X86 Assembly Programming with GNU assembler

Lecture 7

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Some Slides based on those from
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Admin

- Reading: Chapter 3
- Note about pointers: You must explicitly initialize/set to NULL

Assembly Programming (x86)

- Quick Instruction Review
- Assembly Language
- Simple one function program
- High level constructs (control)
- Interfacing to a C program
- Procedure Calling Conventions

Some Arithmetic and Logical Operations

- Two Operand Instructions:
  - Format Computation

addl	Src,Dest	Dest = Dest + Src	
subl	Src,Dest	Dest = Dest - Src	
imull	Src,Dest	Dest = Dest * Src	
sall	Src,Dest	Dest = Dest << Src	Also called shll
sarl	Src,Dest	Dest = Dest >> Src	Arithmetic
shrl	Src,Dest	Dest = Dest >> Src	Logical
xorl	Src,Dest	Dest = Dest ^ Src	
andl	Src,Dest	Dest = Dest & Src	
orl	Src,Dest	Dest = Dest | Src	

- Watch out for argument order!
- No distinction between signed and unsigned int (why?)

Some Arithmetic Operations

- One Operand Instructions

incl	Dest	Dest = Dest + 1
decl	Dest	Dest = Dest - 1
negl	Dest	Dest = - Dest
notl	Dest	Dest = ~Dest

- See book for more instructions
- Note: suffix “l” is for 32-bit values, “b” for byte, “w” for 16-bit

Address Computation Instruction

- `leal` Src,Dest
  - Src is address mode expression
  - Set Dest to address denoted by expression
- Uses
  - Computing addresses without a memory reference
    - E.g., translation of `p = &x[i];`
  - Computing arithmetic expressions of the form x + k*y
    - k = 1, 2, 4, or 8
- Example

```
int mul12(int x)
{
  return x*12;
}
```

Converted to ASM by compiler:

```
leal (%eax,%eax,2), %eax   ;t <- x+x*2
sall $2, %eax              ;return t<<2
```

Condition Codes (Implicit Setting)

- Single bit registers
  - CF Carry Flag (for unsigned) SF Sign Flag (for signed)
  - ZF Zero Flag OF Overflow Flag (for signed)
- Implicitly set (think of it as side effect) by arithmetic operations
- Not set by lea instruction
- Explicitly set by compare and test instructions
- Allow for conditional change of PC via jump instructions

Procedure Control Flow

- Use stack to support procedure call and return
- Procedure call: **`call label`**
  - Push return address on stack
  - Jump to label
- Return address:
  - Address of the next instruction right after call
  - Example from disassembly

```
804854e:  e8 3d 06 00 00     call   8048b90 <main>
8048553:  50                 pushl  %eax
```

  - Return address = `0x8048553`
- Procedure return: **`ret`**
  - Pop address from stack
  - Jump to address

X86 w/ Gnu Assembly Language

- One instruction per line.
- Numbers are base-10 integers or Hex w/ leading 0x.
- Identifiers: alphanumeric, _, . string starting in a letter or _
- Labels: identifiers starting at the beginning of a line followed by ":"
- Comments: everything following # till end-of-line.
- Directives: convey information to the assembler
- Instruction format: Space and "," separated fields.
  - [Label:] <op> src, dest [# comment]
  - [Label:] .Directive [arg1], [arg2], . . .

Assembly Language (cont.)

- Directives: tell the assembler what to do...
- Format "."<string> [arg1], [arg2] . . .

- Examples

```
.data   [address]  # start a data segment.  [optional begining address]
.text  [address]   # start a code segment.
.globl             # declare a label externally visible
.ascii <string>    # store a string in memory.
.asciiz <string>   # store a null terminated string in memory
.long w1, w2, . . . , wn  # store n 32-bit values in memory.
.align n           # align segment on 2^n  byte boundary.
```

A simple function

- Add two numbers together x and y

```
.text                       # declare text segment
.globl sum                  # declare function name for external call

sum:                        # label for function
    movl x, %edx            # load M[x] into %edx
    movl y, %eax            # load M[y] into %eax
    addl %edx, %eax         # %eax = %eax + %edx
    movl %eax, x            # store %eax into M[x]
    ret                     # return to calling function

.data                       # declare data segment
x: .long 10                 # initialize x to 10
y: .long 2                  # initialize y to 2
```

Typical Code Segments-- IF

```
if (x != y)
    x = x + y;
y = 2;
```

- General Rule is to invert condition

```
if (x == y) goto skip
    x = x + y
skip: y = 2;
```

- Assume %ecx contains x and %edx contains y

```
    cmpl %ecx, %edx
    je skip
    addl %edx, %ecx
skip:
    movl $2, %edx
```

Typical Code Segments– IF-else

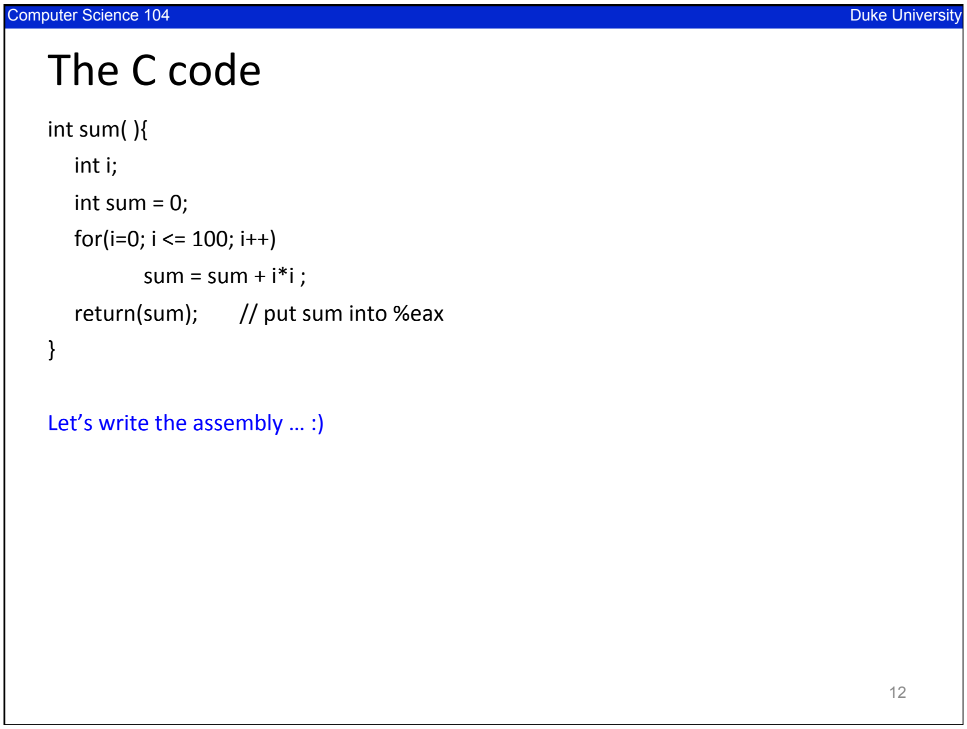
```
if (x != y)
    x = x + y;
else
  x = x – y;
```

- Invert condition check and use goto

```
if (x == y) goto L1
    x = x + y;
    goto done
L1: x = x - y;
done:
```

- Assume %ecx contains x and %edx contains y

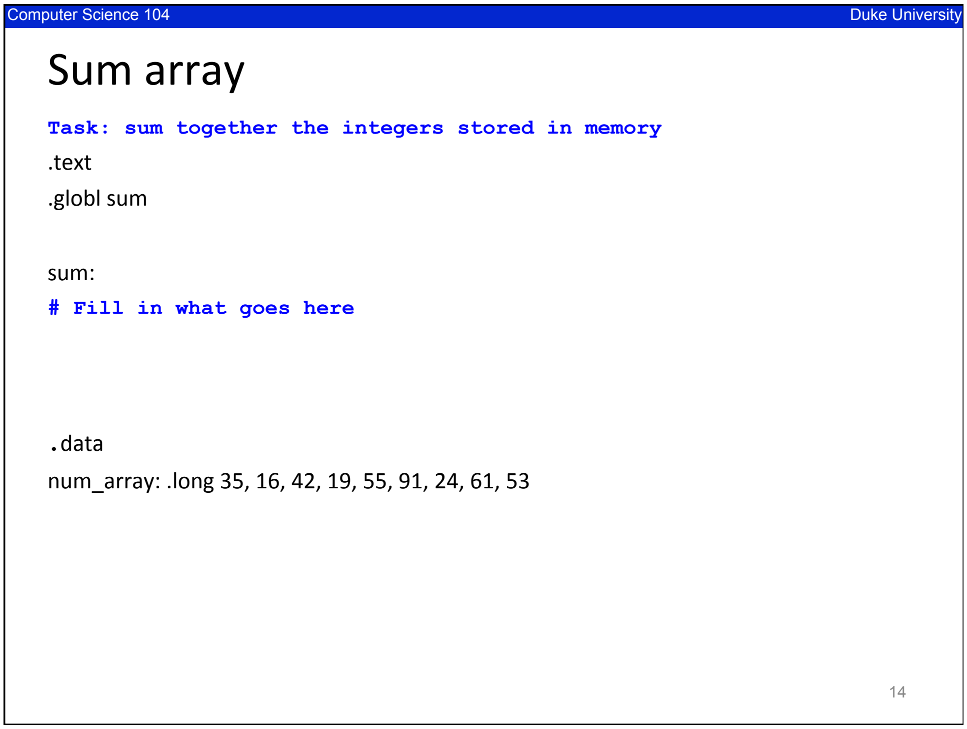
```
    cmpl %ecx, %edx          # compute condition
    je L1               # checking !(condition)
    addl %edx, %ecx          # x = x + y
    jmp done
L1:
    subl %edx, %ecx          # x = x - y
done:
```



The C code

```
int sum( ){
    int i;
    int sum = 0;
    for(i=0; i <= 100; i++)
              sum = sum + i*i ;
    return(sum);      // put sum into %eax
}
```

Let's write the assembly … :)



Sum array

Task: sum together the integers stored in memory

```
.text
.globl sum

sum:
# Fill in what goes here



.data
num_array: .long 35, 16, 42, 19, 55, 91, 24, 61, 53
```

Calling an Assembly Function from C

- Main in normal C file
- Declare function using "extern"
  - E.g., extern int foo();
  - Foo is our assembly function in a .s file

Review: Procedure Call and Return

```
int equal(int a1, int a2) {
    int tsame;
    tsame = 0;
    if (a1 == a2)
            tsame = 1;
    return(tsame);
}
main()
{
    int x,y,same;
    x = 43;
    y = 2;
    same = equal(x,y);
    // other computation
}
```

0x10000	`movl $43, %ecx`
0x10004	`movl $2, %edx`
0x10008	`call 0x30408`

0x30408	`movl $0, %eax`
0x3040c	`cmpl %ecx, %edx`
0x30410	`jne 0x30418`
0x30414	`movl $1, %eax`
0x30418	`addl %edx, %ecx`
0x3041c	`ret`

PC	M[%esp]
0x10000	??
0x10004	??
0x10008	??
0x30408	0x1000c
0x3040c	0x1000c
0x30410	0x1000c
0x30414	0x1000c
0x30418	0x1000c
0x3041c	0x1000c
0x1000c	??

Procedure Call GAP

ISA Level

- call and return instructions

C Level

- Local Name Scope
  - change tsame to same
- Recursion
- Arguments/parameters and Return Value (functions)

Assembly Level

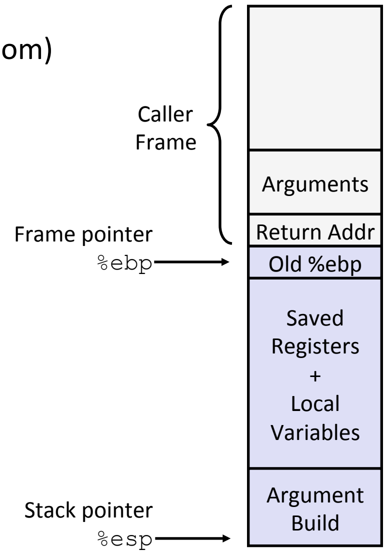
- Must bridge gap between HLL and ISA
- Supporting Local Names
- Passing Arguments/Parameters (arbitrary number?
- What data structure?

Procedure Call (Stack) Frame

- Procedures use a frame in the stack to:
  - Hold values passed to procedures as arguments.
  - Save registers that a procedure may modify, but which the procedure’s caller does not want changed.
  - To provide space for local variables.
    (variables with local scope)
  - To evaluate complex expressions.

IA32/Linux Stack Frame

- Current Stack Frame (“Top” to Bottom)
  - “Argument build:”
    Parameters for function about to call
  - Local variables
    If can’t keep in registers
  - Saved register context
  - Old frame pointer
- Caller Stack Frame
  - Return address
    - Pushed by call instruction
  - Arguments for this call



Register Saving Conventions

- When procedure `yoo` calls `who`:
  - `yoo` is the caller
  - `who` is the callee
- Can Register be used for temporary storage?

```
yoo:
    • • •
    movl  $15213, %edx
    call  who
    addl  %edx, %eax
    • • •
    ret
```

```
who:
    • • •
    movl  8(%ebp), %edx
    addl  $18243, %edx
    • • •
    ret
```

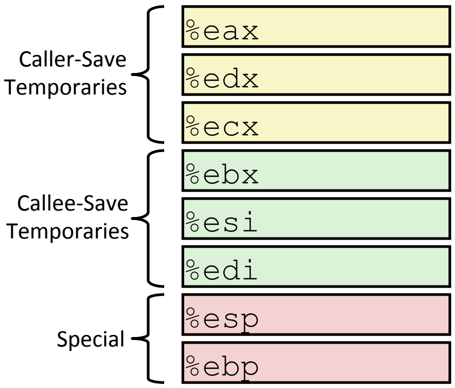
  - This could be trouble ➙ something should be done!
    - Need some coordination

Register Saving Conventions

- When procedure `yoo` calls `who`:
  - `yoo` is the caller
  - `who` is the callee
- Can Register be used for temporary storage?
- Conventions
  - "Caller Save"
    - Caller saves temporary values in its frame before the call
  - "Callee Save"
    - Callee saves temporary values in its frame before using

IA32/Linux+Windows Register Usage

- %eax, %edx, %ecx
  - Caller saves prior to call if values are used later
- %eax
  - also used to return integer or pointer value
- %ebx, %esi, %edi
  - Callee saves if wants to use them
- %esp, %ebp
  - special form of callee save
  - Restored to original values upon exit from procedure



IA32/GCC Procedure Calling Conventions

Calling Procedure

- Step-1: Save caller-saved registers
  - Save registers %eax, %ecx, %edx if they contain live values at the call site.
- Step-2: Setup the arguments:
  - Push arguments onto the stack in reverse order
- Step-3: Execute a call instruction.

IA32/GCC Calling Conventions (cont.)

Called Routine

- Step-1: Update the frame pointer

```
pushl %ebp
movl %esp, %ebp
```

- Step-2: Allocate space for frame
  - Subtract the frame size from the stack pointer

    ```
    subl $<frame-size>, %esp
    ```

  - Space is for local variables and saved registers
  - May often allocate more space than necessary.
- Step-3: Save callee-saved registers in the frame.
  - Registers %ebx, %esi, %edi are saved if they are used.

IA32/GCC Calling Conventions (cont.)

On return from a call

- Step-1: Put return value in register %eax.
  (if value is returned)
- Step-2: Restore callee-saved registers.
  - Restore %ebx, %esi, %edi if needed
- Step-3: "Pop" the stack

  leave

  - Equivalent to

  movl %ebp, %esp

  popl %ebp
- Step-4: Return
  - ret # %eip = M[%esp]; %esp = %esp - 4

C Function call with one parameter

```
#include <stdio.h>
#include <stdlib.h>
// declare the function as externally defined
// computes sum of elements 0 to i of an array defined in sum_array
extern int sum_array(int i);

int main(void) {
   int result;
   result = sum_array(7);
   printf("Array sum = %d\n",result);
   return EXIT_SUCCESS;
}
```

Sample Function

```
.text                           # declare the text segment
.globl sum_array                # declare the function label (note the _ in this label)
                                # the C program calls sum(int)
sum_array:
   pushl %ebp                   # save old frame pointer
   movl %esp, %ebp              # set new stack pointer
   movl 8(%ebp), %eax           # read arg1 from stack, put into %eax
   leal num_array, %edx         # load address of num_array into %edx  (p = &num_array)
   leal (%edx,%eax,4), %ecx     # load address of num_array+arg into %ecx
   movl $0, %eax                # move 0 to running sum (%eax)
loop:                           # label for loop structure
   addl (%edx), %eax            # add value *p to running sum (%eax)
   addl $4, %edx                # increment pointer in memory (p++)
   cmpl %ecx, %edx              # compare pointer to termination (p < (num_array+arg1))
   jl loop                      # jump to loop if (p < (num_array+arg1))
   leave                        # prepare stack for return (movl %ebp, %esp; popl %ebp)
   ret                          # return to calling routine (result is in %eax)

.data                           # declare data segment and array with 9 32-bit integers
num_array: .long 35, 16, 42, 19, 55, 91, 24, 61, 53
```

Simple Assembly Examples

- Return sum of two arguments
- Return pointer to a string (string is declared in .s file)

x86 Assembly Programming

- Assembly Language
  - Text file (with .S for eclipse)
  - One instruction per line
  - Labels, directives, etc.
- High-level Constructs
  - If
  - If-else
  - Loops
  - Memory (array) accesses
- Calling assembly from C
- Calling Conventions
- Examples in “docs” section of course web site
- Next time recursion & pointers!