



Instruction Set Architectures, Stacks

CS 2130: Computer Systems and Organization 1
February 23, 2026

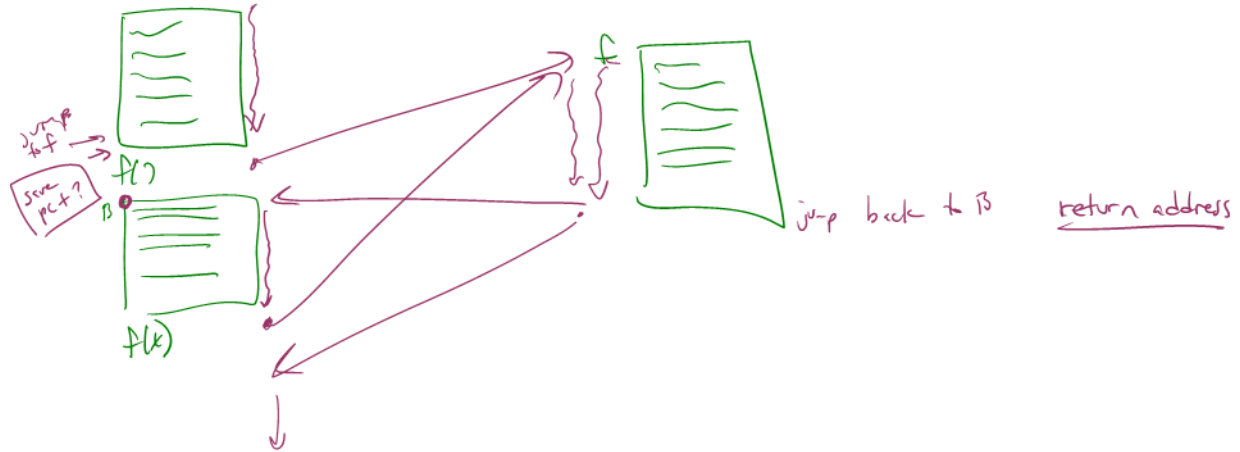
Announcements

- Homework 3 due today
- Homework 4 available soon **due Monday after Spring Break** on Gradescope
 - You have written most of this code already

Instructions

icode	b	meaning
0		$rA = rB$
1		$rA \&= rB$
2		$rA += rB$
3	0	$rA = \sim rA$
	1	$rA = !rA$
	2	$rA = -rA$
	3	$rA = pc$
4		$rA = \text{read from memory at address } rB$
5		write rA to memory at address rB
6	0	$rA = \text{read from memory at } pc + 1$
	1	$rA \&= \text{read from memory at } pc + 1$
	2	$rA += \text{read from memory at } pc + 1$
	3	$rA = \text{read from memory at the address stored at } pc + 1$
		For icode 6, increase pc by 2 at end of instruction
7		Compare rA as 8-bit 2's-complement to 0 if $rA \leq 0$ set $pc = rB$ else increment pc as normal

Function Calls



Memory

What kinds of things do we put in memory?

- Code: binary code like instructions in our example ISA
 - Intel/AMD compatible: x86_64
 - Apple Mx and Ax, ARM: ARM
 - And others!
- Variables: we may have more variables that will fit in registers
- Data Structures: organized data, collection of data
 - Arrays, lists, heaps, stacks, queues, ...

Arrays

Array: a sequence of values (collection of variables)
In Java, arrays have the following properties:

- Fixed number of values
- Not resizable
- All values are the same type

Arrays

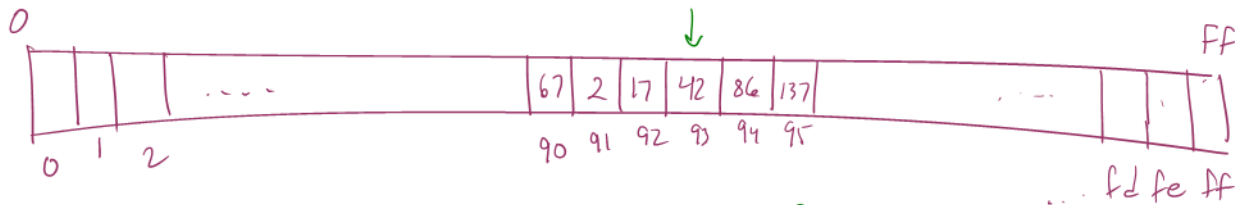
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- Fixed number of values
- Not resizable
- All values are the same type

How do we store them in memory?

Arrays

arr[6] = { 67, 2, 17, 42, 86, 137 }



$$\text{arr}[3] = 42$$

$$m[90+3] = m[93]$$

Storing Arrays

In memory, store array sequentially

- Pick address to store array
- Subsequent elements stored at following addresses
- Access elements with math

Example: Store array *arr* at 0x90

- Access *arr*[3] as $0x90 + 3$ assuming 1-byte values

arr[*i*] → $M[\text{started} + i]$

Arrays - What's Missing?

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What are we missing?

- Nothing says “this is an array” in memory
- Nothing says how long the array is

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Instruction Set Architecture

Instruction Set Architecture (ISA) is an abstract model of a computer defining how the CPU is controlled by software

- Conceptually, set of instructions that are possible and how they should be encoded
- Results in many *different* machines to implement same ISA
 - Example: How many machines implement our example ISA?
- Common in how we design hardware

Instruction Set Architecture

Instruction Set Architecture (ISA) is an abstract model of a computer defining how the CPU is controlled by software

- Provides an abstraction layer between:
 - Everything computer is really doing (hardware)
 - What programmer using the computer needs to know (software)
- Hardware and Software engineers have freedom of design, if conforming to ISA
- Can change the machine without breaking any programs

Instruction Set Architecture

Instruction Set Architecture (ISA) is an abstract model of a computer defining how the CPU is controlled by software

- Provides an abstraction layer between:
 - Everything computer is really doing (hardware)
 - What programmer using the computer needs to know (software)

CSO: covering many of the times we'll need to think across this barrier

Instruction Set Architecture

Backwards compatibility

- Include flexibility to add additional instructions later
- Original instructions will still work
- Same program can be run on PC from 10+ years ago and new PC today

Most manufacturers choose an ISA and stick with it

- Notable Exception: Apple

What about real ISAs?

Our Instruction Set Architecture

What about our ISA?

- Enough instructions to compute what we need
- As is, lot of things that are painful to do
 - This was on purpose! So we can see limitations of ISAs early

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ToyISA Instructions

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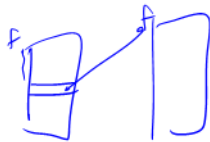
- Enough instructions to compute what we need
- As is, lot of things that are painful to do
 - This was on purpose! So we can see limitations of ISAs early
- Add any number of new instructions using the reserved bit (7)
- Missing something important: *Help to put variables in memory*

Storing Variables in Memory

So far... we/compiler chose location for variable
Consider the following example:

```
f(x):  
    a = x  
    → if (x <= 0) return 0  
       else return f(x-1) + a
```

$$f(x) = \sum_{i=1}^x i$$



Recursion

- The formal study of a function that calls itself

Storing Variables in Memory

```
f(x):  
  a = x  
  if (x <= 0) return 0  
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```

Where do we store a?

The Stack

Stack - a last-in-first-out (LIFO) data structure

- *The* solution for solving this problem

rsp - Special register - the stack pointer

- Points to a special location in memory
- Two operations most ISAs support:
 - **push** - put a new value on the stack
 - **pop** - return the top value off the stack

The Stack: Push and Pop

push r0

- Put a value onto the “top” of the stack

`rsp -= 1`

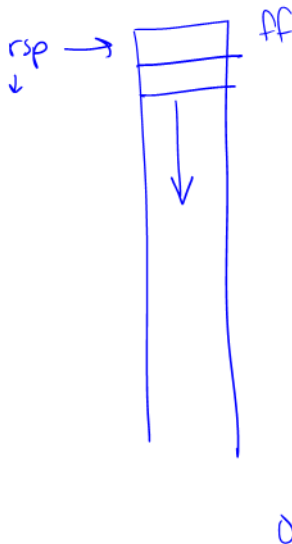
`M[rsp] = r0`

pop r2

- Read value from “top”, save to register

`r2 = M[rsp]`

`rsp += 1`



The Stack: Push and Pop

The Stack: Push and Pop

Function Calls

A short aside...

Time to take over the world!

Backdoors

Backdoor: secret way in to do new *unexpected* things

- Get around the normal barriers of behavior
- Ex: a way in to allow me to take complete control of your computer

Backdoors

Exploit - a way to use a vulnerability or backdoor that has been created

- Our exploit today: a **malicious payload**
 - A passcode and program
 - If it ever gets in memory, run my program regardless of what you want to do

Our Hardware Backdoor

Our backdoor will have 2 components

- Passcode: need to recognize when we see the passcode
- Program: do something bad when I see the passcode

Our Hardware Backdoor

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Will you notice this on your chip?

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Our Hardware Backdoor

Will you notice this on your chip?

- Modern chips have **billions** of transistors
- We're talking adding a few hundred transistors
- *Maybe with a microscope? But you'd need to know where to look!*

Our Hardware Backdoor

Have you heard about something like this before?

Our Hardware Backdoor

Have you heard about something like this before?

- Sounds like something from the movies

Our Hardware Backdoor

Have you heard about something like this before?

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- People claim this might be happening

Our Hardware Backdoor

Have you heard about something like this before?

- Sounds like something from the movies
- People claim this might be happening
- To the best of my knowledge, no one has ever *admitted* to falling in this trap

Ethics, Business, Tech

Are there reasons to do this? Not to do this?

- No technical reason not to, it's easy to do!

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Can we make a system where one bad actor can't break it?

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Can we make a system where one bad actor can't break it?

- Code reviews, double checks, verification systems, automated verification systems, ...

Why does this work?

Why?

Why does this work?

- **It's all bytes!**
- Everything we store in computers are bytes
- We store code and data in the same place: memory

It's all bytes

Memory, Code, Data... It's all bytes!

- **Enumerate** - pick the meaning for each possible byte
- **Adjacency** - store bigger values together (sequentially)
- **Pointers** - a value treated as address of thing we are interested in

Enumerate

Enumerate - pick the meaning for each possible byte

What is 8-bit 0x54?

Unsigned integer

Signed integer

Floating point w/ 4-bit exponent

ASCII

Bitvector sets

Our example ISA

eighty-four

positive eighty-four

twelve

capital letter T: T

The set {2, 3, 5}

Flip all bits of value in r1

Adjacency

Adjacency - store bigger values together (sequentially)

- An array: build bigger values out of many copies of the same type of small values
 - Store them next to each other in memory
 - Arithmetic to find any given value based on index

Adjacency

Adjacency - store bigger values together (sequentially)

- Records, structures, classes
 - Classes have fields! Store them adjacently
 - Know how to access (add offsets from base address)
 - If you tell me where object is, I can find fields

Pointers

Pointers - a value treated as address of thing we are interested in

- A value that really points to another value
- Easy to describe, hard to use properly
- *We'll be talking about these a lot in this class!*

Pointers

Pointers - a value treated as address of thing we are interested in

- Give us strange new powers (represent more complicated things), e.g.,
 - Variable-sized lists
 - Values that we don't know their type without looking
 - Dictionaries, maps

Programs Use These!

How do our programs use these?

- Enumerated icodes, numbers
- Adjacent stored instructions (PC+1)
- Pointers of where to jump/goto (addresses in memory)