CS 271
Computer Architecture & Assembly Language

Lecture 14

Array

Random Number

*Local Variables

2/17/22, Thursday

Oregon State University

Odds and Ends

- Program 5 Clarifications

- Due Sunday 2/20 11:59 pm:
    - Weekly Summary 7

Lecture Topics:

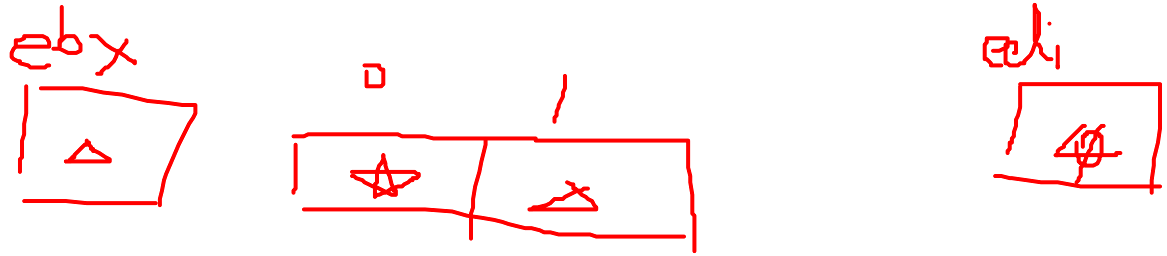
- Introduction to Arrays
- Arrays as Reference Parameters
- Display an Array Sequentially
- “Random” Numbers

Recall: Introduction to Arrays

Recall: Array References in MASM

- Several methods for accessing specific array elements
  - Indexed
  - Register indirect
  - Base-indexed

Recall: Indexed Addressing



- Array name, with "distance" to element in a register
  - Used for global array references (not used in Program #5)
- Examples:

```
mov     edi,0               ;high-level notation
mov     list[edi],eax          ; is list[0]
add     edi,4                  ;* see note below
mov     list[edi],ebx          ;list[1]
```

- This means "add the value in [] to address of list"
- *Note: add 4 because these array elements are DWORD
  - If BYTE, add 1
  - If WORD, add 2
  - If QWORD, add 8
  - Etc.

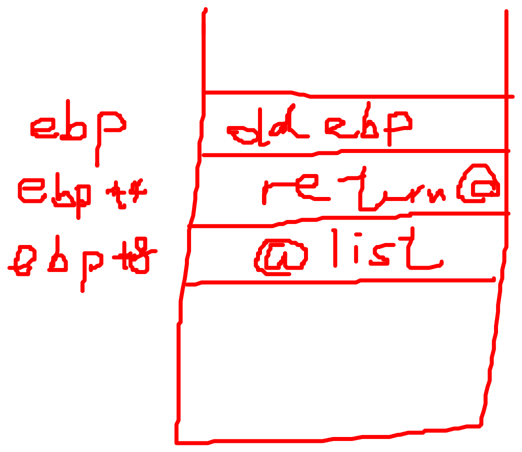
Recall: Register Indirect Addressing

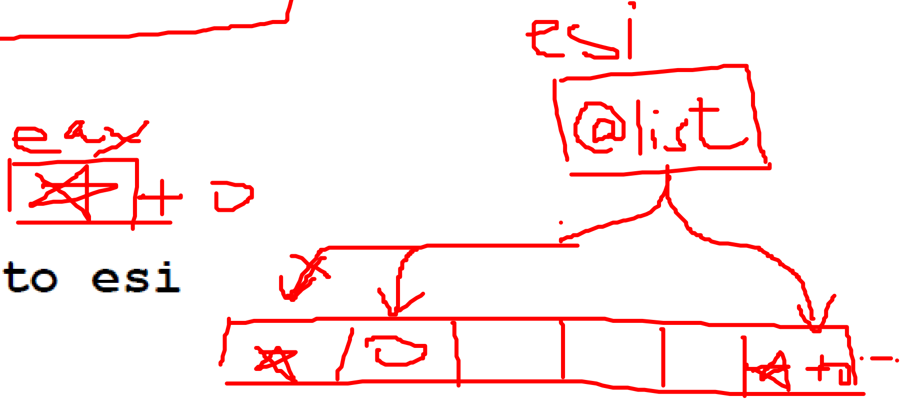
- Actual address of array element in register
  - Used for referencing array elements in procedures
- Examples:
  - In calling procedure…

```
push            OFFSET list
```

  - In called procedure… (example only)

```
... ;set up stack frame
mov esi,[ebp+8]        ; get address of list into esi
mov eax,[esi]          ; get list[0] into eax
add esi,4
add eax,[esi]          ; add list[1] to eax
add esi,16
mov [esi],eax          ; send result to list[5]
```



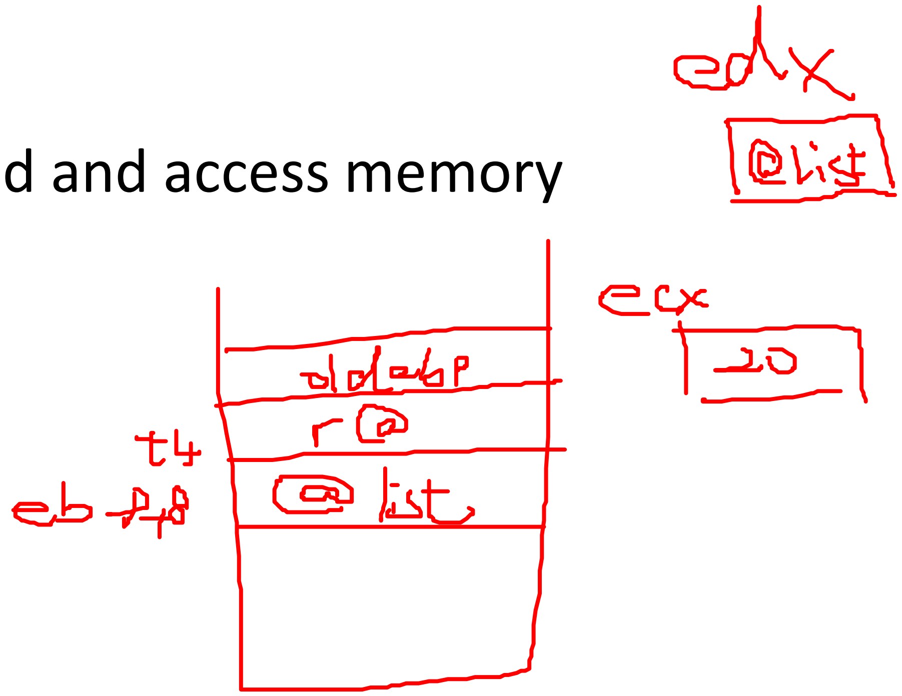


Recall: Base-indexed Addressing

- Starting address in one register, offset in another; add and access memory
  - Used for referencing array elements in procedures
- Examples:
  - In calling procedure …

```
push        OFFSET list
```

  - In called procedure … (example only)




```
... ;set up stack frame
mov edx,[ebp+8]           ; get address of list into edx
mov ecx,20
mov eax,[edx+ecx] ; get list[5] into eax
mov ebx,4
add eax,[edx+ebx] ; add list[1] to eax
mov [edx+ecx],eax ; send result to list[5]
```

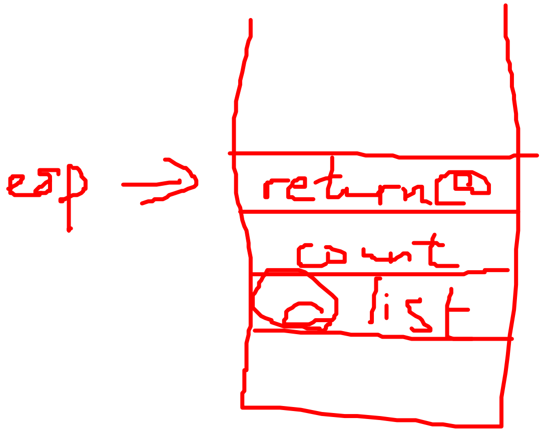
Passing Arrays by Reference

ArrayFill(list, count);

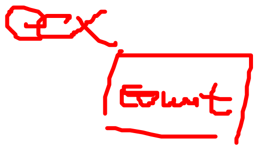
- Never pass an array by value!!!
- Suppose that an *ArrayFill* procedure fills an array with 32-bit integers
- The calling program passed the address of the array, along with *count* of the number of array elements:

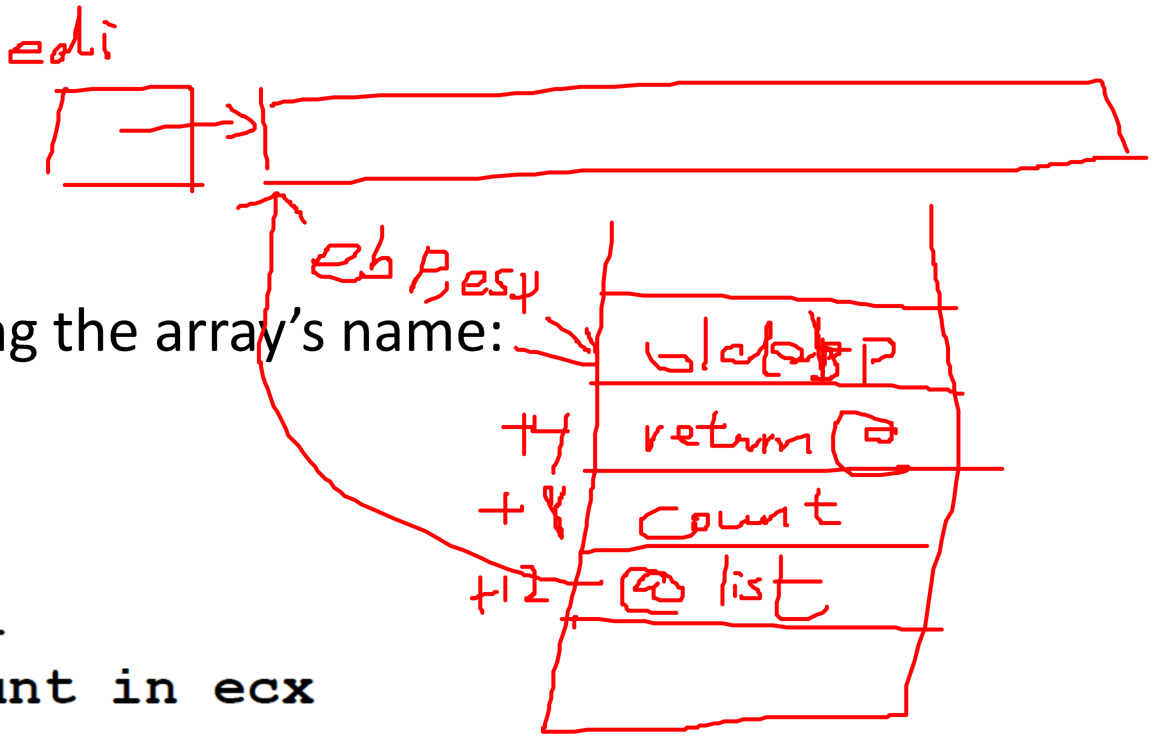
void ArrayFill(int *list, int num)

```
COUNT = 100
.data
list DWORD COUNT DUP(?)
.code
    ...
    push OFFSET list
    push COUNT
    call ArrayFill
```



Passing Arrays by Reference





- *ArrayFill* can refence an array without knowing the array's name:

```
ArrayFill PROC
   push ebp
   mov  ebp,esp
   mov  edi,[ebp+12] ;@list in edi
   mov  ecx,[ebp+8]  ;value of count in ecx
   ; … etc.
```

- **edi** points to the beginning of the array, so it's easy to use a loop to access each array element.

- Style note: We use **edi** because the array is the "destination"

Passing Arrays by Reference

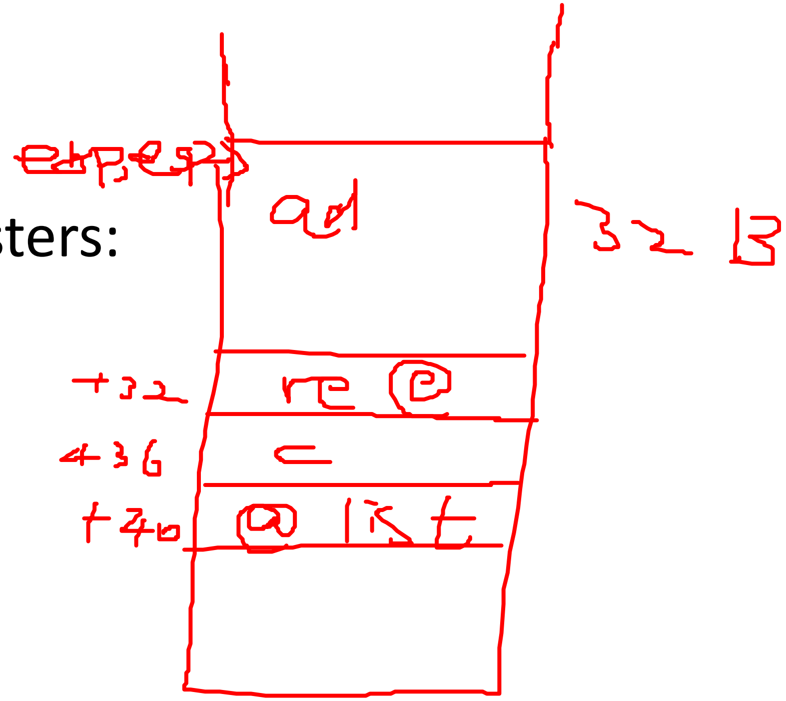
- This *ArrayFill* uses register indirect addressing:

```
ArrayFill   PROC
    push ebp
    mov  ebp,esp
    mov  edi,[ebp+12]     ;@list in edi
    mov  ecx,[ebp+8]      ;value of count in ecx
more:
    ;  .
    ; Code to generate a random number in eax
    ;   goes here.
    mov   [edi],eax
    add   edi,4
    loop  more

    pop   ebp
    ret   8
ArrayFill   ENDP
```

Passing Arrays by Reference

- This *ArrayFill* uses base-indexed addressing, saves registers:

```
ArrayFill    PROC
    pushad                    ;save all registers
    mov   ebp,esp
    mov   edx,[ebp+40]        ;@list in edx
    mov   ebx,0               ;"index" in ebx
    mov   ecx,[ebp+36]        ;value of count in ecx
more:
    ;  .
    ; Code to generate a random number in eax
    ;    goes here.
    mov    [edx+ebx],eax
    add    ebx,4
    loop   more

    popad                     ;restore all registers
    ret    8
ArrayFill    ENDP
```



Lecture Topics:

- Introduction to Arrays
- Arrays as Reference Parameters
- Display an Array Sequentially
- “Random” Numbers

Setup in Calling Procedure

```
.data
list        DWORD       100 DUP(?)
count       DWORD       0

.code
;...
            ;code to initialize list and count
;...
            ;set up parameters and call display
            push  OFFSET list        ;@list
            push  count          ;number of elements
            call  display
;...
```

Display: version 0.1 (register indirect)

```
display     PROC
        push ebp
        mov  ebp,esp
        mov  esi,[ebp+12]     ;@list
        mov  ecx,[ebp+8]      ;ecx is loop control
more:
        mov  eax,[esi]   ;get current element
        call WriteDec
        call Crlf
        add  esi,4       ;next element
        loop more
endMore:
        pop  ebp
        ret  8
display     ENDP
```

Display: version 0.2 (base-indexed)

```
display      PROC
        push   ebp
        mov    ebp,esp
        mov    esi,[ebp+12]        ;@list
        mov    ecx,[ebp+8]  ;ecx is loop control
        mov    edx,0        ;edx is element "pointer"
more:
        mov    eax,[esi+edx]        ;get current element
        call   WriteDec
        call   Crlf
        add    edx,4         ;next element
        loop   more
endMore:
        pop    ebp
        ret    8
display      ENDP
```

Random Numbers

- Irving library has random integer generator
  - “pseudo-random” numbers
- *Randomize* procedure — srand( )
  - Initialize sequence based on system clock (random seed)
  - Call once at the beginning of the program
  - Without *Randomize*, program gets the same sequence every time it is executed

Limiting Random Values

- *RandomRange* procedure
  - Accepts N>0 in **eax**
  - Returns random integer in [0 … N-1] in **eax**
- To generate a random number in [lo … hi]:
  - Find number of integer possible in [lo … hi]: range = hi – lo + 1
  - Put range in **eax**, and call RandomRange
  - Result in **eax** is in [0 … range -1]
  - Add lo to **eax**.

eax

N

rand() % N

(0 — (N-1))

low — high

0 ~ [hi - lo]

low ~ high

RandomRange Example

- Get a random integer in range [18 … 31]

```
call    Randomize
mov     eax,hi          ;31
sub     eax,lo          ;31-18 = 13
inc     eax             ;14
call    RandomRange     ;eax in [0..13]
add     eax,lo          ;eax in [18..31]
```

*Additional Topics:

- Local Variables in Assembly
- LEA instruction

*will NOT be tested!

Local Variables

- Local Variables: created, used, and destroyed within a single subroutine (function, control structure, or loops).
- Local Variables are allocated on the runtime stack, below EBP
- Cannot be assigned default values at assembly time, but can be initialized at runtime

Local Variable Example

- In HLL:

```
void func() {
      int x = 10;
      int y = 20;
}
```

- In Assembly

```
func  PROC
        push  ebp
        mov   ebp, esp
        sub   esp, 8
        mov   DWORD PTR  [ebp - 4], 10
        mov   DWORD PTR  [ebp - 8], 20
        mov   esp, ebp
        pop   ebp
        ret
Func  ENDP
```

Local Variable Visualization

- In HLL:

```
void func() {
        int x = 10;
        int y = 20;
}
```

- In Assembly

```
func  PROC
      push  ebp
      mov   ebp, esp
      sub   esp, 8
      mov   DWORD PTR  [ebp - 4], 10
      mov   DWORD PTR  [ebp - 8], 20
      mov   esp, ebp
      pop   ebp
      ret
Func  ENDP
```

System Stack	
[ESP]	return @
…	…

ESP →

EBP

Local Variable Visualization

- In HLL:

```
void func() {
        int x = 10;
        int y = 20;
}
```

- In Assembly

```
func  PROC
      push  ebp
      mov   ebp, esp
      sub   esp, 8
      mov   DWORD PTR  [ebp - 4], 10
      mov   DWORD PTR  [ebp - 8], 20
      mov   esp, ebp
      pop   ebp
      ret
Func  ENDP
```

System Stack	
[ESP]	old EBP
[ESP + 4]	return @
…	…

ESP →

EBP ↘

Local Variable Visualization

- In HLL:

```
void func() {
        int x = 10;
        int y = 20;
}
```

- In Assembly

```
func  PROC
      push  ebp
      mov   ebp, esp
      sub   esp, 8
      mov   DWORD PTR  [ebp – 4], 10
      mov   DWORD PTR  [ebp – 8], 20
      mov   esp, ebp
      pop   ebp
      ret
Func  ENDP
```

EBP, ESP →

System Stack	
[EBP]	old EBP
[EBP + 4]	return @
…	…

Local Variable Visualization

- In HLL:

```
void func() {
        int x = 10;
        int y = 20;
}
```

- In Assembly

```
func  PROC
      push  ebp
      mov   ebp, esp
      sub   esp, 8
      mov   DWORD PTR  [ebp - 4], 10
      mov   DWORD PTR  [ebp - 8], 20
      mov   esp, ebp
      pop   ebp
      ret
Func  ENDP
```

ESP → [EBP – 8]

EBP → [EBP]

System Stack	
[EBP – 8]	
[EBP – 4]	
[EBP]	old EBP
[EBP + 4]	return @
…	…

Local Variable Visualization

- In HLL:

```
void func() {
        int x = 10;
        int y = 20;
}
```

- In Assembly

```
func  PROC
      push  ebp
      mov   ebp, esp
      sub   esp, 8
      mov   DWORD PTR  [ebp - 4], 10
      mov   DWORD PTR  [ebp - 8], 20
      mov   esp, ebp
      pop   ebp
      ret
Func  ENDP
```

	System Stack	
ESP →	[EBP – 8]	
	[EBP – 4]	10
EBP →	[EBP]	old EBP
	[EBP + 4]	return @
	…	…

Local Variable Visualization

- In HLL:

```
void func() {
        int x = 10;
        int y = 20;
}
```

- In Assembly

```
func  PROC
      push  ebp
      mov   ebp, esp
      sub   esp, 8
      mov   DWORD PTR  [ebp - 4], 10
      mov   DWORD PTR  [ebp - 8], 20
      mov   esp, ebp
      pop   ebp
      ret
Func  ENDP
```

	System Stack	
ESP →	[EBP – 8]	20
	[EBP – 4]	10
EBP →	[EBP]	old EBP
	[EBP + 4]	return @
	…	…

Local Variable Visualization

- In HLL:

```
void func() {
        int x = 10;
        int y = 20;
}
```

- In Assembly

```
func  PROC
      push  ebp
      mov   ebp, esp
      sub   esp, 8
      mov   DWORD PTR  [ebp - 4], 10
      mov   DWORD PTR  [ebp - 8], 20
  =>  mov   esp, ebp
      pop   ebp
      ret
Func  ENDP
```

ESP, EBP → [EBP]

System Stack	
[EBP – 8]	20
[EBP – 4]	10
[EBP]	old EBP
[EBP + 4]	return @
…	…

Local Variable Visualization

- In HLL:

```
void func() {
        int x = 10;
        int y = 20;
}
```

- In Assembly

```
func  PROC
      push  ebp
      mov   ebp, esp
      sub   esp, 8
      mov   DWORD PTR  [ebp - 4], 10
      mov   DWORD PTR  [ebp - 8], 20
      mov   esp, ebp
      pop   ebp
      ret
Func  ENDP
```

System Stack	
	20
	10
	old EBP
[ESP]	return @
…	…

ESP →

EBP

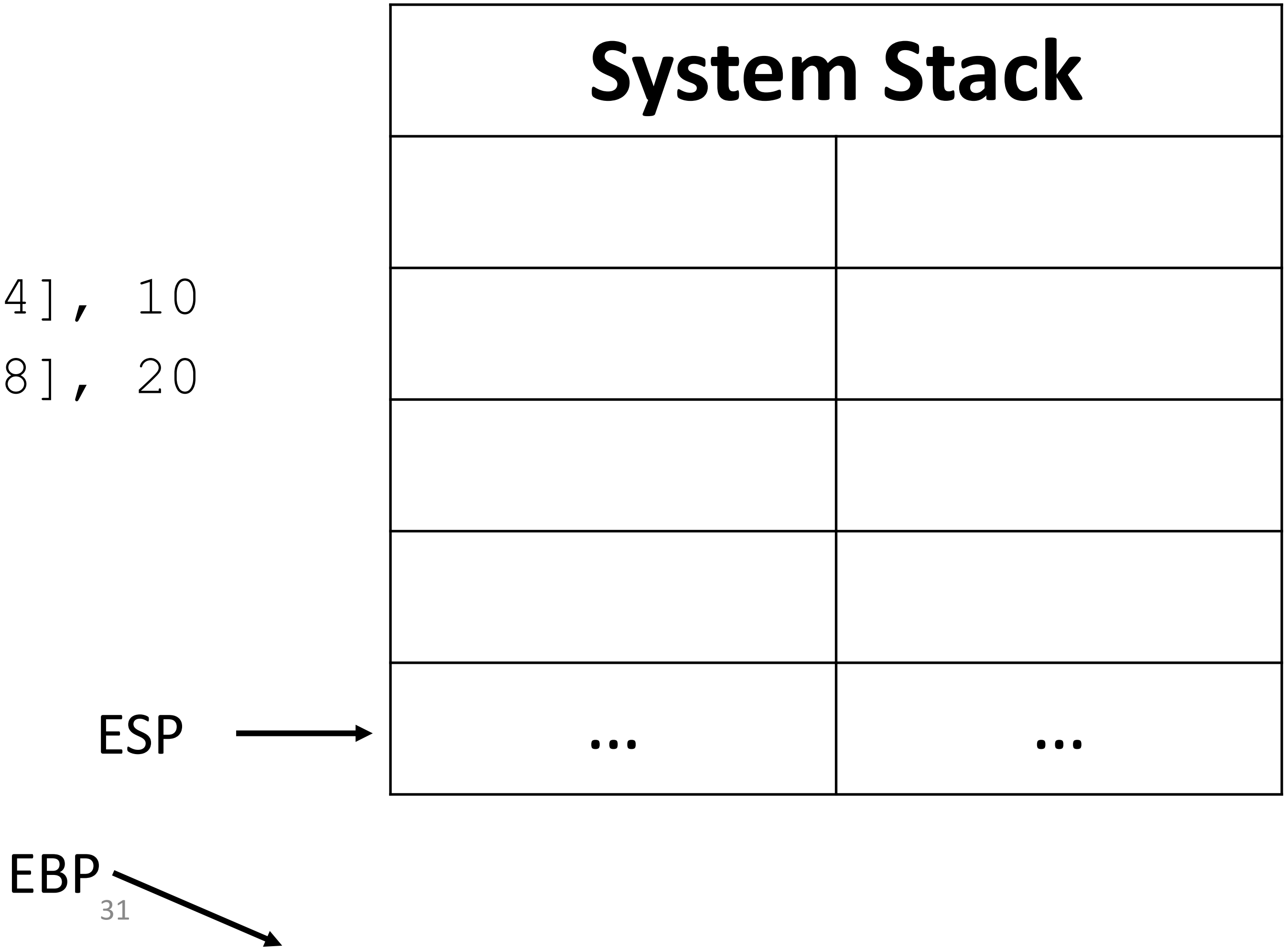
Local Variable Visualization

- In HLL:

```
void func() {
        int x = 10;
        int y = 20;
}
```

- In Assembly

```
func  PROC
      push  ebp
      mov   ebp, esp
      sub   esp, 8
      mov   DWORD PTR  [ebp - 4], 10
      mov   DWORD PTR  [ebp - 8], 20
      mov   esp, ebp
      pop   ebp
      ret
Func  ENDP
```



Local Variable Example

- In HLL:

```
void func() {
      int x = 10;
      int y = 20;
}
```

What if this step is omitted?

ebp - return to invalid addr!

- In Assembly

```
func  PROC
      push  ebp
      mov   ebp, esp
      sub   esp, 8
      mov   DWORD PTR  [ebp - 4], 10
      mov   DWORD PTR  [ebp - 8], 20
      mov   esp, ebp
      pop   ebp
      ret
Func  ENDP
```

*Additional Topics:

- Local Variables in Assembly
- LEA instruction

*will NOT be tested!

LEA: Load Effective Address

- LEA: returns the address of an indirect operand (offset calculated during runtime)

LEA Example

- In HLL:

```
void create_arr(){
      char arr[30];
      for (int i = 0; i < 30; i++)
            arr[i] = '*';
}
```

- In Assembly

```
create_arr      PROC
        push    ebp
        mov     ebp, esp
        sub     esp, 32
        lea     esi, [ebp-30]
        mov     ecx, 30
L1:
        mov     BYTE PTR [esi], '*'
        inc     esi
        loop    L1
        add     esp, 32
        pop     ebp
        ret
create_arr      ENDP
```

LEA Visualization

- In HLL:

```
void create_arr(){
        char arr[30];
        for (int i = 0; i < 30; i++)
                arr[i] = '*';
}
```

- In Assembly

```
create_arr      PROC
        push    ebp
        mov     ebp, esp
        sub     esp, 32
        lea     esi, [ebp-30]
        mov     ecx, 30
L1:
        mov     BYTE PTR [esi], '*'
        inc     esi
        loop    L1
        add     esp, 32
        pop     ebp
        ret
create_arr      ENDP
```

ESP, EBP → [EBP]

System Stack	
[EBP]	old EBP
[EBP + 4]	return @
…	…

LEA Visualization

- In HLL:

```
void create_arr(){
        char arr[30];
        for (int i = 0; i < 30; i++)
                arr[i] = '*';
```

- In Assembly

```
create_arr    PROC
        push    ebp
        mov     ebp, esp
        sub     esp, 32
        lea     esi, [ebp-30]
        mov     ecx, 30
L1:
        mov     BYTE PTR [esi], '*'
        inc     esi
        loop    L1
        add     esp, 32
        pop     ebp
        ret
create_arr    ENDP
```

Why 32 instead of 30?

	System Stack	
ESP →	[EBP – 32]	
	….	….
EBP →	[EBP]	old EBP
	[EBP + 4]	return @
	…	…

LEA Visualization

- In HLL:

```
void create_arr(){
        char arr[30];
        for (int i = 0; i < 30; i++)
                arr[i] = '*';
```

- In Assembly

```
create_arr    PROC
        push    ebp
        mov     ebp, esp
        sub     esp, 32
        lea     esi, [ebp-30]
        mov     ecx, 30
L1:
        mov     BYTE PTR [esi], '*'
        inc     esi
        loop    L1
        add     esp, 32
        pop     ebp
        ret
create_arr    ENDP
```

Can we do:
mov esi, OFFSET [ebp-30]?

error!

&(*(ebp-30))

ESI

EBP - 30

ESP →

EBP →

System Stack	
[EBP – 32]	
….	….
[EBP]	old EBP
[EBP + 4]	return @
…	…

LEA Visualization

- In HLL:

```
void create_arr(){
        char arr[30];
        for (int i = 0; i < 30; i++)
                arr[i] = '*';
```

- In Assembly

```
create_arr      PROC
        push    ebp
        mov     ebp, esp
        sub     esp, 32
        lea     esi, [ebp-30]
        mov     ecx, 30
L1:
        mov     BYTE PTR [esi], '*'
        inc     esi
        loop    L1
        add     esp, 32
        pop     ebp
        ret
create_arr      ENDP
```

Can we do:
mov esi, ebp-30?

ESI

EBP - 30

ESP →

EBP →

System Stack	
[EBP – 32]	
....	....
[EBP]	old EBP
[EBP + 4]	return @
...	...

LEA: Another Example

```c
struct Point {
        int xcoord;
        int ycoord;
};

int y = points[i].ycoord;

int *p = &points[i].ycoord;
```

```asm
; right side is "effective address"
mov edx, [ebx + 8 * eax + 4]

lea esi, [ebx + 8 * eax + 4] ;addr in esi
```


https://stackoverflow.com/questions/1658294/whats-the-purpose-of-the-lea-instruction