables/arrays

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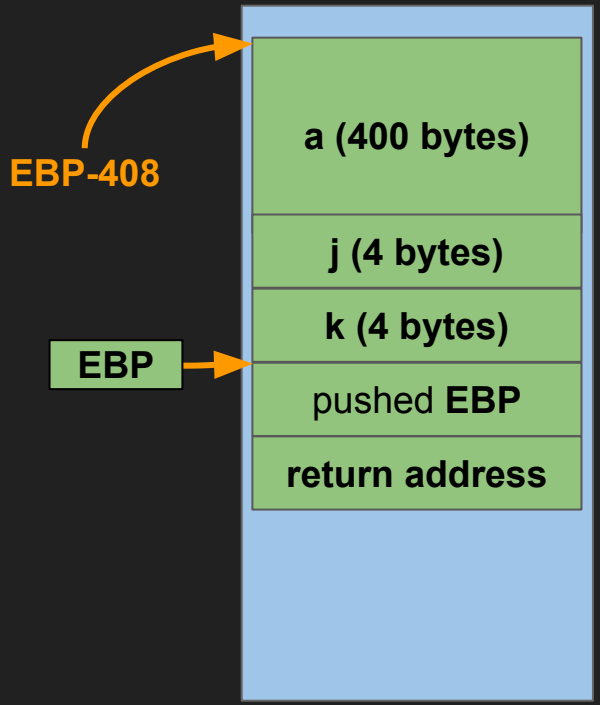
array6.asm

```
endloop:

        mov  eax, ebp
        sub  eax, 408
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```



local variables/arrays

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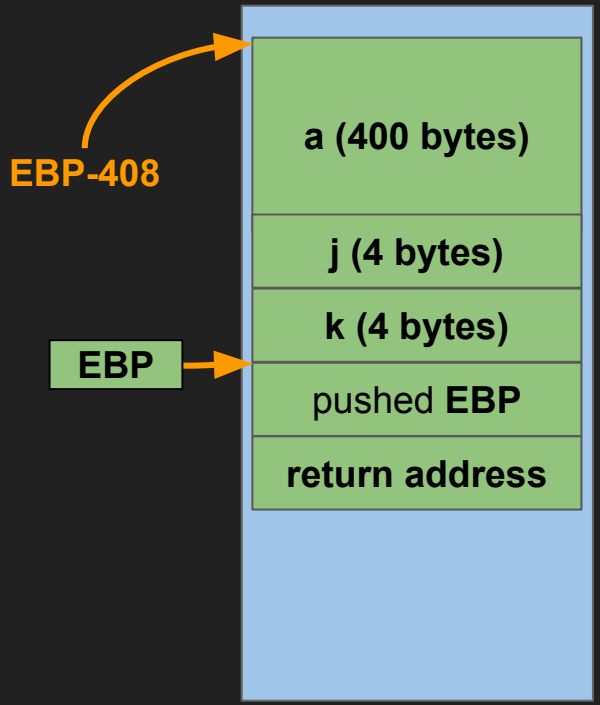
array6.asm

```
endloop:

        mov  eax, ebp
        sub  eax, 408
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

EAX = EBP - 408



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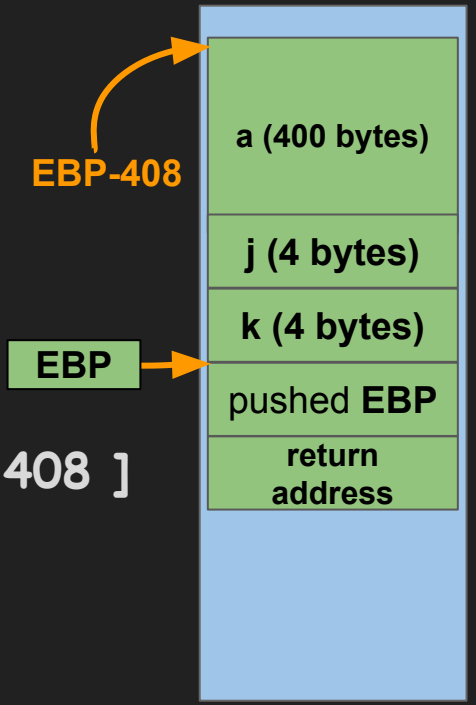
array6.asm

```
endloop:

        mov  eax, ebp
        sub  eax, 408
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

EAX = EBP - 408



mov eax, [ebp-408]

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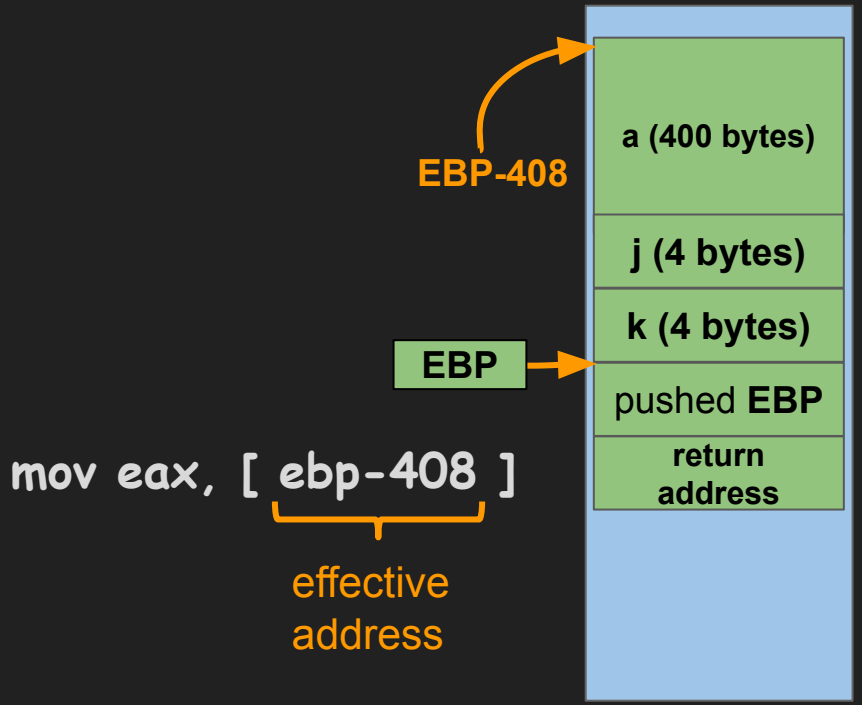
array6.asm

```
endloop:

        mov  eax, ebp
        sub  eax, 408
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

EAX = EBP - 408



local variables/arrays

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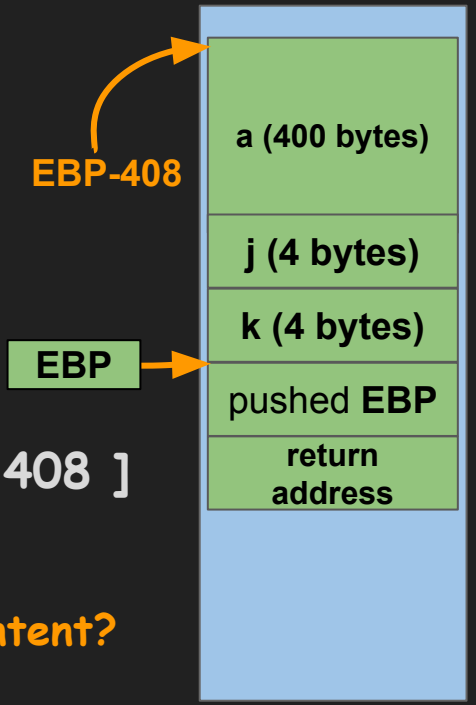
array6.asm

```
endloop:

        mov  eax, ebp
        sub  eax, 408
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

EAX = EBP - 408



mov eax, [ebp-408]

How to move the effective address instead of the content?

local variables/arrays

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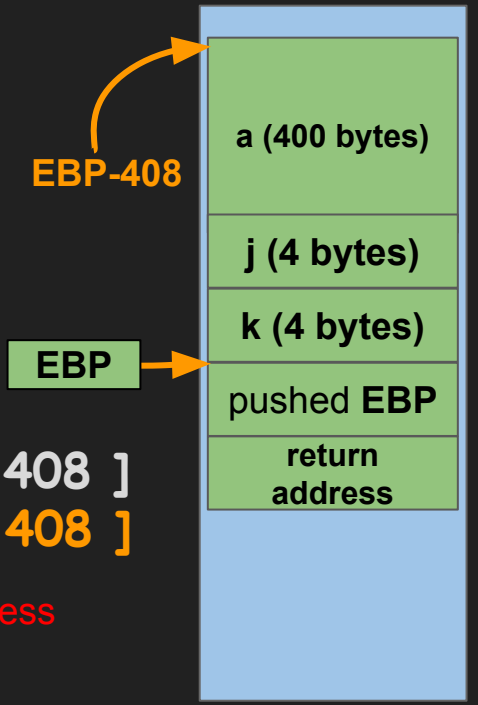
array6.asm

```
endloop:

        mov  eax, ebp
        sub  eax, 408
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

EAX = EBP - 408




```
mov eax, [ ebp-408 ]
lea  eax, [ ebp-408 ]
```

Load Effective Address

load effective address

array6.asm

```
endloop:

        mov  eax, ebp
        sub  eax, 408
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

EAX = EBP - 408

array7.asm

```
endloop:

        lea eax, [ebp-408]
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

load effective address

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array6.asm

```
endloop:

        mov  eax, ebp
        sub  eax, 408
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

EAX = EBP - 408

array7.asm

```
endloop:

        lea eax, [ebp-408]
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

address generation unit (AGU)

final program

```c
void myfunc() {
  int k;
  int j;
  int a[100];

  for (int i = 0; i < 100; i++) {
    a[i] = i*i;
  }

  printArray(a,100);
}
```

array7.asm

```
myfunc:
        push ebp
        mov  ebp, esp
        sub  esp, 4+4+100*4

        mov ecx, 0
beginloop:
        cmp ecx, 100
        jge endloop

        mov eax, ecx
        mul ecx

        mov [ebp+4*ecx-408], eax

        inc ecx
        jmp beginloop
endloop:
        lea eax, [ebp-408]
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

load effective address

effective address

```
MOV reg, [ base-reg + scale * index-reg + constant ]

  reg = *(base-reg + scale * index-reg + constant)
```

```
LEA reg, [ base-reg + scale * index-reg + constant ]

    reg = base-reg + scale * index-reg + constant
```

get address of local variables / arrays

- storing a pointer to a local variable
- pushing on stack for function call

```
endloop:

        lea eax, [ebp-408]
        push 100
        push eax
        call printArray

        mov esp, ebp
        pop ebp
        ret
```

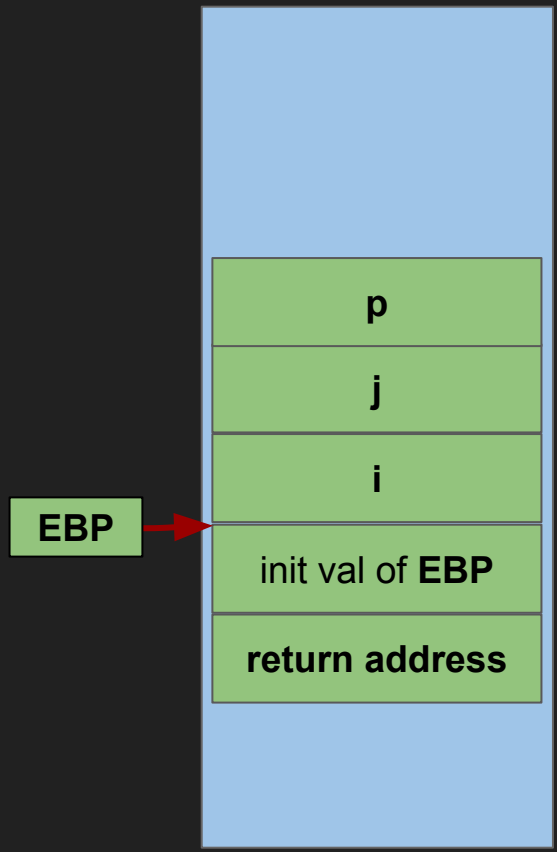
get address of local variables / arrays

- storing a pointer to a local variable
- pushing on stack for function call

```
void myfunc() {
  int i;
  int j;
  int *p;

  p = &j;

}
```



get address of local variables / arrays

- storing a pointer to a local variable
- pushing on stack for function call

```
void myfunc() {
  int i;
  int j;
  int *p;

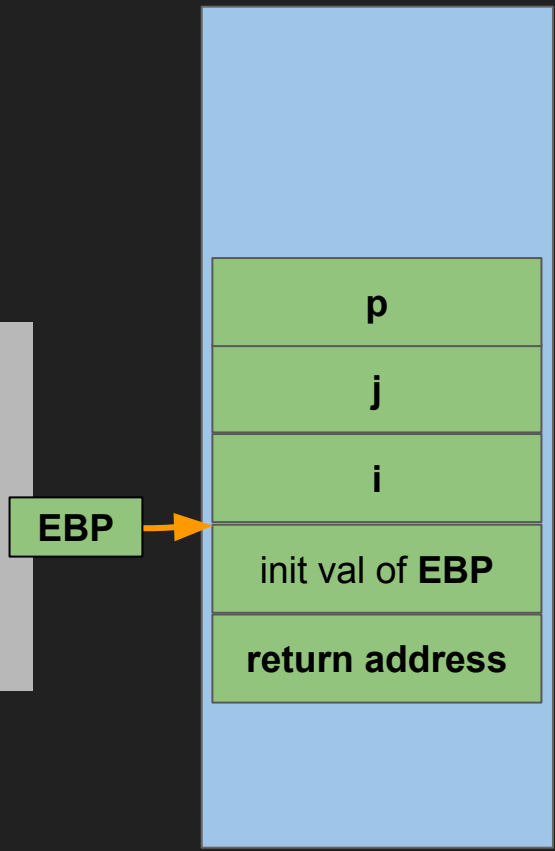
  p = &j;

}
```

```
myfunc:
        push ebp
        mov  ebp, esp
        sub  esp, 4+4+4

        lea  eax, [ebp-8]
        mov  [ebp-12], eax
```

assuming 32-bit addressing
(pointers are 32 bits long)



fast computations


```
lea EAX, [ EAX + 4 * EAX ]
```

fast computations


```
lea EAX, [ EAX + 4 * EAX ]        EAX *= 5
```

fast computations


```
lea EAX, [ EAX + 4 * EAX ]        EAX *= 5

????                              EAX *= 6
```

fast computations


```
lea EAX, [ EAX + 4 * EAX ]        EAX *= 5

lea EAX, [ EAX + 5 * EAX ]        EAX *= 6
```

fast computations


```
lea EAX, [ EAX + 4 * EAX ]        EAX *= 5
```

~~`lea EAX, [ EAX + 5 * EAX ]        EAX *= 6`~~

```
nasihatkon@kntu:code$ nasm -f elf lea.asm
lea.asm:21: error: invalid effective address
```

fast computations


```
lea EAX, [ EAX + 4 * EAX ]          EAX *= 5

lea EAX, [ EAX + 5 * EAX ]          EAX *= 6
```

```
nasihatkon@kntu:code$ nasm -f elf lea.asm
lea.asm:21: error: invalid effective address
```

[base-reg + scale * index-reg + constant]

scale: 1,2,4,8

fast computations


```
lea EAX, [ EAX + 4 * EAX ]        EAX *= 5
```

~~`lea EAX, [ EAX + 5 * EAX ]        EAX *= 6`~~

```
nasihatkon@kntu:code$ nasm -f elf lea.asm
lea.asm:21: error: invalid effective address
```

```
lea EAX, [ EAX + 2 * EAX ]
sal EAX
```

fast computations


```
lea EAX, [ EAX + 4 * EAX ]          EAX *= 5

lea EAX, [ EAX + 5 * EAX ]          EAX *= 6
```

```
nasihatkon@kntu:code$ nasm -f elf lea.asm
lea.asm:21: error: invalid effective address
```

```
lea EAX, [ EAX + 8 * EAX ]
lea EAX, [ EAX + 4 * EAX ]
```

fast computations


```
lea EAX, [ EAX + 4 * EAX ]        EAX *= 5

lea EAX, [ EAX + 5 * EAX ]        EAX *= 6
```

```
nasihatkon@kntu:code$ nasm -f elf lea.asm
lea.asm:21: error: invalid effective address
```

```
lea EAX, [ EAX + 8 * EAX ]
lea EAX, [ EAX + 4 * EAX ]        EAX *= 45
```

Arrays in inline assembly

array9.c

```
void printArray(const int a[], int n) {
  for (int i = 0; i < n; i++)
    printf("%d, ", a[i]);
  putchar('\n');
}

int main() {
  int array[10] = {1,2,3,4,5,6,7,8,9,10};
  printArray(array,10);

  for (int i = 0; i < 10; i++) {
    asm volatile ("mov eax, [ebx+4*esi];"
                  "lea eax, [eax+8*eax];"
                  "mov [ebx+4*esi], eax"
                  :
                  : "b" (array), "S" (i)
                  : "memory", "eax");
  }

  printArray(array,10);
}
```

Arrays in inline assembly

array9.c

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void printArray(const int a[], int n) {
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                  "lea eax, [eax+8*eax];"
                  "mov [ebx+4*esi], eax"
                  :
                  : "b" (array), "S" (i)
                  : "memory", "eax");
  }

  printArray(array,10);
}
```

```
b.nasihatkon@kntu:lecture16$ gcc -m32 -masm=intel array9.c && ./a.out
1, 2, 3, 4, 5, 6, 7, 8, 9, 10,
9, 18, 27, 36, 45, 54, 63, 72, 81, 90,
```