Computer Systems I

Class 4

Systems I

Chapter 3

- **It is long!**
- **You will definitely want to refer to it.**
  - In class, we can go a bit fast
  - You can read about the same topics at your own pace until you understand
  - Make sure to do the practice problems to verify that you understand.

Systems I

Vital Preparation for the next lab

- **Lab 2 will take significantly longer than lab 1.**
  - Bad news: It took me about twice as long.
  - Only six puzzles, but each one will take much longer to solve.
  - No code writing, but a huge amount of debugging and analysis on your part.
  - You will need to use a number of tools:
    - gdb
    - objdump
    - strings
  - More about objdump and strings as we need it. A little about gdb now to get your feet wet.

Using gdb

- You must familiarize yourself with gdb
  - You cannot waste time learning gdb once the lab starts
  - gdb will take time, reading, and practice
  - Resources for gdb:
    - Section 3.11
    - man gdb
    - help command inside gdb
- Book's website (link on D2L) has links to
  - GDB manual
  - GDB tutorial
  - GDB reference sheet
- Play with gdb on some simple toy programs
- Consider using it inside emacs or opening a second connection to the server.

GDB practice

or just type **`gdb practice`** at command line

- Practice on the practice files
  - get the files: **`cp –r /csc406/practice ~`**
  - move into the directory: **`cd ~/practice`**
  - start emacs: **`emacs`**
  - start up gdb: **`<Esc> x gud-gdb <Enter>`**
  - When prompted with **`gdb --fullname practice`** just hit Enter
  - Set a breakpoint in main: **`break main`**
  - Start up the program: **`run`**
  - See references for gdb commands and make sure you can:
    - step through the program
    - look at the values of different variables
    - step into function calls and step out of functions.

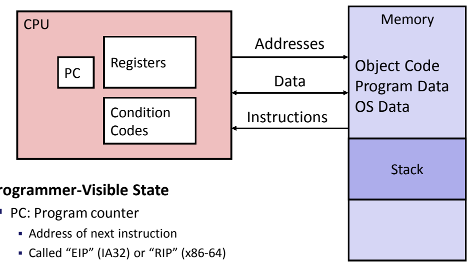
Emacs info

- **I give a minimal set of instructions below. You may want to get more training/information about info as follows:**
  - For a tutorial on how to use info:
    - Start emacs
    - Hit: ctrl-h i m info <Enter> h
    - This is a learn/do as you read.
  - Important: Mouse commands do not work through ssh
- **To access info on gdb:**
  - Start emacs
  - Hit: ctrl-h i m gdb <Enter>
  - Move cursor around the document as usual.
  - To access a particular menu item within the document, move the cursor to the item and hit enter
  - To "go back" hit U (for up)

Definitions

- **Architecture:** (also instruction set architecture: ISA) The parts of a processor design that one needs to understand to write assembly code.
- **Microarchitecture:** Implementation of the architecture.
- **Architecture examples:** instruction set specification, registers.
- **Microarchitecture examples:** cache sizes and core frequency.

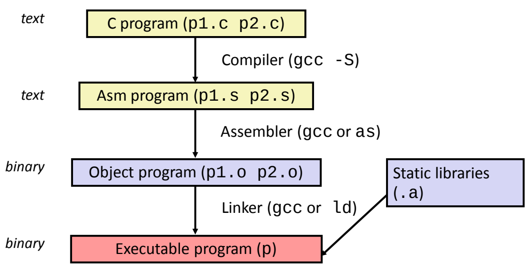
Assembly Programmer's View



- **Programmer-Visible State**
  - PC: Program counter
    - Address of next instruction
    - Called "EIP" (IA32) or "RIP" (x86-64)
  - Register file
    - Heavily used program data
  - Condition codes
    - Store status information about most recent arithmetic operation
    - Used for conditional branching
- **Memory**
  - Byte addressable array
  - Code, user data, (some) OS data
  - Includes stack used to support procedures

Turning C into Object Code

- Code in files `p1.c p2.c`
- Compile with command: `gcc -O p1.c p2.c -o p`
  - Use optimizations (`-O`)
  - Put resulting binary in file **p**



Systems I

Compiling Into Assembly

C Code

```
int sum(int x, int y)
{
  int t = x+y;
  return t;
}
```

Generated IA32 Assembly

```
sum:
    pushl %ebp
    movl %esp,%ebp
    movl 12(%ebp),%eax
    addl 8(%ebp),%eax
    movl %ebp,%esp
    popl %ebp
    ret
```

Obtain with command

`gcc -O -S code.c`

Produces file `code.s`

Some compilers use single instruction "`leave`"

Systems I

Assembly Characteristics: Data Types

- **"Integer" data of 1, 2, or 4 bytes**
  - Data values
  - Addresses (untyped pointers)
- **Floating point data of 4, 8, or 10 bytes**
- **No aggregate types such as arrays or structures**
  - Just contiguously allocated bytes in memory

Systems I

Assembly Characteristics: Operations

- **Perform arithmetic function on register or memory data**
- **Transfer data between memory and register**
  - Load data from memory into register
  - Store register data into memory
- **Transfer control**
  - Unconditional jumps to/from procedures
  - Conditional branches

Object Code

Code for `sum`

```
0x401040 <sum>:
    0x55
    0x89
    0xe5
    0x8b
    0x45
    0x0c
    0x03
    0x45
    0x08
    0x89
    0xec
    0x5d
    0xc3
```

- Total of 13 bytes
- Each instruction 1, 2, or 3 bytes
- Starts at address `0x401040`

- **Assembler**
  - Translates `.s` into `.o`
  - Binary encoding of each instruction
  - Nearly-complete image of executable code
  - Missing linkages between code in different files
- **Linker**
  - Resolves references between files
  - Combines with static run-time libraries
    - E.g., code for `malloc`, `printf`
  - Some libraries are *dynamically linked*
    - Linking occurs when program begins execution

Machine Instruction Example

```
int t = x+y;
```

```
addl 8(%ebp),%eax
```

Similar to expression:

```
x += y
```

More precisely:

```
int eax;
int *ebp;
eax += ebp[2]
```

```
0x401046:     03 45 08
```

- **C Code**
  - Add two signed integers
- **Assembly**
  - Add 2 4-byte integers
    - "Long" words in GCC parlance
    - Same instruction whether signed or unsigned
  - Operands:
    - **x:** Register **`%eax`**
    - **y:** Memory **`M[%ebp+8]`**
    - **t:** Register **`%eax`**
      - Return function value in **`%eax`**
- **Object Code**
  - 3-byte instruction
  - Stored at address **`0x401046`**

Disassembling Object Code

Disassembled

```
00401040 <_sum>:
   0:      55               push   %ebp
   1:      89 e5            mov    %esp,%ebp
   3:      8b 45 0c         mov    0xc(%ebp),%eax
   6:      03 45 08         add    0x8(%ebp),%eax
   9:      89 ec            mov    %ebp,%esp
   b:      5d               pop    %ebp
   c:      c3               ret
   d:      8d 76 00         lea    0x0(%esi),%esi
```

- **Disassembler**

  `objdump -d p`
  - Useful tool for examining object code
  - Analyzes bit pattern of series of instructions
  - Produces approximate rendition of assembly code
  - Can be run on either `a.out` (complete executable) or `.o` file

Alternate Disassembly

Object

```
0x401040:
    0x55
    0x89
    0xe5
    0x8b
    0x45
    0x0c
    0x03
    0x45
    0x08
    0x89
    0xec
    0x5d
    0xc3
```

Disassembled

```
0x401040 <sum>:      push   %ebp
0x401041 <sum+1>:    mov    %esp,%ebp
0x401043 <sum+3>:    mov    0xc(%ebp),%eax
0x401046 <sum+6>:    add    0x8(%ebp),%eax
0x401049 <sum+9>:    mov    %ebp,%esp
0x40104b <sum+11>:   pop    %ebp
0x40104c <sum+12>:   ret
0x40104d <sum+13>:   lea    0x0(%esi),%esi
```

- **Within gdb Debugger**
  - **`gdb p`**
  - **`disassemble sum`**
    - Disassemble procedure
  - **`x/13b sum`**
    - Examine the 13 bytes starting at `sum`

What Can be Disassembled?

```
% objdump -d WINWORD.EXE

WINWORD.EXE:     file format pei-i386

No symbols in "WINWORD.EXE".
Disassembly of section .text:

30001000 <.text>:
30001000:  55              push   %ebp
30001001:  8b ec           mov    %esp,%ebp
30001003:  6a ff           push   $0xffffffff
30001005:  68 90 10 00 30  push   $0x30001090
3000100a:  68 91 dc 4c 30  push   $0x304cdc91
```

- **Anything that can be interpreted as executable code**
- **Disassembler examines bytes and reconstructs assembly source**

Machine Programming I: Basics

- History of Intel processors and architectures
- C, assembly, machine code
- **Assembly Basics: Registers, operands, move**

Integer Registers (IA32)

				Origin (mostly obsolete)
%eax	%ax	%ah	%al	*accumulate*
%ecx	%cx	%ch	%cl	*counter*
%edx	%dx	%dh	%dl	*data*
%ebx	%bx	%bh	%bl	*base*
%esi	%si			*source index*
%edi	%di			*destination index*
%esp	%sp			*stack pointer*
%ebp	%bp			*base pointer*

general purpose

16-bit virtual registers
(backwards compatibility)

Moving Data: IA32

- **Moving Data**
  - **`movx`** ***Source*, *Dest***
  - **`x`** in {**`b, w, l`**}

  - **`movl`** ***Source*, *Dest***:
    Move 4-byte "long word"
  - **`movw`** ***Source*, *Dest***:
    Move 2-byte "word"
  - **`movb`** ***Source*, *Dest***:
    Move 1-byte "byte"

- **Lots of these in typical code**

%eax
%ecx
%edx
%ebx
%esi
%edi
%esp
%ebp

Moving Data: IA32

- **Moving Data**
  `movl` ***Source*, *Dest***:
- **Operand Types**
  - ***Immediate:*** Constant integer data
    - Example: **`$0x400`**, **`$-533`**
    - Like C constant, but prefixed with **'`$`'**
    - Encoded with 1, 2, or 4 bytes
  - ***Register:*** One of 8 integer registers
    - Example: **`%eax, %edx`**
    - But **`%esp`** and **`%ebp`** reserved for special use
    - Others have special uses for particular instructions
  - ***Memory:*** 4 consecutive bytes of memory at address given by register
    - Simplest example: **`(%eax)`**
    - Various other "address modes"

%eax
%ecx
%edx
%ebx
%esi
%edi
%esp
%ebp

`movl` Operand Combinations

Source	Dest	Src,Dest	C Analog
Imm	*Reg*	`movl $0x4,%eax`	`temp = 0x4;`
Imm	*Mem*	`movl $-147,(%eax)`	`*p = -147;`
Reg	*Reg*	`movl %eax,%edx`	`temp2 = temp1;`
Reg	*Mem*	`movl %eax,(%edx)`	`*p = temp;`
Mem	*Reg*	`movl (%eax),%edx`	`temp = *p;`

Cannot do memory-memory transfer with a single instruction

Simple Memory Addressing Modes

- **Normal (R) Mem[Reg[R]]**
  - Register R specifies memory address

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

- **Displacement D(R) Mem[Reg[R]+D]**
  - Register R specifies start of memory region
  - Constant displacement D specifies offset

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


Pointers

- **What is a pointer?**
- **How do you declare one?**
- **How do you use one?**
- **How do you give a pointer variable a value?**
- **Strings in C**
- **Arrays in C**

- **See section 3.10**

Using Simple Addressing Modes

```
void swap(int *xp, int *yp)
{
  int t0 = *xp;
  int t1 = *yp;
  *xp = t1;
  *yp = t0;
}
```

```
swap:
   pushl %ebp
   movl  %esp,%ebp
   pushl %ebx

   movl 12(%ebp),%ecx
   movl 8(%ebp),%edx
   movl (%ecx),%eax
   movl (%edx),%ebx
   movl %eax,(%edx)
   movl %ebx,(%ecx)

   movl -4(%ebp),%ebx
   movl %ebp,%esp
   popl %ebp
   ret
```

Set Up

Body

Finish

Using Simple Addressing Modes

```
void swap(int *xp, int *yp)
{
  int t0 = *xp;
  int t1 = *yp;
  *xp = t1;
  *yp = t0;
}
```

```
swap:
   pushl %ebp
   movl  %esp,%ebp
   pushl %ebx

   movl 12(%ebp),%ecx
   movl 8(%ebp),%edx
   movl (%ecx),%eax
   movl (%edx),%ebx
   movl %eax,(%edx)
   movl %ebx,(%ecx)

   movl -4(%ebp),%ebx
   movl %ebp,%esp
   popl %ebp
   ret
```

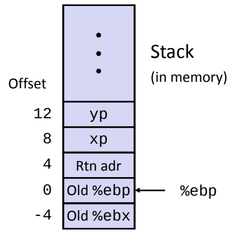
Set Up

Body

Finish

Understanding Swap

```
void swap(int *xp, int *yp)
{
  int t0 = *xp;
  int t1 = *yp;
  *xp = t1;
  *yp = t0;
}
```



Register	Value
%ecx	yp
%edx	xp
%eax	t1
%ebx	t0

```
movl 12(%ebp),%ecx  # ecx = yp
movl 8(%ebp),%edx   # edx = xp
movl (%ecx),%eax    # eax = *yp (t1)
movl (%edx),%ebx    # ebx = *xp (t0)
movl %eax,(%edx)    # *xp = eax
movl %ebx,(%ecx)    # *yp = ebx
```

Understanding Swap

Systems I

Register	Value
%eax	
%edx	
%ecx	
%ebx	
%esi	
%edi	
%esp	
%ebp	0x104

	Offset	Value	Address
		123	0x124
		456	0x120
			0x11c
			0x118
			0x114
yp	12	0x120	0x110
xp	8	0x124	0x10c
	4	Rtn adr	0x108
%ebp →	0		0x104
	-4		0x100

```
movl 12(%ebp),%ecx     # ecx = yp
movl 8(%ebp),%edx      # edx = xp
movl (%ecx),%eax       # eax = *yp (t1)
movl (%edx),%ebx       # ebx = *xp (t0)
movl %eax,(%edx)       # *xp = eax
movl %ebx,(%ecx)       # *yp = ebx
```

Understanding Swap

Systems I

Register	Value
%eax	
%edx	
%ecx	0x120
%ebx	
%esi	
%edi	
%esp	
%ebp	0x104

	Offset	Value	Address
		123	0x124
		456	0x120
			0x11c
			0x118
			0x114
yp	12	0x120	0x110
xp	8	0x124	0x10c
	4	Rtn adr	0x108
%ebp →	0		0x104
	-4		0x100

```
movl 12(%ebp),%ecx     # ecx = yp
movl 8(%ebp),%edx      # edx = xp
movl (%ecx),%eax       # eax = *yp (t1)
movl (%edx),%ebx       # ebx = *xp (t0)
movl %eax,(%edx)       # *xp = eax
movl %ebx,(%ecx)       # *yp = ebx
```

Understanding Swap

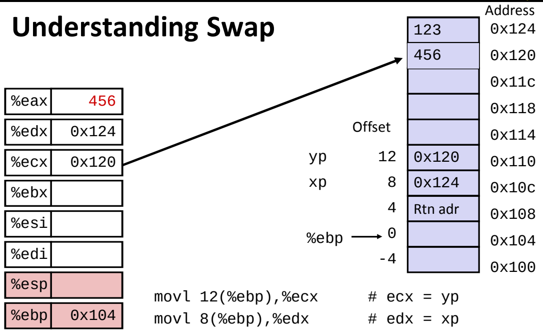
Systems I

Register	Value
%eax	
%edx	0x124
%ecx	0x120
%ebx	
%esi	
%edi	
%esp	
%ebp	0x104

	Offset	Value	Address
		123	0x124
		456	0x120
			0x11c
			0x118
			0x114
yp	12	0x120	0x110
xp	8	0x124	0x10c
	4	Rtn adr	0x108
%ebp →	0		0x104
	-4		0x100

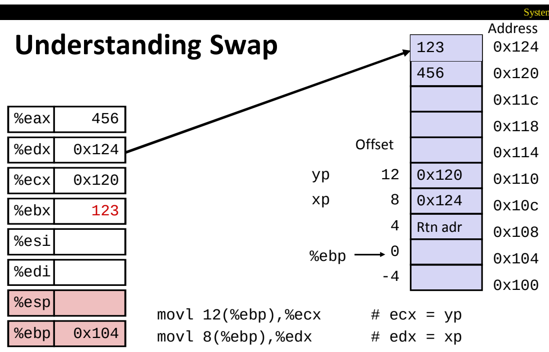
```
movl 12(%ebp),%ecx     # ecx = yp
movl 8(%ebp),%edx      # edx = xp
movl (%ecx),%eax       # eax = *yp (t1)
movl (%edx),%ebx       # ebx = *xp (t0)
movl %eax,(%edx)       # *xp = eax
movl %ebx,(%ecx)       # *yp = ebx
```

Understanding Swap



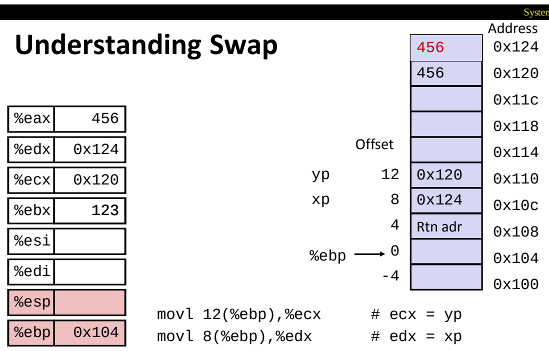

```
movl 12(%ebp),%ecx     # ecx = yp
movl 8(%ebp),%edx      # edx = xp
movl (%ecx),%eax       # eax = *yp (t1)
movl (%edx),%ebx       # ebx = *xp (t0)
movl %eax,(%edx)       # *xp = eax
movl %ebx,(%ecx)       # *yp = ebx
```


Understanding Swap




```
movl 12(%ebp),%ecx     # ecx = yp
movl 8(%ebp),%edx      # edx = xp
movl (%ecx),%eax       # eax = *yp (t1)
movl (%edx),%ebx       # ebx = *xp (t0)
movl %eax,(%edx)       # *xp = eax
movl %ebx,(%ecx)       # *yp = ebx
```


Understanding Swap




```
movl 12(%ebp),%ecx     # ecx = yp
movl 8(%ebp),%edx      # edx = xp
movl (%ecx),%eax       # eax = *yp (t1)
movl (%edx),%ebx       # ebx = *xp (t0)
movl %eax,(%edx)       # *xp = eax
movl %ebx,(%ecx)       # *yp = ebx
```

Understanding Swap

%eax	456
%edx	0x124
%ecx	0x120
%ebx	123
%esi	
%edi	
%esp	
%ebp	0x104

	Offset		Address
		456	0x124
		123	0x120
			0x11c
			0x118
			0x114
yp	12	0x120	0x110
xp	8	0x124	0x10c
	4	Rtn adr	0x108
%ebp →	0		0x104
	-4		0x100

```
movl 12(%ebp),%ecx      # ecx = yp
movl 8(%ebp),%edx       # edx = xp
movl (%ecx),%eax        # eax = *yp (t1)
movl (%edx),%ebx        # ebx = *xp (t0)
movl %eax,(%edx)        # *xp = eax
movl %ebx,(%ecx)        # *yp = ebx
```


Complete Memory Addressing Modes

- **Most General Form**

  D(Rb,Ri,S) **Mem[Reg[Rb]+S*Reg[Ri]+ D]**
  - D: Constant “displacement” 1, 2, or 4 bytes
  - Rb: Base register: Any of 8 integer registers
  - Ri: Index register: Any, except for **%esp**
    - Unlikely you’d use **%ebp**, either
  - S: Scale: 1, 2, 4, or 8 (*why these numbers?*)

- **Special Cases**

(Rb,Ri)	**Mem[Reg[Rb]+Reg[Ri]]**
D(Rb,Ri)	**Mem[Reg[Rb]+Reg[Ri]+D]**
(Rb,Ri,S)	**Mem[Reg[Rb]+S*Reg[Ri]]**

Address Computation Examples

%edx	0xf000
%ecx	0x100

Expression	Address Computation	Address
0x8(%edx)		
(%edx,%ecx)		
(%edx,%ecx,4)		
0x80(,%edx,2)		

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**

Some Arithmetic 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*	

- **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**

Using `leal` for Arithmetic Expressions

```
int arith
  (int x, int y, int z)
{
  int t1 = x+y;
  int t2 = z+t1;
  int t3 = x+4;
  int t4 = y * 48;
  int t5 = t3 + t4;
  int rval = t2 * t5;
  return rval;
}
```

```
arith:
    pushl %ebp
    movl %esp,%ebp

    movl 8(%ebp),%eax
    movl 12(%ebp),%edx
    leal (%edx,%eax),%ecx
    leal (%edx,%edx,2),%edx
    sall $4,%edx
    addl 16(%ebp),%ecx
    leal 4(%edx,%eax),%eax
    imull %ecx,%eax

    movl %ebp,%esp
    popl %ebp
    ret
```

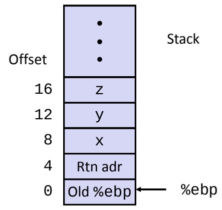
Set Up

Body

Finish

Understanding `arith`

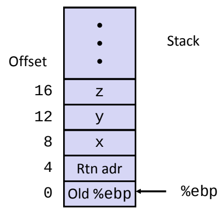
```
int arith
  (int x, int y, int z)
{
  int t1 = x+y;
  int t2 = z+t1;
  int t3 = x+4;
  int t4 = y * 48;
  int t5 = t3 + t4;
  int rval = t2 * t5;
  return rval;
}
```




```
movl 8(%ebp),%eax
movl 12(%ebp),%edx
leal (%edx,%eax),%ecx
leal (%edx,%edx,2),%edx
sall $4,%edx
addl 16(%ebp),%ecx
leal 4(%edx,%eax),%eax
imull %ecx,%eax
```


Understanding `arith`

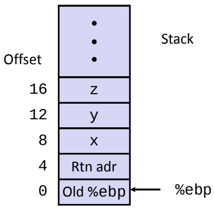
```
int arith
  (int x, int y, int z)
{
  int t1 = x+y;
  int t2 = z+t1;
  int t3 = x+4;
  int t4 = y * 48;
  int t5 = t3 + t4;
  int rval = t2 * t5;
  return rval;
}
```




```
movl 8(%ebp),%eax        # eax = x
movl 12(%ebp),%edx       # edx = y
leal (%edx,%eax),%ecx    # ecx = x+y  (t1)
leal (%edx,%edx,2),%edx  # edx = 3*y
sall $4,%edx             # edx = 48*y (t4)
addl 16(%ebp),%ecx       # ecx = z+t1 (t2)
leal 4(%edx,%eax),%eax   # eax = 4+t4+x (t5)
imull %ecx,%eax          # eax = t5*t2 (rval)
```

Understanding `arith`

```
int arith
  (int x, int y, int z)
{
  int t1 = x+y;
  int t2 = z+t1;
  int t3 = x+4;
  int t4 = y * 48;
  int t5 = t3 + t4;
  int rval = t2 * t5;
  return rval;
}
```

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leal (%edx,%eax),%ecx      # ecx = x+y  (t1)
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leal 4(%edx,%eax),%eax     # eax = 4+t4+x (t5)
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```

Systems I

Understanding `arith`

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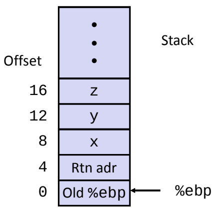


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Systems I

Understanding `arith`

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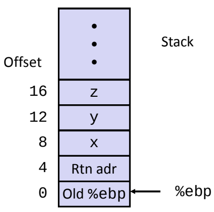


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```

Another Example

```
int logical(int x, int y)
{
  int t1 = x^y;
  int t2 = t1 >> 17;
  int mask = (1<<13) - 7;
  int rval = t2 & mask;
  return rval;
}
```

```
logical:
    pushl %ebp          } Set Up
    movl %esp,%ebp

    movl 8(%ebp),%eax   }
    xorl 12(%ebp),%eax  }
    sarl $17,%eax       }
    andl $8185,%eax     } Body

    movl %ebp,%esp      }
    popl %ebp           } Finish
    ret
```

```
movl 8(%ebp),%eax     # eax = x
xorl 12(%ebp),%eax    # eax = x^y
sarl $17,%eax         # eax = t1>>17
andl $8185,%eax       # eax = t2 & 8185
```


Another Example

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```
logical:
    pushl %ebp          } Set Up
    movl %esp,%ebp

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    xorl 12(%ebp),%eax  }
    sarl $17,%eax       }
    andl $8185,%eax     } Body

    movl %ebp,%esp      }
    popl %ebp           } Finish
    ret
```

```
movl 8(%ebp),%eax     eax = x
xorl 12(%ebp),%eax    eax = x^y     (t1)
sarl $17,%eax         eax = t1>>17  (t2)
andl $8185,%eax       eax = t2 & 8185
```


Another Example

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logical:
    pushl %ebp          } Set Up
    movl %esp,%ebp

    movl 8(%ebp),%eax   }
    xorl 12(%ebp),%eax  }
    sarl $17,%eax       }
    andl $8185,%eax     } Body

    movl %ebp,%esp      }
    popl %ebp           } Finish
    ret
```

```
movl 8(%ebp),%eax     eax = x
xorl 12(%ebp),%eax    eax = x^y     (t1)
sarl $17,%eax         eax = t1>>17  (t2)
andl $8185,%eax       eax = t2 & 8185
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Another Example

```
int logical(int x, int y)
{
  int t1 = x^y;
  int t2 = t1 >> 17;
  int mask = (1<<13) - 7;
  int rval = t2 & mask;
  return rval;
}
```

$2^{13} = 8192$, $2^{13} - 7 = 8185$

```
logical:
    pushl %ebp              Set
    movl %esp,%ebp          Up

    movl 8(%ebp),%eax
    xorl 12(%ebp),%eax
    sarl $17,%eax
    andl $8185,%eax         Body

    movl %ebp,%esp
    popl %ebp               Finish
    ret
```

```
movl 8(%ebp),%eax      eax = x
xorl 12(%ebp),%eax     eax = x^y     (t1)
sarl $17,%eax          eax = t1>>17  (t2)
andl $8185,%eax        eax = t2 & 8185
```


Today

- Complete addressing mode, address computation (leal)
- Arithmetic operations
- **x86-64**
- Control: Condition codes
- Conditional branches
- While loops

Data Representations: IA32 + x86-64

- **Sizes of C Objects (in Bytes)**

C Data Type	*Typical 32-bit*	*Intel IA32*	*x86-64*
unsigned	4	4	4
int	4	4	4
long int	4	4	8
char	1	1	1
short	2	2	2
float	4	4	4
double	8	8	8
long double	8	10/12	16
char *	4	4	8

Or any other pointer

Systems I

x86-64 Integer Registers

%rax	%eax	%r8	%r8d
%rbx	%ebx	%r9	%r9d
%rcx	%ecx	%r10	%r10d
%rdx	%edx	%r11	%r11d
%rsi	%esi	%r12	%r12d
%rdi	%edi	%r13	%r13d
%rsp	%esp	%r14	%r14d
%rbp	%ebp	%r15	%r15d

- Extend existing registers. Add 8 new ones.
- Make **%ebp/%rbp** general purpose

Systems I

Instructions

- **Long word `l` (4 Bytes) ↔ Quad word `q` (8 Bytes)**

- **New instructions:**
  - **movl** → **movq**
  - **addl** → **addq**
  - **sall** → **salq**
  - etc.

- **32-bit instructions that generate 32-bit results**
  - Set higher order bits of destination register to 0
  - Example: **addl**

Systems I

Swap in 32-bit Mode

```
void swap(int *xp, int *yp)
{
  int t0 = *xp;
  int t1 = *yp;
  *xp = t1;
  *yp = t0;
}
```

```
swap:
    pushl %ebp
    movl  %esp,%ebp          } Setup
    pushl %ebx

    movl 12(%ebp),%ecx
    movl 8(%ebp),%edx
    movl (%ecx),%eax         } Body
    movl (%edx),%ebx
    movl %eax,(%edx)
    movl %ebx,(%ecx)

    movl -4(%ebp),%ebx
    movl %ebp,%esp           } Finish
    popl %ebp
    ret
```

Swap in 64-bit Mode

```
void swap(int *xp, int *yp)
{
  int t0 = *xp;
  int t1 = *yp;
  *xp = t1;
  *yp = t0;
}
```

```
swap:
    movl    (%rdi), %edx
    movl    (%rsi), %eax
    movl    %eax, (%rdi)
    movl    %edx, (%rsi)
    retq
```

- **Operands passed in registers (why useful?)**
  - First (**xp**) in **%rdi**, second (**yp**) in **%rsi**
  - 64-bit pointers
- **No stack operations required**
- **32-bit data**
  - Data held in registers **%eax** and **%edx**
  - **movl** operation

Swap Long Ints in 64-bit Mode

```
void swap_l
  (long int *xp, long int *yp)
{
  long int t0 = *xp;
  long int t1 = *yp;
  *xp = t1;
  *yp = t0;
}
```

```
swap_l:
    movq    (%rdi), %rdx
    movq    (%rsi), %rax
    movq    %rax, (%rdi)
    movq    %rdx, (%rsi)
    retq
```

- **64-bit data**
  - Data held in registers **%rax** and **%rdx**
  - **movq** operation
  - "q" stands for quad-word