CS 4400

Computer Systems

LECTURE 7

Representing procedure calls

New to C?: structs, unions, and functions

Procedure Calls

- A procedure call involves passing *data* (via procedure arguments and return value) and *control* from one part of the program to another.
- Each invocation of a procedure must allocate and deallocate memory in which to store its local variables.
- For IA32, very simple instructions transfer control:
  - `call`, `leave`, `ret`
- The compiler must generate additional instructions for passing arguments and allocation/deallocation of locals.

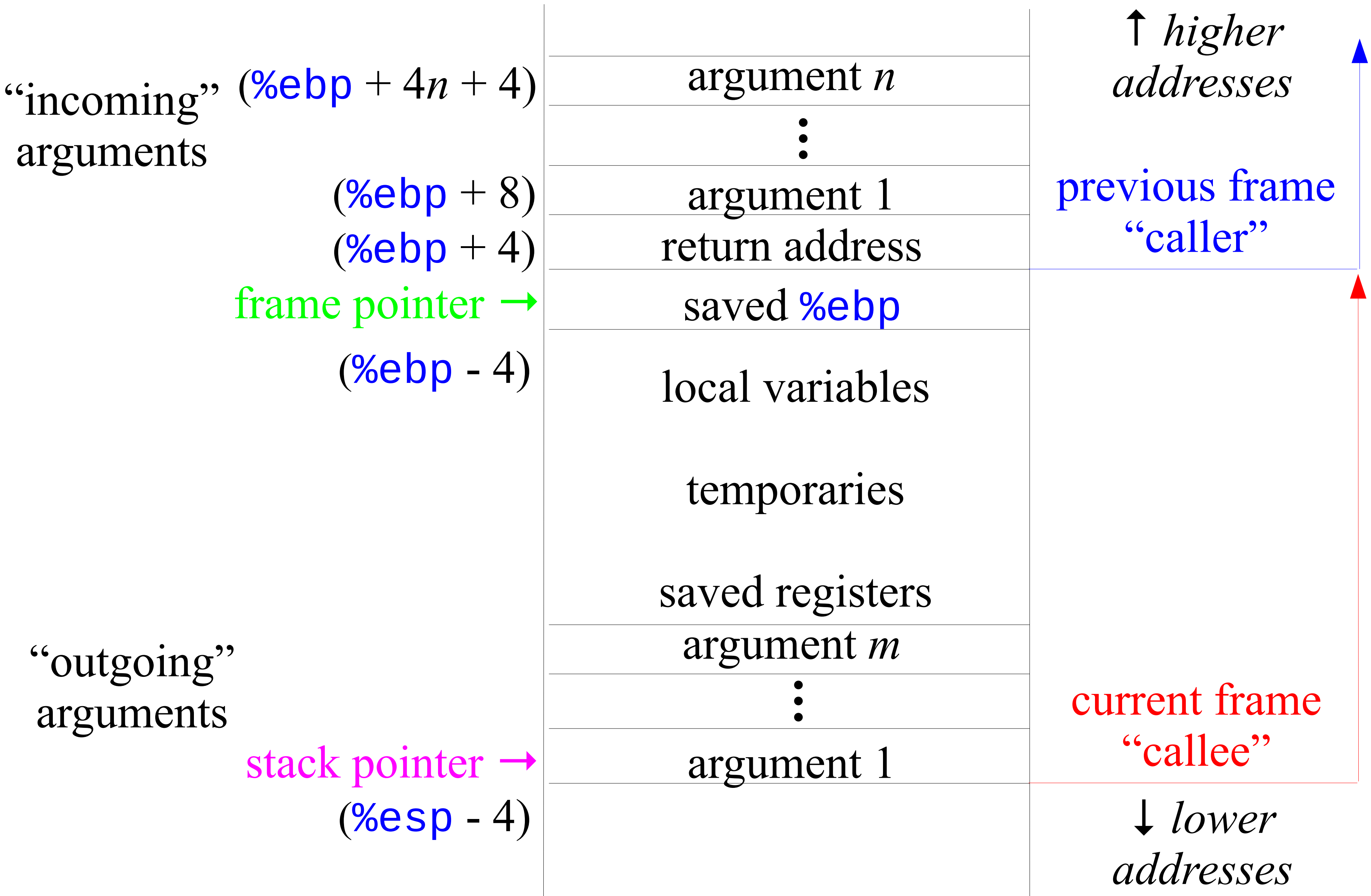
Run-Time Stack

- We use a *stack* as the LIFO data structure for holding local variable instantiations.
- A "real" stack supports only *push* and *pop* operations.
  - However, local variables may be pushed (upon function entry) and popped (upon function exit) in large batches.
  - Also, after pushing on many variables, we may want to continue accessing variables deep in the stack.
  - Thus, we treat the stack as a large array.
- The *stack pointer* is a special register (`%esp`) that always points to the "top" of the stack.

Stack Frame

- A procedure's *stack frame* (or activation record) is the area on the stack devoted to its local variables, arguments, return address, and other temporaries.
- Usually, run-time stacks start at high memory addresses and grow to low memory addresses.
  - What addresses are "allocated"? What addresses are "garbage"?
- Often, each computer architecture has a standard stack frame layout, making it possible for procedures written in one language to call procedures written in another.

Stack Frame Layout



More on Stack Frames

- Because the stack pointer can move while a procedure is executing, information is accessed using its address relative to the frame pointer.
- When possible, local variables are stored in registers. Locals must reside in the stack when:
  - there are not enough registers
  - a local variable has its address taken
  - a local variable is an array or structure
- The return address is the address of the next instruction after the `call` instruction in the caller.

Transferring Control

- `call` *label* and `call` `*`*operand*
  - push the return address on the stack (`%eip` + 4)
  - jump to the instruction indicated by *label* (or *operand*)
- `leave`
  - prepare stack so that stack pointer points to return address
  - equivalent to
    ```
    movl %ebp,%esp
    popl %ebp
    ```
- `ret`
  - pops return address from stack and jumps to that address

Register Usage

- All procedures must share a single set of registers.
- It is critical that the callee does not overwrite the contents of registers that the caller is still planning to use.
- *caller-save* registers: `%eax`, `%edx`, `%ecx`

  callee-save registers: `%ebx`, `%esi`, `%edi`
- *Example*:

```
int P(int x) {
    int y  = x * x;
    int z = Q(y);
    return y + z;
}
```

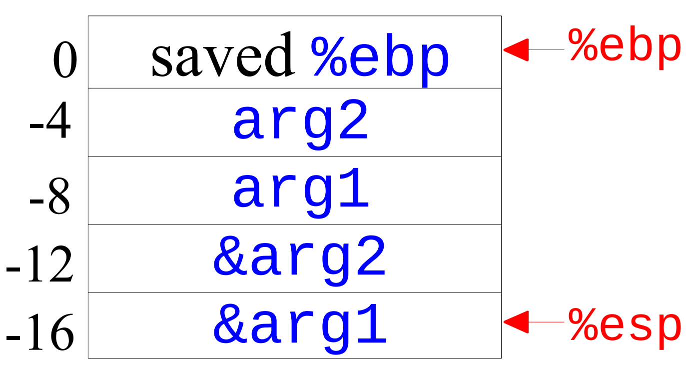
In what ways can `P` ensure that the value of `y` is available after `Q` returns? What is most efficient?

```c
int swap_add(int *xp, int *yp) {
  int x = *xp;
  int y = *yp;

  *xp = y;
  *yp = x;
  return x + y;
}

int caller() {
  int arg1 = 534;
  int arg2 = 1057;
  int sum = swap_add(&arg1, &arg2);
  int diff = arg1 - arg2;

  return sum * diff;
}
```

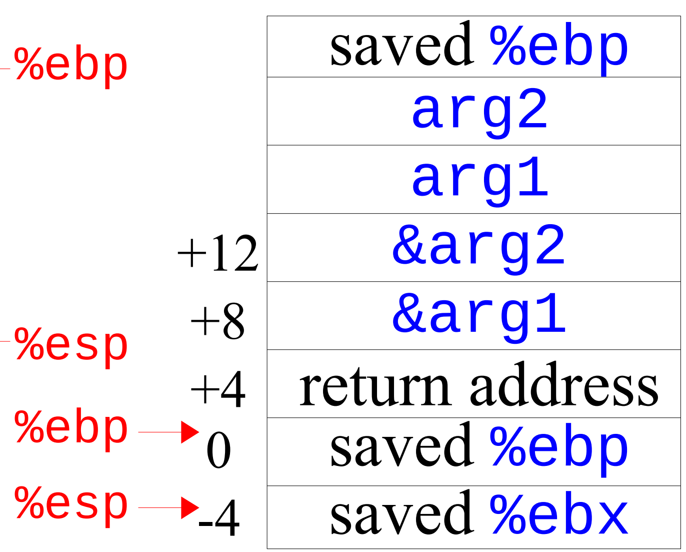
```
caller:
   ...
   leal -4(%ebp),%eax
   pushl %eax
   leal -8(%ebp),%eax
   pushl %eax
   call swap_add
   movl %eax,%edx
   ...
swap_add:
   pushl %ebp
   movl %esp,%ebp
   pushl %ebx
   movl 8(%ebp),%edx
   movl 12(%ebp),%ecx
   movl (%edx),%ebx
   movl (%ecx),%eax
   movl %eax,(%edx)
   movl %ebx,(%ecx)
   addl %ebx,%eax
   popl %ebx
   movl %ebp,%esp
   popl %ebp
   ret
```

prologue: pushl %ebp … movl 12(%ebp),%ecx

epilogue: popl %ebx … ret



just before call



in body of swap_add

Exercise: Procedures

```
int proc(void) {
  int x, y;
  scanf(“%x %x”, &y, &x);
  return x-y;
}
```

```
proc:
  pushl %ebp
  movl %esp,%ebp
  subl $24,%esp
  addl $-4,%esp
  leal -4(%ebp),%eax
  pushl %eax
  leal -8(%ebp),%eax
  pushl %eax
  pushl $.LC0 ;string
  call scanf
  movl -8(%ebp),%eax
  movl -4(%ebp),%edx
  subl %eax,%edx
  movl %edx,%eax
  movl %ebp,%esp
  popl %ebp
  ret
```

initially:

`%esp` `0x800040`

`%ebp` `0x800060`

- Where are the locals stored?
- What is the value of `%esp` just before the call?
- How does run-time stack look?
- How are recursive procedure calls implemented?

New to C?: Structures

- In C, a user-defined type is accomplished with a `struct`.
- *Example:*

```
struct element {
  char name[10];
  char symbol[5];
  float weight;
  float mass;
};
```

- The new type is `struct element`.
- Declaration of a structure variable

```
struct element e1;
```

allocates contiguous storage for all structure members.

(10 + 5 + 2 * `sizeof(float)` bytes)

More on Structures

- To access a member of the structure variable, use the dot `.` operator.

```
e1.mass = 3.0;
strcpy(e1.name, “hydrogen”);
```

- Use `typedef` to avoid the awkward two-word type.

```
typedef struct element {
  char name[10];
  char symbol[5];
  float weight;
  float mass;
} ELT;

ELT e1;
```

- What is the difference in a structure and an array?

Pointers to Structures

- As with objects in C++, the pointer operator `->` can be used with pointers to structures.

```
ELT e1;
ELT* elt_ptr = &e1;
printf(“%s”, (*elt_ptr).symbol);
printf(“%s”, elt_ptr->symbol);
```

- A self-referential structure declaration has a member that is a pointer to an instance of itself.

```
typedef struct node {
  int data;
  struct node* next;
} NODE;
... x->next->next->data ...
```

New to C?: Unions

- Unions provide a way for a single object to be referenced according to multiple types.
- *Example:*

```
union u {
  char c;
  int i[2];
  double v;
} x;
x.v = 4.5;
printf("%d %d\n", x.i[0], x.i[1]);
```

- `sizeof(union u)` is the max size of any of its fields.
- Technically, you should only read the variant you wrote.

New to C?: Dynamic Memory Alloc

- For allocation of memory at run time, library routine `malloc` is used.
  - arguments specify number of bytes to be allocated
  - return value is a pointer to the allocated memory or NULL
- `malloc` allocates one contiguous block (of specified size).

```
NODE* head = malloc(sizeof(NODE));  // implicit
head->next = malloc(sizeof(NODE));  // cast
```

- To release dynamically-allocated memory, the library routine `free` is used.
  - argument is the pointer to the block of memory to be released

```
free(ptr);
```

New to C?: Parameter Passing

- In C, parameters are passed by value.
  - get the effect of call-by-reference by passing an address

- Array names are pointer constants.

- For a structure variable argument, its value is its content.

  unlike Java, where a declaration `ELT e` means that the value of `e` is a reference to an `ELT` object

- Which parameters may be modified from caller's view?

```
foo(char a, int b[], ELT c, float* d, NODE* e)
```

New to C?: Function Pointers

- Like an array name, a function name is a pointer constant.
- Why have function pointers? We can pass a function as an argument to another function.

```
void sort(int (*fn)(int, int), int arr[], int size) { ... }
int compare_incr(int a, int b) { return a < b; }
int compare_decr(int a, int b) { return a > b; }

int main(int argc, char* argv[]) {
  int a[8] = {5, -8, 19, 0, 2, 11, -90, 34};
  if(strcmp(argv[1], "ascending_order") == 0 )
    sort(compare_incr, a, 8);
  else
    sort(compare_decr, a, 8);
  return 0;
}
```