CS 354 - Machine Organization & Programming
Tuesday Nov 12, Thursday Nov 14, 2024

Exam Results expected by Friday Nov 15
Homework hw5DUE Monday 11/11 **Homework hw6:** DUE on or before Monday 11/18
Homework hw7: DUE on or before Monday 11/25
Project p5: DUE on or before _______________

Learning Objectives

- able to trace function call and its stack frame
- able to access parameters and local variables based on location from %ebp and %esp
- able to trace recursive function calls through their stack frame
- identify and describe effects of ASM **call**, **ret**, **leave** instructions
- able to access 1D array element using ASM instructions and memory operand types
- able to access multidimensional array via ASM instructions and memory operand types
- describe, compute, and use alignment requirements of elements in structs and unions
- understand the difference and use of structs and unions in C.

This Week

Function Call-Return Example (from W10) Recursion Stack Allocated Arrays in C Stack Allocated Arrays in Assembly Stack Allocated Multidimensional Arrays	Stack Allocated Structs Alignment Alignment Practice Unions
Next Week: Pointers in Assembly, Stack Smashing, and Exceptions B&O 3.10 Putting it Together: Understanding Pointers 3.12 Out-of-Bounds Memory References and Buffer Overflow 8.1 Exceptions 8.2 Processes 8.3 System Call Error Handling 8.4 Process Control through p719	

Recursion

Use a stack trace to determine the result
of the call `fact(3)`:

```
int fact(int n) {
   int result;
   if (n <= 1) result = 1;
   else        result = n * fact(n - 1);
   return result;
}
```

direct recursion

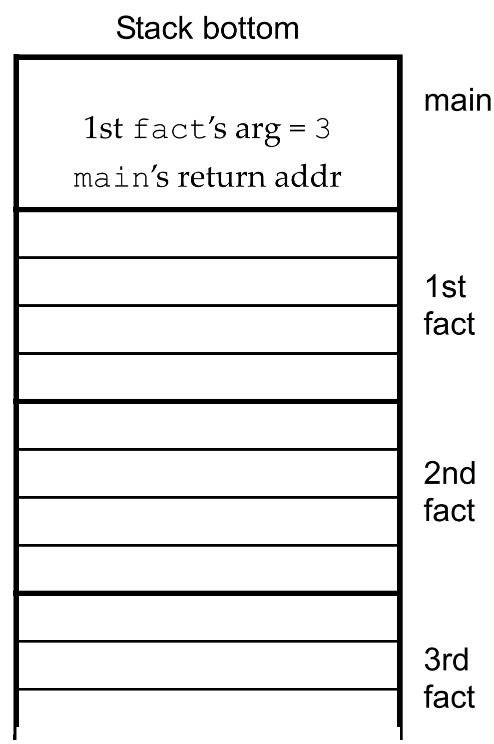
recursive case

base case

"infinite" recursion

Assembly Trace

```
fact:
   pushl %ebp
   movl %esp, %ebp
   pushl %ebx
   subl $4,%esp

   movl 8(%ebp),%ebx
   movl $1,%eax

   cmpl $1,%ebx
   jle .L1

   leal -1(%ebx),%eax
   movl %eax,(%esp)
   call fact

   imull %ebx,%eax

.L1:
   addl $4,%esp
   popl %ebx
   popl %ebp
   ret
```



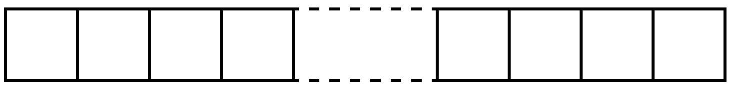
- *"Infinite" recursion causes*

- *When tracing functions in assembly code*

Stack Allocated Arrays in C

Recall Array Basics

T `A[`*N*`];` where *T* is the element datatype of size *L* bytes
and *N* is the number of elements



1.

2.

❋ *The elements of* `A`

Recall Array Indexing and Address Arithmetic

`&A[i]`

→ For each array declarations below, what is L (element size), the address arithmetic for the ith element, and the total size of the array?

	C code	L	address of ith element	total array size
1.	`int I[11]`			
2.	`char C[7]`			
3.	`double D[11]`			
4.	`short S[42]`			
5.	`char *C[13]`			
6.	`int **I[11]`			
7.	`double *D[7]`			

Stack Allocated Arrays in Assembly

Arrays on the Stack

→ How is an array laid out on the stack? Option 1 or 2:

higher addresses

earlier frames	
1.	**2.**
`A[0]`	`A[N-1]`
`A[1]`	`...`
`...`	`A[1]`
`A[N-1]`	`A[0]`

Stack Top

❋ *The first element (index 0) of an array*

Accessing 1D Arrays in Assembly

Assume array's start address in %edx and index is in %ecx

```
movl (%edx, %ecx, 4), %eax
```

→ Assume `I` is an `int` array, `S` is a `short int` array, for both the array's start address is in %edx, and the index `i` is in %ecx. Determine the element type and instruction for each:

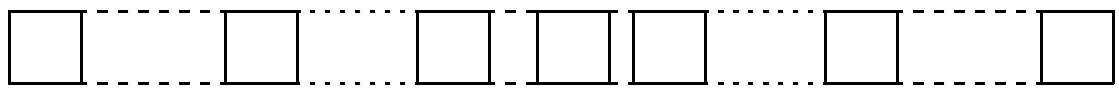
C code   type   assembly instruction to move C code's value into %eax

1. `I`
2. `I[0]`
3. `*I`
4. `I[i]`
5. `&I[2]`
6. `I+i-1`
7. `*(I+i-3)`
8. `S[3]`
9. `S+1`
10. `&S[i]`
11. `S[4*i+1]`
12. `S+i-5`

Stack Allocated Multidimensional Arrays

Recall 2D Array Basics

T `A[`*R*`][`*C*`];` where *T* is the element datatype of size *L* bytes,
R is the number of rows and *C* is the number of columns



✵ *Recall that 2D arrays are stored on the stack*

```
int A[5][3];        typedef int row_t[3];
                    row_t A[5];
```

Accessing 2D Arrays in Assembly

```
&A[i][j]
```

Given array `A` as declared above, if x_A in %eax, i in %ecx, j in %edx
then `A[i][j]` in assembly is:

```
leal (%ecx, %ecx, 2), %ecx
sall $2, %edx
addl %eax, %edx
movl (%edx, %ecx, 4), %eax
```

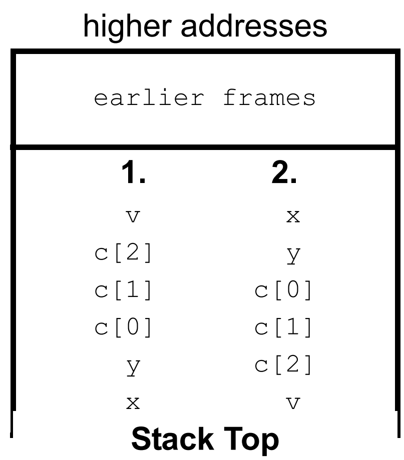
Compiler Optimizations

- If only accessing part of array

- If taking a fixed stride through the array

Stack Allocated Structures

Structures on the Stack

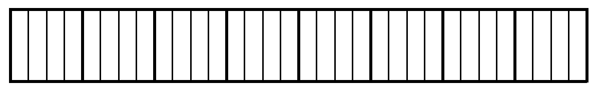



```
struct iCell {
   int x;
   int y;
   int c[3];
   int *v;
};
```

→ How is a structure laid out on the stack? Option 1 or 2:

The compiler

-



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✵ *The first data member of a structure*

Accessing Structures in Assembly

Given:

```
struct iCell ic = //assume ic is initialized

void function(iCell *ip) {
```

→ Assume `ic` is at the top of the stack, %edx stores `ip` and %esi stores `i`.
Determine for each the assembly instruction to move the C code's value into %eax:

C code   assembly

1. `ic.v`

2. `ic.c[i]`

3. `ip->x`

4. `ip->y`

5. `&ip->c[i]`

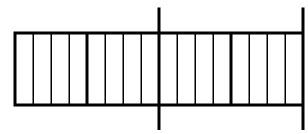
✵ *Assembly code to access a structure*

Alignment

What?

Why?

Example: Assume cpu reads 8 byte words
f is a misaligned float



Restrictions

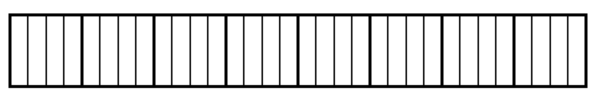
Linux: short
int, float, pointer, double

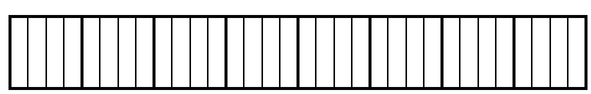
Windows: same as Linux except
double

Implications

Structure Example

```
struct s1 {
   int i;
   char c;
   int j;
};
```





✵ *The total size of a structure*

Alignment Practice

→ For each structure below, complete the memory layout and determine the total bytes allocated.

```
1) struct sA {
      int i;
      int j;
      char c;
   };
```

```
2) struct sB {
      char a;
      char b;
      char c;
   };
```

```
3) struct sC {
      char c;
      short s;
      int i;
      char d;
   };
```

```
4) struct sD {
      short s;
      int i;
      char c;
   };
```

```
5) struct sE {
      int i;
      short s;
      char c;
   };
```

❋ *The order that a structure's data members are listed*

Unions

What? A *union* is

-

-

Why?

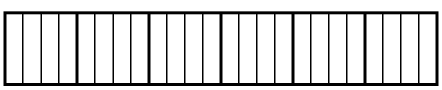
-

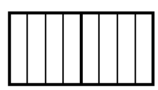
-

-

How?

```
struct s {                    union u {
   char c;                       char c;
   int i[2];                     int i[2];
   double d;                     double d;
};                            };
```





Example

```
typedef union {
   unsigned char cntrlrByte;
   struct {
      unsigned char playbutn  : 1;
      unsigned char pausebutn : 1;
      unsigned char ctrlbutn  : 1;
      unsigned char fire1butn : 1;
      unsigned char fire2butn : 1;
      unsigned char direction : 3;
   } bits;
} CntrlrReg;
```