Endianness

CS 2130: Computer Systems and Organization 1

Xinyao Yi Ph.D.
Assistant Professor

UNIVERSITY of VIRGINIA | ENGINEERING

Announcements

- Homework 4 **due tonight at 11:59pm** on Gradescope
  - Note the earlier deadline!
  - You have written most of this code already
  - Lab 6 may provide a fast way to get started
- No quiz this weekend!

64-bit Machines

How much can we address with 64-bits?

- 16 EiB (2^{64} addresses = $2^4 \times 2^{60}$)
- But I only have 8 GiB of RAM

A Challenge

There is a disconnect:

- Registers: 64-bits values
- Memory: 8-bit values (i.e., **1 byte** values) What we are storing is still 8 bits (1 byte).
  - Each address addresses an 8-bit value in memory
  - Each address points to a 1-byte slot in memory

A Challenge

There is a disconnect:

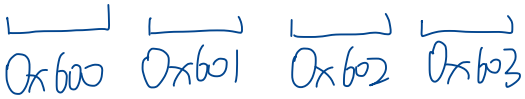
- Registers: 64-bits values
- Memory: 8-bit values (i.e., **1 byte** values)
  - Each address addresses an 8-bit value in memory
  - Each address points to a 1-byte slot in memory
- How do we store a 64-bit value in an 8-bit spot?

Rules

0x | 00 | AB | CD | EF (4 bytes)

Rules to break "big values" into bytes (memory)

1. Break it into bytes
2. Store them adjacently
3. Address of the overall value = smallest address of its bytes
4. Order the bytes
   - If parts are ordered (i.e., array), first goes in smallest address
   - Else, hardware implementation gets to pick (!!)
     – Little-endian
     – Big-endian



starting from an address and going up.

Ordering Values

0x|00|AB|CD|EF

Little-endian

- Store the low order part/byte first
- Most hardware today is little-endian

EF CD AB 00
0x600 0x601 0x602 0x603

Big-endian

- Store the high order part/byte first

00 AB CD EF
0x600 0x601 0x602 0x603

Why we want to talk about 2 ways?
Because people decided to do different things.
We write 00ABCDEF, but we calculate from F to 0,

Maybe that's the reason to see EF first?

Example

array of 2 numbers, each number should use 2 bytes.

Store [0x1234, 0x5678] at address 0xF00

	address	little endian	big endian
0x1234	0xF00	34	12
	0xF01	12	34
0x5678	0xF02	78	56
	0xF03	56	78

Endianness

Why do we study endianness?

- It is **everywhere**
- It is a source of weird bugs
- Ex: It's likely your computer uses:
  - Little-endian from CPU to memory
  - Big-endian from CPU to network
  - File formats are roughly half and half

People didn't use the same thing.

In fact, your computers are probably doing different things now.

Moving up!

Assembly

General principle of all **assembly languages**

- Code (text, not binary!)
- 1 line of code = 1 machine instruction
- One-to-one reversible mapping between binary and assembly
  - We do not need to remember binary encodings!
  - A program will turn text to binary for us!

- ISA is like the grammar and vocabulary of a language.
- Assembly code is a sentence written in that language.

Assembly

Features of assembly

- Automatic addresses - use **labels** to keep track of addresses
  - Assembler will remember location of labels and use where appropriate
  - Labels will not exist in machine code
- Metadata - data about data
  - Data that helps turn assembly into code the machine can use
- As complicated as machine instructions
  - There are a lot of instructions, and it is one-to-one!

(.text .data .byte)

(extra information)

It's going to replace them with the actual addresses when it builds the binary that we're going to run.

Assembly Languages

There are many assembly languages

Each CPU family has its own unique set of machine instructions – therefore it's own assembly language.

- But, they're backed by hardware!
- Two big ones these days: x86-64 and ARM
  - most computers
  - M1/M2 chips on MAC and cellphones
  – You likely have machines that use one of these
- Others: RISC-V, MIPS, ... PowerPC

We will focus on **x86-64**

x86-64

x86-64 has a weird and long history

- Expansion of the 8086 series (Intel)

8 bits 16 bits 32 bits
8008 – 8086, 8286, 8386, 8486, x86

- AMD expanded it with AMD64 A 64-bit that was backward compatible with X86.
- Intel decide to use same build, but called it x86-64
- Backwards compatible with the 8086 series

x86-64

Two dialects - two ways to write the same thing

- Intel - likely using with Windows

  mov QWORD PTR [rdx+0x227],rax

- AT&T - likely using with anything else

  movq %rax,0x227(%rdx)

We will use AT&T dialect

AT&T x86-84 Assembly

`instruction source, destination`

- Instruction followed by 0 or more operands (arguments)
- 4 types of operands:
  - Number (immediate value): `$0x123`
  - Register: `%rax`
  - Address of memory: `(%rax)` or 24 or `labelname`
  - Value at an address in memory: `(%rax)` or 24 or `labelname`

(typically we will not see more than 2)

lea loading the addresses

In most of the cases, we are doing something using the value. Except for

AT&T x86-84 Assembly

`mylabelname:` end with a colon

- Label - remember the address of next thing to use later

`.something something` start with a dot

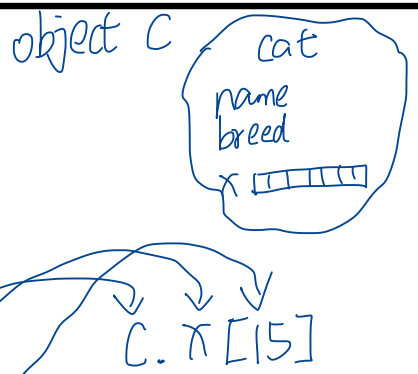
- Metadirective - extra information that is not code
- How the code works with other things (i.e., talk to OS)
- Ex: `.globl main`

`// we can have comments!`

Addressing Memory

`2130(%rax, %rsp, 8)`

- Address can have up to 4 parts: 2 numbers, 2 registers
- Combines as: `2130 + %rax + (%rsp * 8)`
- Common usage from this example:
  - `rax` - address of an object in memory
  - 2130 - offset of an array into the object
  - `rsp` - index into the array
  - 8 - size of the values in the array (used to calculate the offset)
- Don't need all parts: `(%rax)` or `(%rax, 4)` or `4(%rax)`
- This is all one operand (one memory address)

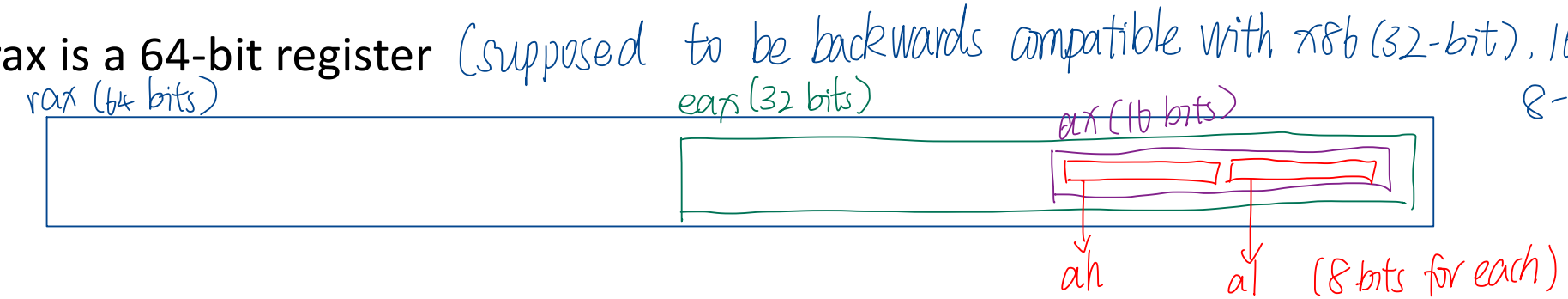


If I don't have all the pieces, it will calculate what it can.

hello.s example

Registers

rax is a 64-bit register (supposed to be backwards compatible with x86 (32-bit), 16-bit, 8-bit)



If I look at 32-bit version, it will just zero out the top 32 bits.

We'll see this with all our registers, in slightly different way.

(check the reading)

Instructions (short acronyms for what we want to do, like mov, add, and, or, xor, neg)

Instructions have different versions depending on number of bits to use

- `movq` - 64-bit move (similar for addq, subq)
  - `q` = quad word
- `movl` - 32-bit move
  - `l` = long

The instruction followed by how wide of the thing we want to do.

- There are encodings for shorter things, but we will mostly see 32- and 64-bit

More powerful than our ISA

Instructions can move/operate between memory and register

- `movq %rax, %rcx` - register to register
  - Remember our icode 0
- `movq (%rax), %rcx` - memory to register
  - Remember our icode 3
- `movq %rax, (%rcx)` - register to memory
  - Remember our icode 4
- `movq $21, %rax` - Immediate to register
  - Remember our icode 6 (b=0)

Note: at most one memory address per instruction

We cannot do memory to memory calculations.

Other Instructions

Other instructions work the same way

- `addq %rax, %rcx` — rcx += rax
- `subq (%rbx), %rax` — rax -= M[rbx]
- xor, and, and others work the same way!
- Assembly has virtually no 3-argument instructions
  - All will be modifying something (i.e., +=, &=, …)

Jumps

`jmp foo`

- Unconditional jump to `foo`
- `foo` is a label or memory address
- Need `jmp*` to use register value

Conditional jumps

- `jl`, `jle`, `je`, `jne`, `jg`, `jge`, `ja`, `jb`, `js`, `jo`

Unlike our Toy ISA, these do not compare given register to 0

Jumps

Condition codes - 4 1-bit registers set by every math operation, `cmp`, and `test`

- Result for the operation compared to 0 (if no overflow)
- Example:

```
addq $-5, %rax
// ...code that doesn't set condition codes...
je foo
```

  - Sets condition codes from doing math (subtract 5 from rax)
  - Tells whether result was positive, negative, 0, if there was overflow, ...
  - Then jump if the result of operation should have been = 0

Jumps: compare…

`cmpq %rax, %rdx`

- Compare checks result of -= and sets condition codes
- How `rdx - rax` compares with 0
- Be aware of ordering!
  - if `rax` is bigger, sets < flag
  - if `rdx` is bigger, sets > flag

Jumps: … and test

`testq %rax, %rdx`

- Sets the condition codes based on `rdx & rax`
- Less common

Neither save their result, just set condition codes!

Function Calls: Calling Conventions

`callq myfun`

- Push return address, then jump to myfun
- Convention: Store arguments in registers and stack before call
  - First 6 arguments (in order): `rdi`, `rsi`, `rdx`, `rcx`, `r8`, `r9`
  - If more arguments, pushed onto stack (last to first)

`retq`

- Pop return address from stack and jump back
- Convention: store return value in `rax` before calling `retq`

This is similar to our Toy ISA's function calls in homework 4

Debugger

Debugger - step through code!

- You will be using this for lab 7
- Experience seeing results of these instructions step-by-step
- **Please read the x86-64 summary reading before lab!**