University of Kansas | Drew Davidson

x64 Basics

Last Lecture

Encoding Programs

Representing Whole Programs in Hardware

- Data
- Code

ISAs

- X86 – Example target

What you should know:

- ISA concept
- That data and code share memory
  - The instruction pointer
- How to play with ASM code

Architecture

Recall: Instructions

Review x64 Intro

We've already seen two instructions:

`movq <o1> <o2>` *Flow of data* →

- Move quadword in o_1 into quadword o_2

`syscall`

- Invoke a system service

```
.text
.globl _start
_start:
    movq $60, %rax      # Choose syscall exit
    movq $4, %rdi       # Set syscall arg - return code
    syscall
```

Recall: x64 Registers

Review x64 Intro

Computation needs to be done on registers

- General workflow:

src code

a = b <opr> c

asm code

Load b into a register

Load c into another register

Do opr on registers

Store result register into a

Name	Number	"Nickname"	
%rax	0	Accumulator	General purpose For our needs
%rbx	1	Base	
%rcx	2	Counter	
%rdx	3	I/O	
%rsi	4	String source	
%rdi	5	String destination	
%rbp	6	Base pointer	Used for bookkeeping
%rsp	7	Stack pointer	
%r08 – %r15	8 - 15	General purpose	Bonus general purpose for us
%rip	-	Instruction pointer	Inaccessible as regular operands
%rflags	-	Status flags	

Today's Lecture

X64 Basics

X64 Discussion

- Some perspective

Architecture Details

- Basic operators
- Memory Directives

Architecture

ASM Instruction Syntax

Lecture Outline –Writing x64

As with everything x86-related, it's complicated

- We'll use the AT&T Syntax:

  <opcode><sizesuffix> <src operand(s)> <dst operand>

- Immediates (i.e. constant values) prefixed by $
- Registers prefixed by %
- Memory lookup (i.e. dereference) in parens

```
movq $5, (%rax)
```

mov the 64-bit value 5 into the 64-bit memory address specified by register rax

Directives

Lecture Outline –Writing x64

- Indicates a command to the assembler
  - Layout, program entrypoint, etc.

Example:

.globl X

Indicates that symbol X is visible outside of the file

Segment Directives

Lecture Outline –Writing x64

`.text`

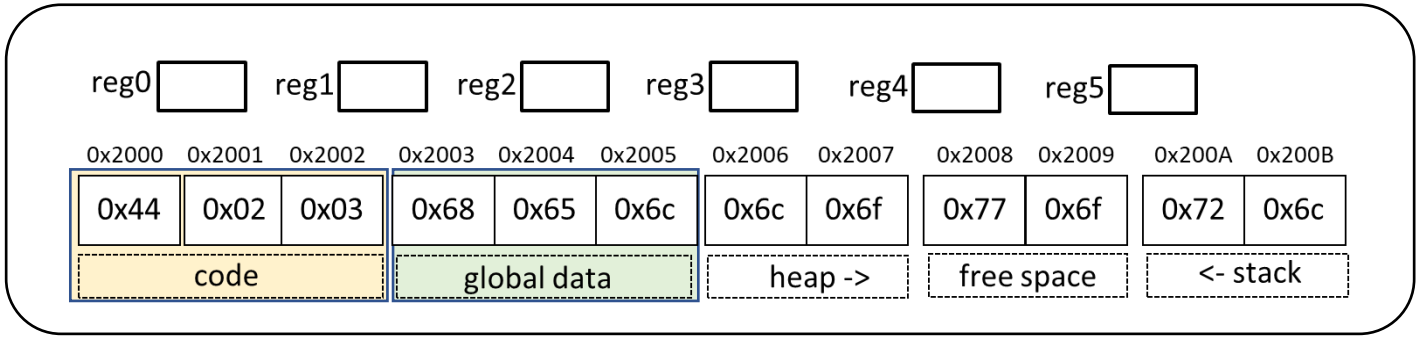
Lay out items in the user text segment

Instructions go here

`.data`

Lay out items in the data segment

Globals go here



Labels

Lecture Outline –Writing x64

- The assembler allows us to specify “placeholder” addresses that will be used later
  - Translated to “real” addresses by a utility called the linker
- Valid for both data and code locations

```
jmp  LBL1
 …
LBL1: movq $5 (%rax)
```

```
jmp 0x12d34a5678a
```

System Calls

Lecture Outline –Writing x64

To interact outside program memory, need the help of the OS

```
syscall
```

```
%rax     # Which system call (60 is exit)
%rdi     # Set syscall arg – (exit takes the return code)
```

Time to put it all together!

Lecture Outline –Writing x64

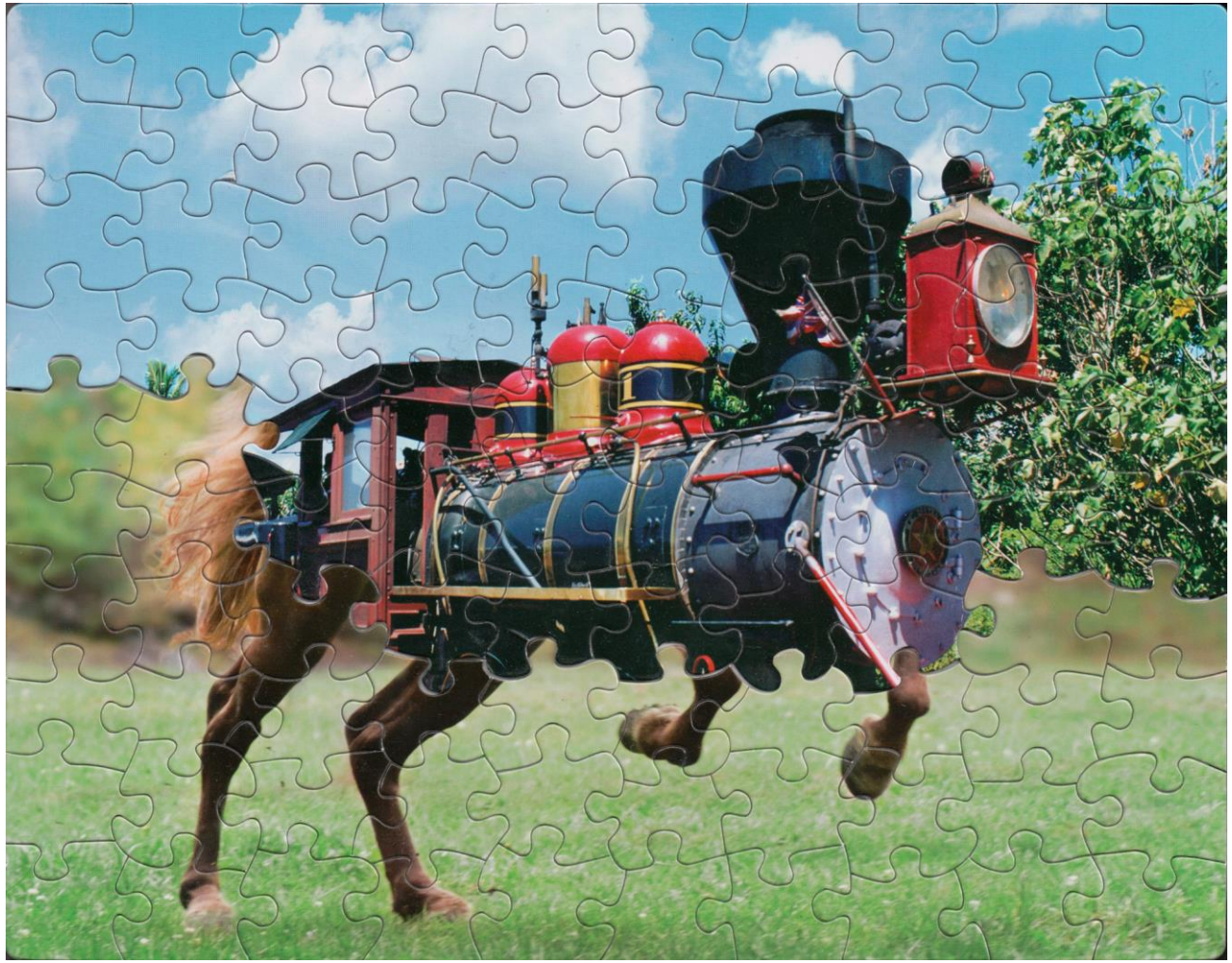


Photo Credit: Tim Klein - https://puzzlemontage.crevado.com

A Complete Program

Lecture Outline –Writing x64

```
.text
.globl _start
_start:
    movq $60, %rax      # Choose syscall exit
    movq $4, %rdi       # Set syscall arg - return code
    syscall
```

Actually Running a Program

Lecture Outline –Writing x64

Invoking the assembler and linker

```
as –o start.o start.s
ld start.o –o prog
./prog
echo $?
```

Summary

ISAs

ISAs

- Provide an interface from software to hardware
- We'll target assembly code, assembler will take it from there

X64

- A popular architecture
- We've covered the basic instruction format and a simple program

Compiler Construction

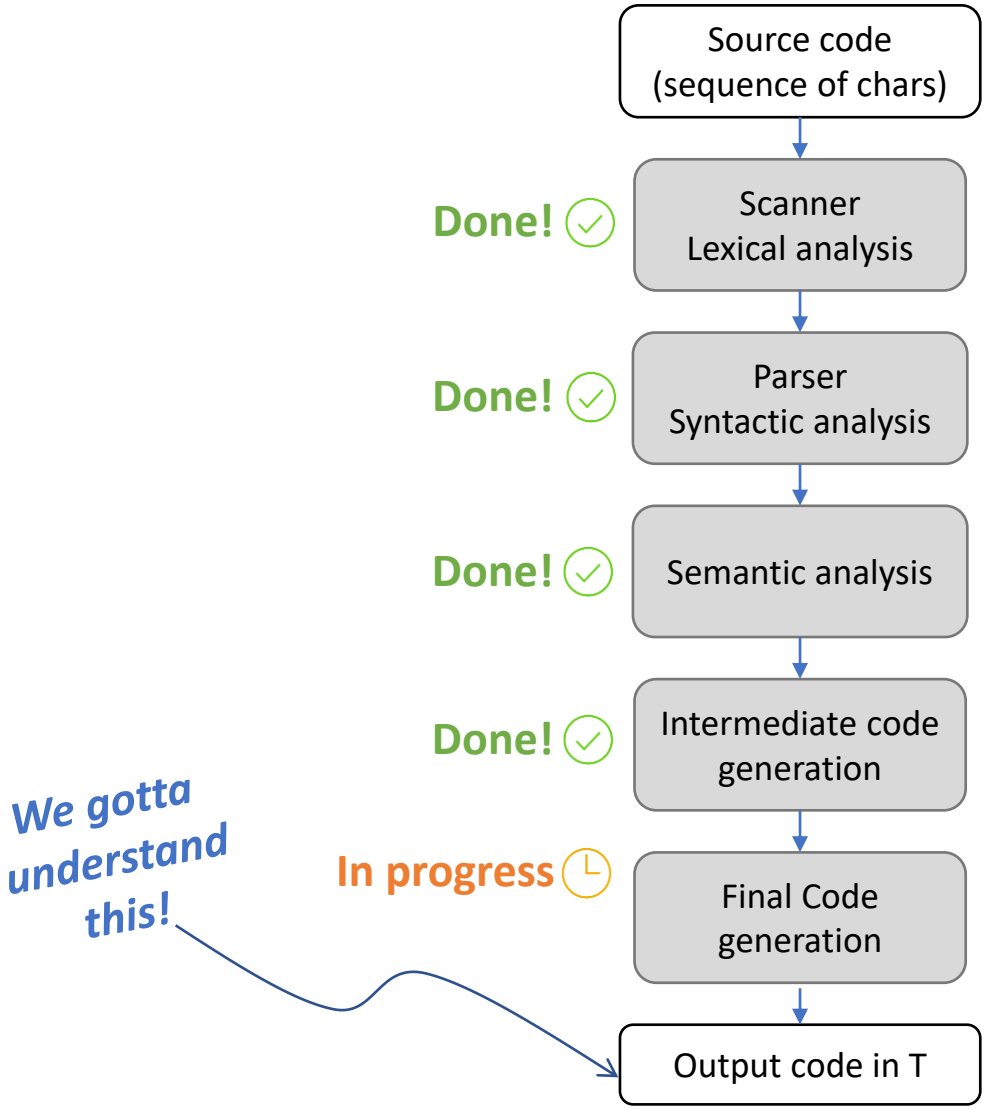
Progress Pics

Done:

- Validated and abstracted input program
- Flattened the input program to a linear representation

ToDo:

- Concretize to the target architecture



A Moment of Appreciation

x64 Basics: Perspective

We're writing real-deal x64 - no special tools needed

- Our x64 code looks (mostly) like what comes out of gcc

```
gcc –S prog.c –o prog.s
gcc –c prog.s –o prog.o
gcc  prog.o –o prog.exe
```

Unfortunately for clarity, there are a lot of extra directives we might want to strip:

```
gcc -fno-asynchronous-unwind-tables -fno-dwarf2-cfi-asm -O0 -S
blah.c -o blah.nodebug.S
```

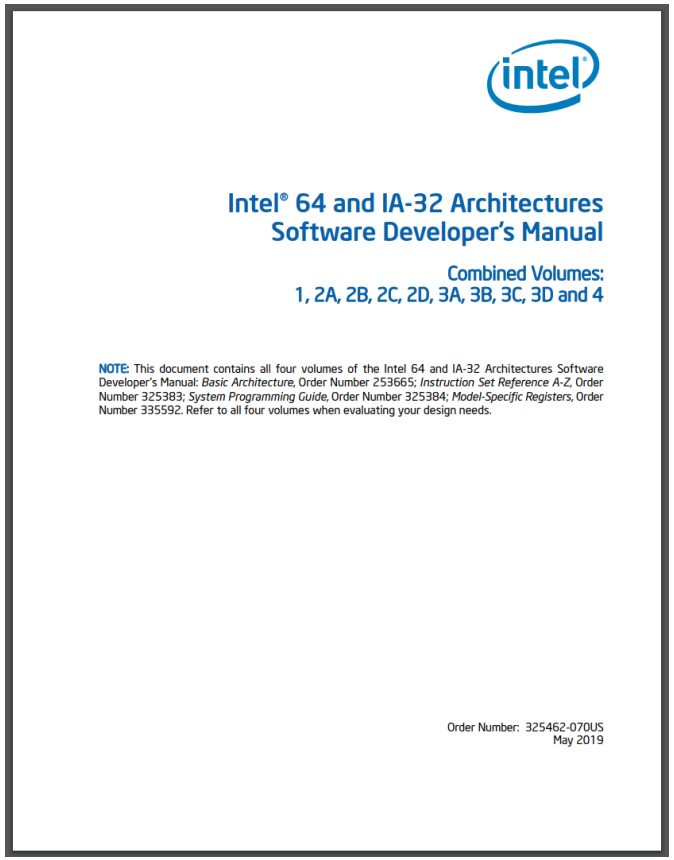
Docs: A Benefit to x64's Popularity

x64 Basics: Perspective

Lots of good, thorough documentation out there

- Some best used as reference rather than walkthrough

4922 Pages!



https://software.intel.com/sites/default/files/managed/39/c5/325462-sdm-vol-1-2abcd-3abcd.pdf

There are a LOT of Instructions in X64!

X64 Basics: Perspective

Keeping to the "Easy" Path

X64 Basics: Perspective

We'll sidestep most of the x64 complexity

- We'll just stick to those instructions we need
- Give you the pointers to explore the rest of the ISA

Today's Lecture

X64 Basics

X64 Discussion

- Some perspective

Architecture Details

- Basic operators
- Memory Directives

Architecture

Let's Dive In to X64!

X64 Basics – Architecture Details

Simple Arithmetic Instructions

x64 Basics

`negq <o1>`

$o_1 = -o_1$

Example

```
movq $4, %rax
negq %rax
```

At this pt:
%rax = -4

"Support" operand *"Main" operand*

`addq <o1> <o2>`

$o_2 = o_2 + o_1$ *Take <o_2> and "do" <o_1> to it*

Example

```
movq $4, %rax
movq $5, %rbx
addq %rax, %rbx
```

At this pt:
%rbx = 9

`subq <o1> <o2>`

$o_2 = o_2 - o_1$

Example

```
movq $4, %rax
movq $5, %rbx
subq %rax, %rbx
```

At this pt:
%rbx = 1

Wacky Arithmetic Instructions

x64 Basics

`imulq <o1>`

*%rdx:%rax = %rax * o_1*

Example

```
movq $2, %rax
movq $4, %r11
imulq %r11
```

*2 * 4*

At this pt:
%rax = 8
%rdx = 0

`idivq <o1>`

%rax = %rdx:%rax / o_1
%rdx = %rdx:%rax % o_1

Example

```
movq $0, %rdx
movq $6, %rax
movq $2, %r8
idivq %r8
```

6 / 2

At this pt:
%rax = 3
%rdx = 0

Logical Instructions

x64 Basics

`notq <o1>`

o_1 = bitflip o_1

Example

```
movq $1, %rcx
notq %rcx
```

At this pt:
%rcx = -2

Why -2?

Before bitflip

```
%rcx 0..01
```

After bitflip

```
%rcx 1..10
```

2's complement…

```
0..01   Flip all bits
0..10   Add 1
```

0 + 2 + 0 = (negative) 2

`andq <o1> <o2>`

$o_2 = o_2$ & o_1

Example

```
movq $12, %rdx
movq $10, %rax
andq %rax, %rdx
```

At this pt:
%rdx = 8

Before and

```
%rdx 0..1100
%rax 0..1010
```

After and

```
%rax 0..1000
```

0 + 8 + 0 + 0 + 0 = 8

`orq <o1> <o2>`

$o_2 = o_2$ | o_1

Example

```
movq $12, %rdx
movq $10, %rax
orq %rax, %rdx
```

At this pt:
%rdx = 14

Before or

```
%rdx 0..1100
%rax 0..1010
```

After or

```
%rax 0..1110
```

0 + 8 + 4 + 2 + 0 = 14

`xorq <o1> <o2>`

$o_2 = o_1$ ^ o_2

Example

```
movq $9, %rdx
movq $10, %rax
xorq %rax, %rdx
```

At this pt:
%rdx = 3

Before xor

```
%rdx 0..0101
%rax 0..0110
```

After xor

```
%rax 0..0011
```

0 + 2 + 1 = 3

Conditionals

x64 Basics

```
movq $1, %rbx
movq $1, %rax
cmpq %rax, %rbx
je LBL_1
```

Jump to LBL_1

Another weird x86 thing

- conditional jump instructions – no explicit condition!
- Uses the flags register rflags
  - Assumes a previous operation has set the flags register

```
je <LBL>
```

Jump to label LBL if equal, else fallthrough

"Wait… jump if *what* is equal?"

```
cmpq %rax, %rbx
je <LBL>
```

Jump to label LBL if rax and rbx are equal, else fallthrough

Conditionals and rflags

x64 Basics

rflags: bitvector register of conditions

OF “Overflow Flag”	Result exceeds storage
SF “Sign Flag”	Result was negative
ZF “Zero Flag”	Result was zero

cmpq src1 src2 : Set flags as though computing src2 – src1

je	sete	E	(E)quality	ZF
jne	setne	NE	(N)ot (E)qual	$\neg$ZF
		G	(G)reater	$(\neg ZF \wedge \neg SF) \oplus OF$
jg	setg	L	(L)ess	$SF \oplus OF$
jl	setl	GE	(G)reater or (E)qual	$\neg SF \oplus OF$
jge	setge			
jle	setle	LE	(L)ess or (E)qual	$(SF \oplus OF) \vee ZF$

```
movq $1, %rax
movq $2, %rbx
cmpq %rax, %rbx
sete <o1>
```

At this pt: $\langle o_1 \rangle = 0$

✗ sete %rax

✓ sete %al

You can now (kinda) write assembly programs!

x64 Basics

src code

```
int main(){
  return 2 - 1;
}
```

asm code

```
.globl _start
.text
_start:
        movq $1, %r10
        movq $2, %r11
        subq %r10, %r11

        #exit
        movq $60, %rax
        movq %r11, %rdi
        syscall
```

Today's Lecture

X64 Basics

X64 Discussion

- Some assurances

Architecture Details

- Basic operators
- Memory directives

Architecture

Manipulating Memory

X64 Basics

Data can’t always fit into registers

Two things we need to do:

1. Allocate memory
2. Read/write memory

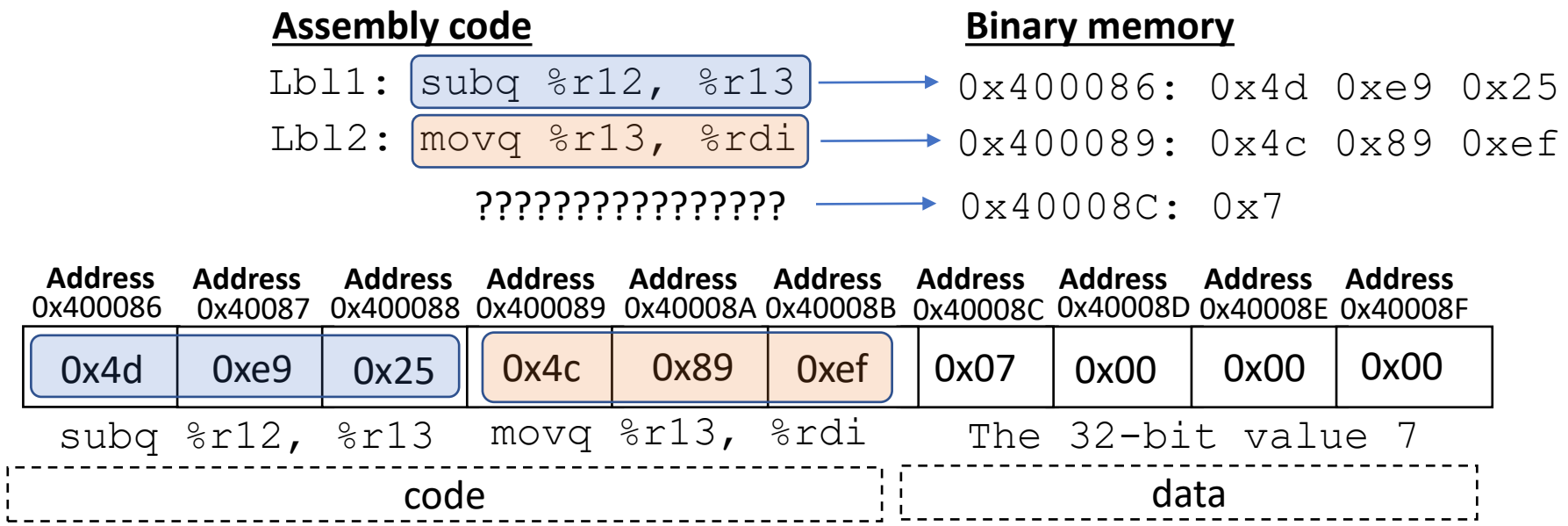
A different kind of memory being manipulated

Recall: Memory as an Array

X64 Basics

Memory is just a big ol' array of bytes (with OS mediation)

- Assembler and friends will map the code into memory
- We still need to map data to memory
  - variables, objects, strings, arrays, etc.



Lecture Done!

x64 Basics: Summary

Some basic x64 details

- Instructions
- Data directives
- Memory intuition

Next Time

- Dive further into x64
- Describe memory operations