The Stack and Memory in IA32

10/6/16

Tuesday, we covered these IA32 convenience instructions…

- `pushl src`
```
subl $4, %esp
movl src, (%esp)
```
- `popl dst`
```
movl (%esp), dst
addl $4, %esp
```
- `leave`
```
%esp = %ebp
popl %ebp
```

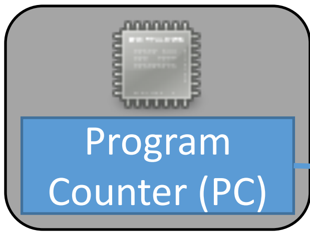
Next up: `call` and `ret`

- Call jumps to the start of the callee's instructions.
  - indicated by a label

- Ret jumps back to the next instruction of the caller.

Why don't we just do this with `jmp`?

Function calls



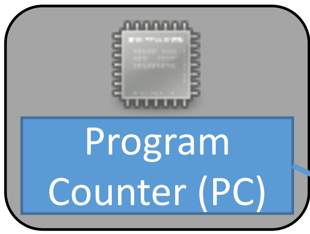
What we'd like this to do:

Text Memory Region

```
funcA:
addl $5, %ecx
movl %ecx, -4(%ebp)
…
call funcB
addl %eax, %ecx
…

funcB:
pushl %ebp
movl %esp, %ebp
…
movl $10, %eax
leave
ret
```

Function calls



What we'd like this to do:

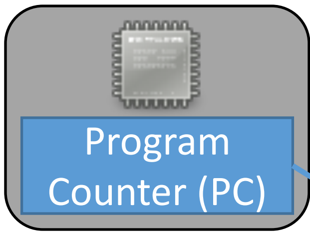
Set up function B's stack.

Text Memory Region

```
funcA:
addl $5, %ecx
movl %ecx, -4(%ebp)
…
call funcB
addl %eax, %ecx
…

funcB:
pushl %ebp
movl %esp, %ebp
…
movl $10, %eax
leave
ret
```

Function calls



What we'd like this to do:

Set up function B's stack.

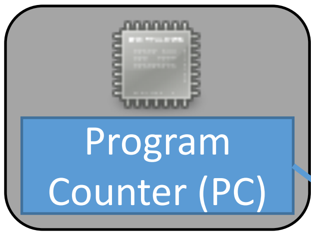
Execute the body of B, produce result (stored in %eax).

Text Memory Region

```
funcA:
addl $5, %ecx
movl %ecx, -4(%ebp)
…
call funcB
addl %eax, %ecx
…

funcB:
pushl %ebp
movl %esp, %ebp
…
movl $10, %eax
leave
ret
```

Function calls



What we'd like this to do:

Set up function B's stack.

Execute the body of B, produce result (stored in %eax).

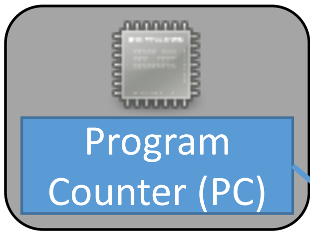
Restore function A's stack.

Text Memory Region

```
funcA:
addl $5, %ecx
movl %ecx, -4(%ebp)
…
call funcB
addl %eax, %ecx
…

funcB:
pushl %ebp
movl %esp, %ebp
…
movl $10, %eax
leave
ret
```

Function calls



What we'd like to do:

Return:
Go back to what we were doing before funcB started.

Text Memory Region

```
funcA:
addl $5, %ecx
movl %ecx, -4(%ebp)
…
call funcB
addl %eax, %ecx
…

funcB:
pushl %ebp
movl %esp, %ebp
…
movl $10, %eax
leave
ret
```

Unlike jumping, we intend to go back!

We need to get `%eip` back.

- `call` should save `%eip` then jump to callee.
- `ret` should restore `%eip` to jump back to the caller.

We could accomplish this without `call` and `ret`. They're just convenience instructions (like `push`, `pop`, and `leave`).

Write write `call` and `ret` using other IA32 instructions.

- `call f`: save `%eip` then jump to the start of `f`.

```
push %eip
jmp f
```

- `ret`: restore `%eip` to jump back to the caller.

```
popl %eip
```

IA32 Stack / Function Call Instructions

`pushl`	Create space on the stack and place the source there.	`subl $4, %esp` `movl src, (%esp)`
`popl`	Remove the top item off the stack and store it at the destination.	`movl (%esp), dst` `addl $4, %esp`
`call`	1. Push return address on stack 2. Jump to start of function	`push %eip` `jmp target`
`leave`	Prepare the stack for return (restoring caller's stack frame)	`movl %ebp, %esp` `popl %ebp`
`ret`	Return to the caller, PC ← saved PC (pop return address off the stack into PC (eip))	`popl %eip`

On the stack between the caller's and the callee's stack frames…

- Caller's base pointer (to reset the stack).
- Caller's instruction pointer (to continue execution).
- Function parameters.

What order should we store all of these things on the stack? Why?

A

callee parameters
return address
caller’s base pointer

B

return address
caller’s base pointer
callee parameters

C

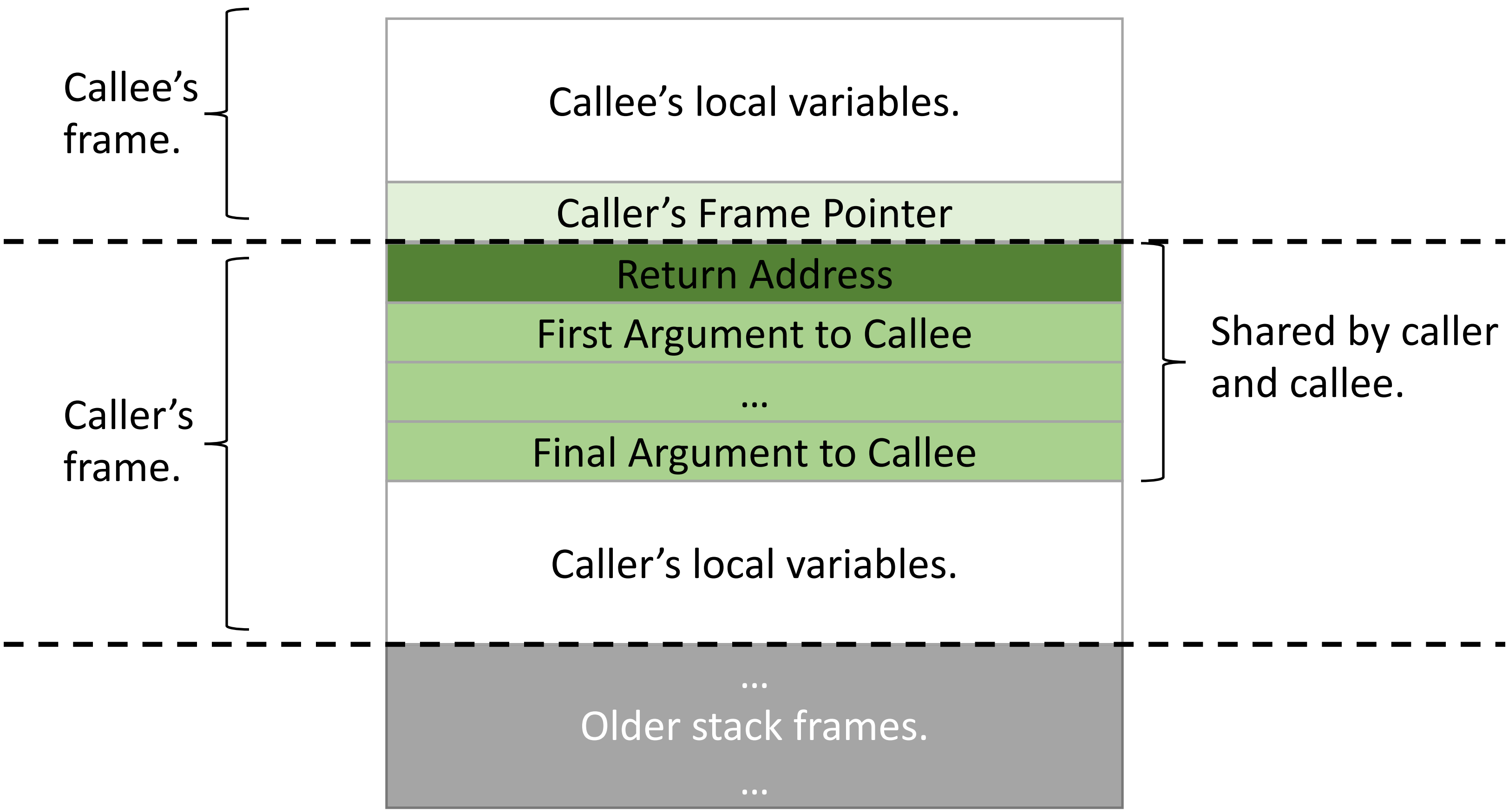
caller’s base pointer
callee parameters
return address

D

callee parameters
caller’s base pointer
return address

E: some other order.

Putting it all together…

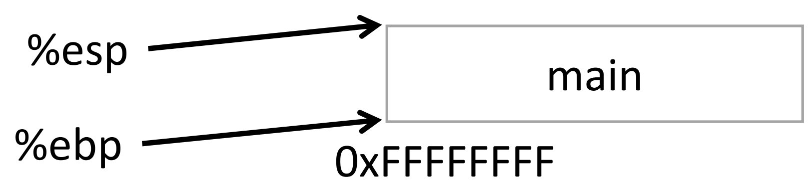


Translate this to IA32.
What should be on the stack?

```
int add_them(int a, int b, int c) {
  return a+b+c;
}

int main() {
  add_them(1, 2, 3);
}
```

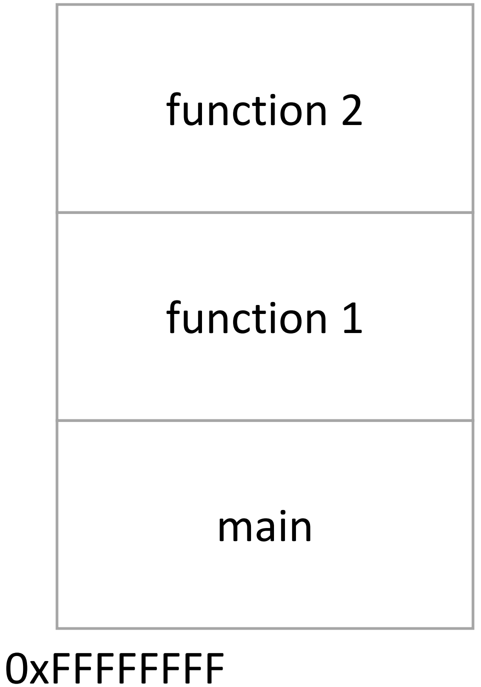
Assume the stack initially looks like:



Stack Frame Contents

- Local variables
- Previous stack frame base address
- Function arguments
- Return value
- Return address

- Saved registers
- Spilled temporaries



Saving Registers

- Registers are a scarce resource, but they're fast to access. Memory is plentiful, but slower to access.

- Should the caller save its registers to free them up for the callee to use?
- Should the callee save the registers in case the caller was using them?
- Who needs more registers for temporary calculations, the caller or callee?

- Clearly the answers depend on what the functions do…

Splitting the difference…

- We can't know the answers to those questions in advance…

- We have six general-purpose registers, let's divide them into two groups:
  - Caller-saved: %eax, %ecx, %edx
  - Callee-saved: %ebx, %esi, %edi

Register Convention

This is why lab 4 had the comment about using only %eax, %ecx, and %edx.

- Caller-saved: %eax, %ecx, %edx
  - If the caller wants to preserve these registers, it must save them prior to calling callee.
  - The callee is free to trash these; the caller will restore if needed.

- Callee-saved: %ebx, %esi, %edi
  - If the callee wants to use these registers, it must save them first, and restore them before returning.
  - The caller can assume these will be preserved.

Running Out of Registers

- Some computations require more than six registers to store temporary values.

- *Register spilling*: The compiler will move some temporary values to memory, if necessary.
  - Values pushed onto stack, popped off later
  - No explicit variable declared by user

IA32 addressing modes

- Direct addressing (what we've seen so far)

```
-4(%ebp)
```

offset

base address

- Indexed addressing

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

base address

index

scale

Indexed Addressing Mode

- General form:

```
offset(%base, %index, scale)
```

- Translation: Access the memory at address…

```
base + (index * scale) + offset
```

Discussion: when would this mode be useful?

Example

ECX: Array base address

Registers:

%ecx	0x0824
%edx	2

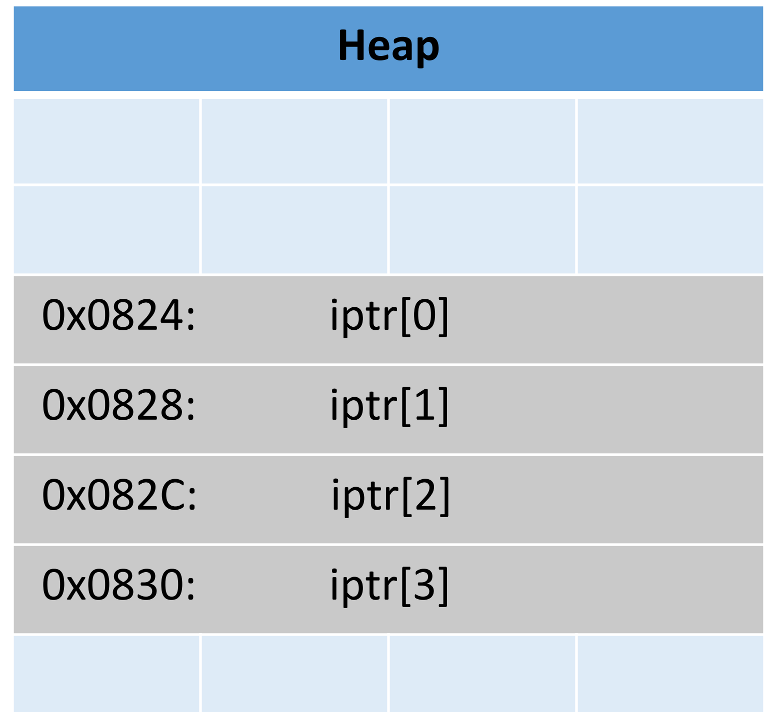
Suppose `i` is at `%ebp-8`, and equals 2.

User says:

```
float_arr[i] = 9;
```

Translates to:

```
movl -8(%ebp), %edx
```



Example

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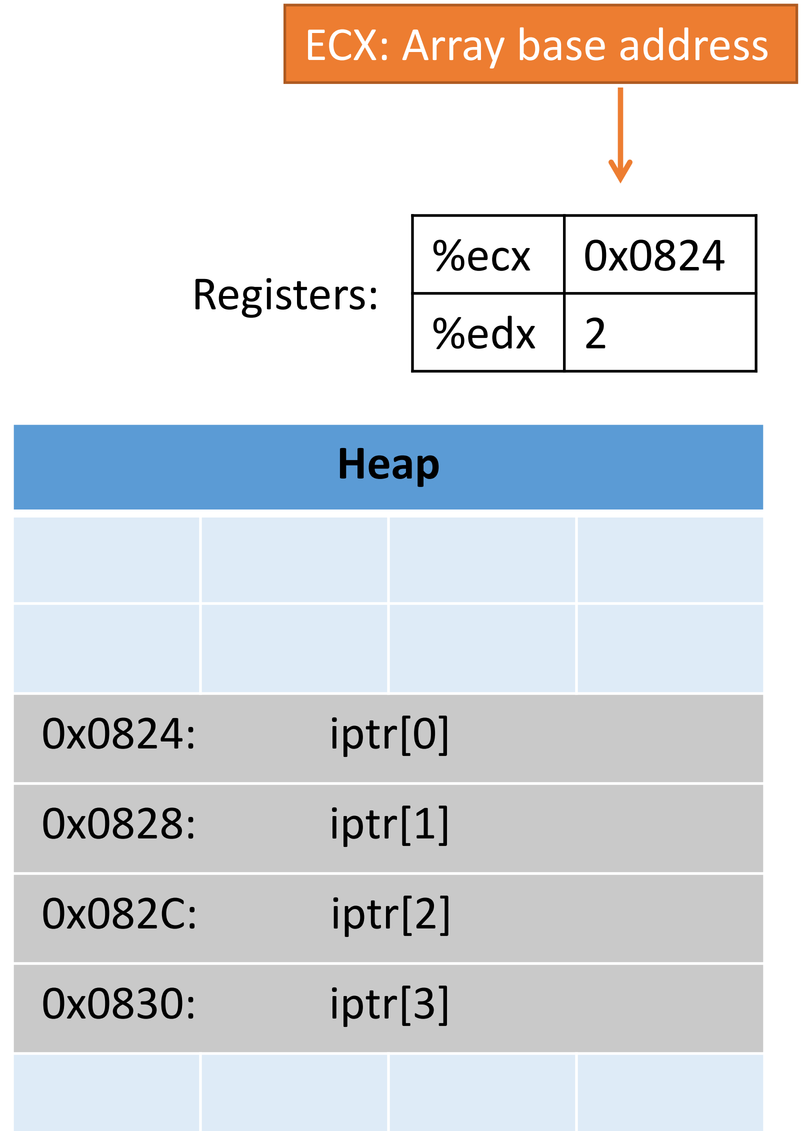


Example

Suppose `i` is at `%ebp-8`, and equals 2.

User says:

```
float_arr[i] = 9;
```

Translates to:

```
movl -8(%ebp), %edx
movl $9, (%ecx, %edx, 4)
```

ECX: Array base address

Registers:

%ecx	0x0824
%edx	2

Heap	
0x0824:	iptr[0]
0x0828:	iptr[1]
0x082C:	iptr[2]
0x0830:	iptr[3]

Example

Suppose `i` is at `%ebp-8`, and equals 2.

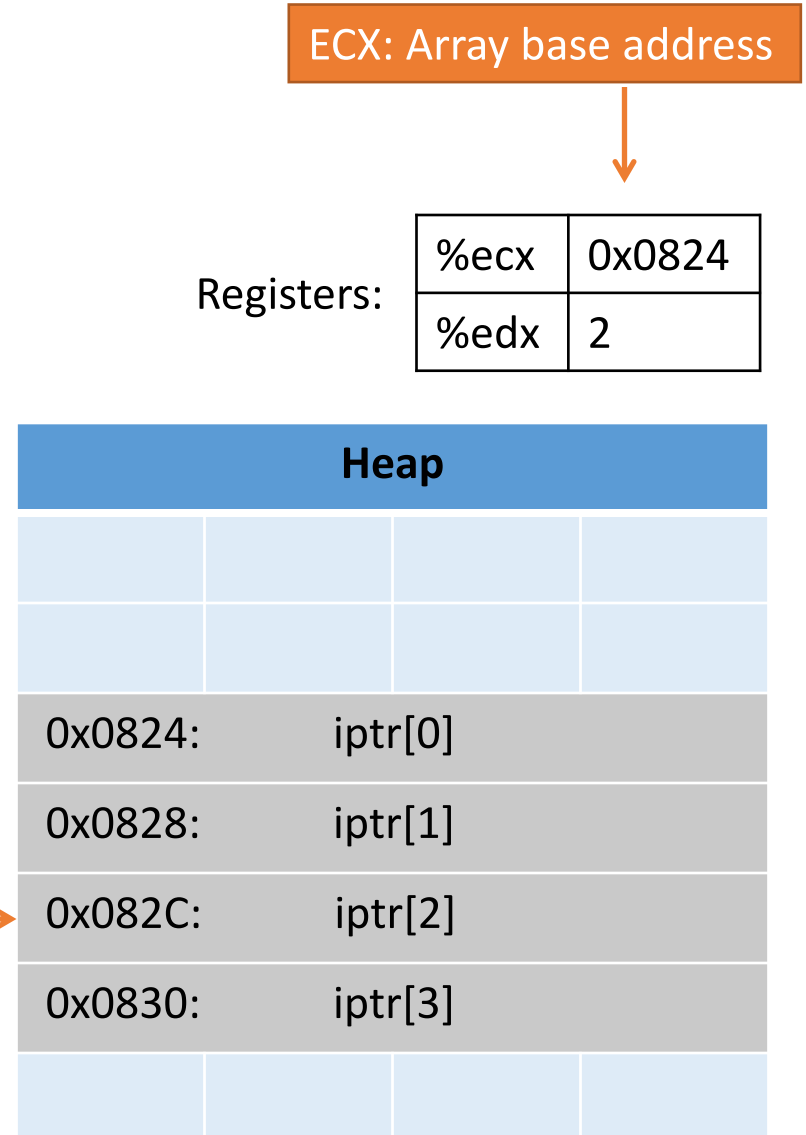
User says:

```
float_arr[i] = 9;
```

Translates to:

```
movl -8(%ebp), %edx
movl $9, (%ecx, %edx, 4)
```

```
0x0824 + (2 * 4) + 0
0x0824 + 8 = 0x082C
```



What is the final state after this code?

```
addl $4, %eax
movl (%eax), %eax
sall $1, %eax
movl %edx, (%ecx, %eax, 2)
```

(Initial state)
Registers:

%eax	0x2464
%ecx	0x246C
%edx	7

Memory:

Heap	
0x2464:	5
0x2468:	1
0x246C:	42
0x2470:	3
0x2474:	9

Translate this array access to IA32

```
int *x;
x = malloc(10*sizeof(int));

...

x[i] = -12;
```

At this point, suppose that the variable `x` is stored at `%ebp+8`. And `i` is in `%edx`. Use indexed addressing to assign into the array.

The `leal` instruction

- Uses the circuitry that computes addresses.
- Doesn't actually access memory.
- Compute an "address" and store it in a register.
- Can use the full version of indexed addressing.

```
leal offset(%base, %index, scale), dest
```

```
leal 5(%eax, %esi, 2), %edx
#put %eax + 5 + (2*%esi) in %edx
```