More Variables, Arrays, and More

CS 2130: Computer Systems and Organization 1

February 20, 2023

Announcements

- Homework 3 due **Wednesday** at 11pm on Gradescope
- Exam 1 Friday in class, review on Wednesday
    - Review session in class on Wednesday (bring questions!)
    - Pen/pencil and paper, we'll provide scratch paper
    - No calculator needed

High-level Instructions

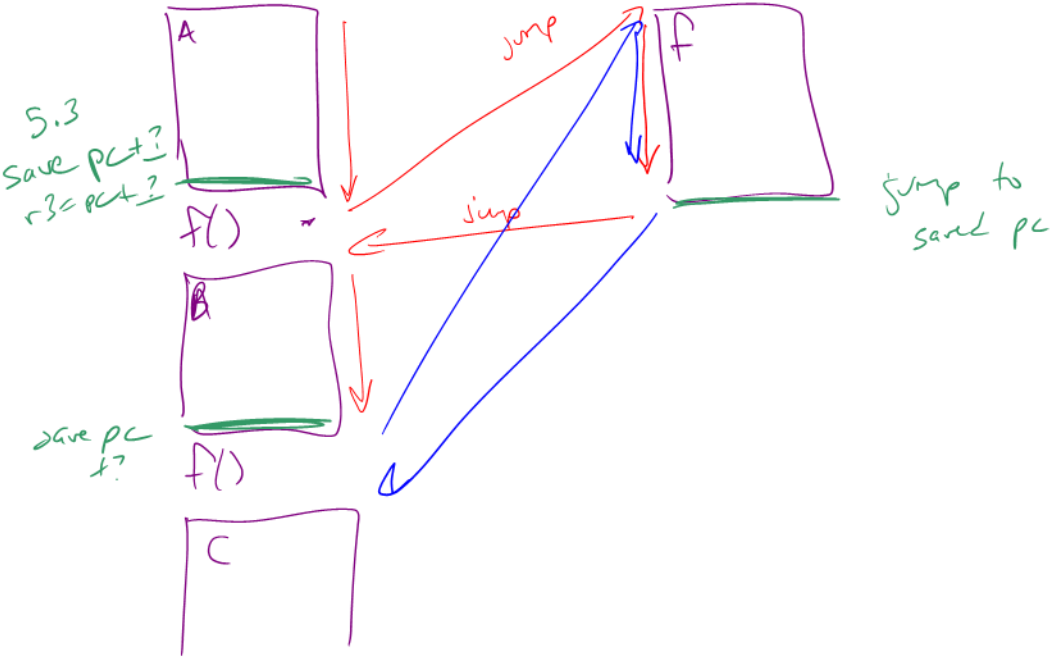
In general, 3 kinds of instructions

- **moves** - move values around without doing “work”
- **math** - broadly doing “work”
- **jumps** - jump to a new place in the code

Jumps

- Moves and math are large portion of our code
- We also need **control constructs**
  - Change what we are going to do next
  - `if`, `while`, `for`, functions, …
- Jumps provide mechanism to perform these control constructs
- We jump by assigning a new value to the program counter **PC**

Function Calls



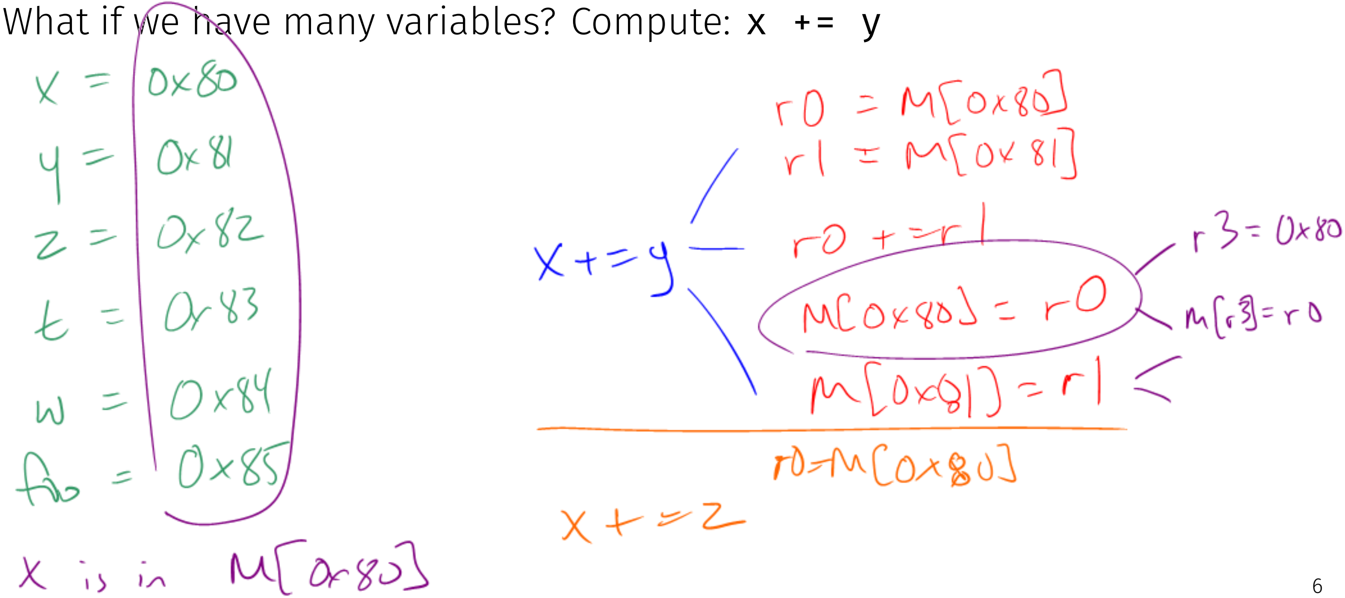
Memory

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, ...

Dealing with Variables and Memory

What if we have many variables? Compute: `x += y`



Arrays

Array: a sequence of values (collection of variables)

In Java, arrays have the following properties:

- Fixed number of values
- Not resizable
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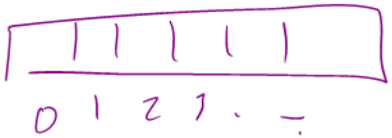
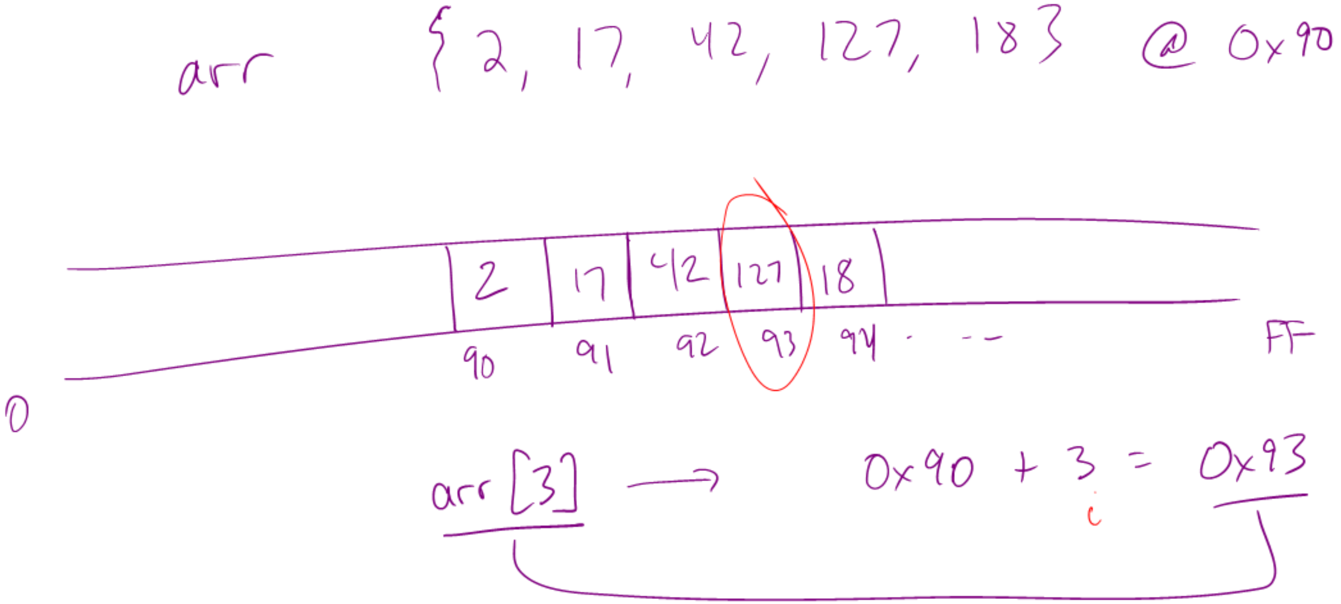
How do we store them in memory?



Arrays


arr
{2, 17, 42, 127, 18}
@ 0x90
2
17
42
127
18
90
91
92
93
94
FF
0
arr[3]
0x90 + 3 = 0x93
i

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[5] = 0x27
m[90 + 5] = 0x27

What’s Missing?

What are we missing?

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

Instructions

icode	b	meaning
0		`rA = rB`
1		`rA += rB`
2		`rA &= rB`
3		`rA` = read from memory at address `rB`
4		write `rA` to memory at address `rB`
5	0	`rA = ~rA`
	1	`rA = -rA`
	2	`rA = !rA`
	3	`rA = pc`
6	0	`rA` = read from memory at `pc + 1`
	1	`rA` += read from memory at `pc + 1`
	2	`rA` &= read from memory at `pc + 1`
	3	`rA` = 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 <= 0` set `pc = rB`
		else increment `pc` as normal

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

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

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
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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
- 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
```

Recursion

- The formal study of a function that calls itself

Storing Variables in Memory

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

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

What about real ISAs?