# CMSC 216
# Introduction to Computer Systems
# Lecture 16
# Procedures,
# & Process Control

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## Administrivia

- Project 2 grades visible, reports sent out later today
- Project 3 secret tests available on Grace after late deadline
- Project 4 posted today, with public tests to follow by tomorrow
- Read Sections 8.2-8.5, on process control



Section 3.7, Bryant and O'Hallaron

## PROCEDURE IMPLEMENTATION



## Simple function call example

```
0x000: 308400100000 | main:    irmovl $0x1000, %esp
0x006: 801d000000   |          call   f
0x00b: 308301000000 |          irmovl $1, %ebx
0x011: 40384c000000 |          rmmovl %ebx, n
0x017: 8023000000   |          call   g
0x01c: 10           |          halt
0x01d: 8023000000   | f:       call   g
0x022: 90           |          ret
0x023: 50184c000000 | g:       mrmovl n, %ecx
0x029: 308000000000 | Loop:    irmovl $0, %eax
0x02f: 6001         |          addl   %eax, %ecx
0x031: 714b000000   |          jle    EndLoop
0x036: f318         |          wrint  %ecx
0x038: 308201000000 |          irmovl $1, %edx
0x03e: 6121         |          subl   %edx, %ecx
0x040: 40184c000000 |          rmmovl %ecx, n
0x046: 7029000000   |          jmp    Loop
0x04b: 90           | EndLoop: ret
0x04c:              |          .align 4
0x04c: 02000000     | n:       .long 2
```

# Simple recursion example

```
int n = 3;

void f();

int main() {
  f();
  return 0;
}
void f() {
  if (n > 0) {
    printf("%d", n--);
    f();
  }
}
```

```
main:     irmovl $0x1000, %esp
          call   f
          halt
f:        mrmovl n, %ecx
          irmovl $0, %eax
          addl   %eax, %ecx
          jle    EndIf
          wrint  %ecx
          irmovl $1, %eax
          subl   %eax, %ecx
          rmmovl %ecx, n
          call   f
EndIf:    ret
          .align 4
n:        .long 3
```



# Simple recursion example

```
0x000: 308400100000 | main:    irmovl $0x1000, %esp
0x006: 800c000000   |          call   f
0x00b: 10           |          halt
0x00c: 501838000000 | f:       mrmovl n, %ecx
0x012: 308000000000 |          irmovl $0, %eax
0x018: 6001         |          addl   %eax, %ecx
0x01a: 7134000000   |          jle    EndIf
0x01f: f318         |          wrint  %ecx
0x021: 308001000000 |          irmovl $1, %eax
0x027: 6101         |          subl   %eax, %ecx
0x029: 401838000000 |          rmmovl %ecx, n
0x02f: 800c000000   |          call   f
0x034: 90           | EndIf:   ret
0x038:              |          .align 4
0x038: 03000000     | n:       .long 3
```

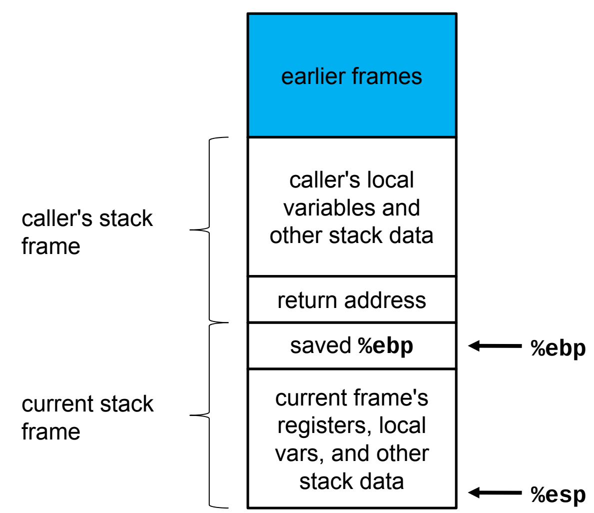


# Local automatic variables

- These are also kept on the stack
- Multiple versions of the "same" variable can be kept; think of local variables in a recursive function
- We organize the stack into *frames* - one frame exists for each active (not yet returned) function call
  - We use the register **%ebp** to point to the first element in the current frame (the *frame pointer*)



# Stack frames



# Leaving a function

- x86 has a **`leave`** instruction, to make things easier for assembly programmers just before a return
- The equivalent Y86 code is:

```
rrmovl %ebp, %esp  # give up current frame
popl %ebp  # restore caller's frame pointer
```

- This puts the stack pointer in the correct position so that a subsequent **`ret`** instruction will return to the correct location

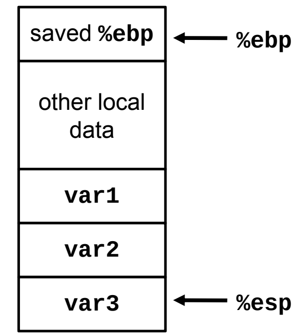


# Storing local variables

- These are stored at the top of the stack (nearest to **`%esp`**)
- Inside the current frame:

```
void f() {
  int var1, var2, var3;
  ...
}
```

- Accessed by offsets from **`%esp`**






# Local variable example

```
void f();

int main() {
  f();
  f();
  return 0;
}

void f() {
  int a, b, c, d;
  a = 30;
  b = 25;
  c = a + b;
  printf("%d", c);
  d = 300;
}
```

```
main:   irmovl $0x1000, %esp  # init stack ptr
        call   f
        call   f
        halt
f:      pushl  %ebp           # save old frame ptr
        rrmovl %esp, %ebp     # set new frame ptr
        irmovl $16, %eax      # sub 16 (4 ints)
        subl   %eax, %esp     #  from stack ptr
        irmovl $30, %eax      # a = 30
        rmmovl %eax, 12(%esp) # store a in stack
        irmovl $25, %eax      # b = 25
        rmmovl %eax, 8(%esp)  # store b in stack
        mrmovl 12(%esp), %eax # load a
        mrmovl 8(%esp), %ecx  # load b
        addl   %eax, %ecx     # c = a + b
        rmmovl %ecx, 4(%esp)  # store c in stack
        mrmovl 4(%esp), %eax  # load c
        wrint  %eax           # print c
        irmovl $300, %eax     # d = 300
        rmmovl %eax, 0(%esp)  # store d in stack
        rrmovl %ebp, %esp     # reset stack ptr
        popl   %ebp           # restore old frame
        ret
```



# Passing parameters

- Similar to local variables, but are pushed on the stack in the calling frame
- Accessed by offsets of **`%ebp`**; a function has to reach into the calling frame to access these
- If you're just passing one or two parameters, you may be able to just store the values in registers (faster than stack storage), but we'll just cover stack usage here

# Parameter example

```
void f(int);

int main() {
  f(72);
  printf("\n");
  return 0;
}

void f(int i) {
  printf("%d", i);
}
```

```
main: irmovl $0x1000, %esp   # init stack ptr
      irmovl $72, %eax       # load arg to reg
      pushl  %eax            # push arg on stack
      call   f
      irmovl $10, %eax       # printf("\n");
      wrch   %eax
      halt                   # return 0;
f:    pushl  %ebp            # save old frame ptr
      rrmovl %esp, %ebp      # set new frame ptr
      mrmovl 8(%ebp), %eax   # load i param
      wrint  %eax            # print i
      rrmovl %ebp, %esp      # reset stack ptr
      popl   %ebp            # restore frame ptr
      ret
```



# Recursive parameter example

```
void f(int);

int main() {
  f(5);
  printf("\n");
  return 0;
}

void f(int i) {
  if (i > 0)
    f(i-1);
  printf("%d", i);
}
```

```
main:  irmovl $0x1000, %esp   # init stack ptr
       irmovl $5, %eax        # load arg to reg
       pushl  %eax            # push arg on stack
       call   f
       irmovl $10, %eax       # printf("\n");
       wrch   %eax
       halt                   # return 0;
f:     pushl  %ebp            # save old frame ptr
       rrmovl %esp, %ebp      # set new frame ptr
       mrmovl 8(%ebp), %eax   # load i param
       irmovl $0, %ecx        # load 0 to reg
       addl   %ecx, %eax      # test value of i
       jle    EndIf           # if i > 0, rec. call
       irmovl $-1, %ecx
       addl   %eax, %ecx      # create i-1 arg
       pushl  %ecx            # push arg on stack
       call   f
EndIf: mrmovl 8(%ebp), %eax   # load i param again
       wrint  %eax            # print i
       rrmovl %ebp, %esp      # reset stack ptr
       popl   %ebp            # restore frame ptr
       ret
```



# Register usage conventions

- Notice in the last example we had to reload the value of the parameter **`i`** after the recursive function call, because recursive calls to **`f`** would destroy the value in **`%eax`**
- A convention has developed as to which registers can be used by a procedure without destroying data from the caller
- When P calls Q...
  - Q can do anything it wants with the *caller save* registers; P is required to store these before the call if there's important data there
  - Q must save the values of the *callee save* registers, and restore them before returning (if Q uses these registers); P can use these to maintain data across function calls
- For reference (i.e., don't memorize this), and by convention, **`%eax`**, **`%edx`**, and **`%ecx`** are caller save, while **`%ebx`**, **`%esi`**, and **`%edi`** are callee save



# Using callee save registers

```
f:     pushl  %ebp
       rrmovl %esp, %ebp

       mrmovl 8(%ebp), %eax
       irmovl $0, %ecx
       addl   %ecx, %eax
       jle    EndIf
       irmovl $-1, %ecx
       addl   %eax, %ecx
       pushl  %ecx
       call   f

EndIf: mrmovl 8(%ebp), %eax
       wrint  %eax
       rrmovl %ebp, %esp
       popl   %ebp
       ret
```

```
f:     pushl  %ebp
       rrmovl %esp, %ebp
       pushl  %ebx            # store callee save
       mrmovl 8(%ebp), %ebx   # holds value of i
       irmovl $0, %ecx
       addl   %ecx, %ebx
       jle    EndIf
       irmovl $-1, %ecx
       addl   %ebx, %ecx
       pushl  %ecx
       call   f
       popl   %ecx            # pop arg off stack
EndIf: wrint  %ebx            # no need for reload
       popl   %ebx            # restore val of reg
       rrmovl %ebp, %esp
       popl   %ebp
       ret
```

# Returning values

- In Y86 (and x86), the convention is to store return values in **`%eax`**, and have the caller read this value after the call returns
- This works well enough for integers, but what about something like structs?
  - If the struct has ≤ 3 values, you could use all the caller save registers to pass the value back
  - The struct could be placed in the stack and accessed immediately after the function call



# Example of returning values

```c
int f(int);

int main() {
  static int n;
  n = f(5);
  printf("%d", n);
  printf("\n");
  return 0;
}

int f(int i) {
  return (i+1) * 3;
}
```

```
main:  irmovl $0x1000, %esp   # init stack ptr
       irmovl $5, %eax        # load arg to reg
       pushl  %eax            # push arg on stack
       call   f
       rmmovl %eax, n         # store return value
       mrmovl n, %eax         # load value of n
       wrint  %eax
       irmovl $10, %eax       # printf("\n");
       wrch   %eax
       halt                   # return 0;

f:     pushl  %ebp            # save old frame ptr
       rrmovl %esp, %ebp      # set new frame ptr
       mrmovl 8(%ebp), %eax   # load param i
       irmovl $1, %ecx        # m + 1
       addl   %ecx, %eax      # add 1
       irmovl $3, %ecx        # for * 3
       multl  %ecx, %eax      # multiply by 3
       rrmovl %ebp, %esp      # reset stack ptr
       popl   %ebp            # restore frame ptr
       ret

       .align 4
n:     .long 0
```