Introduction to Assembly Language

CS 64: Computer Organization and Design Logic
Lecture #4
Fall 2018

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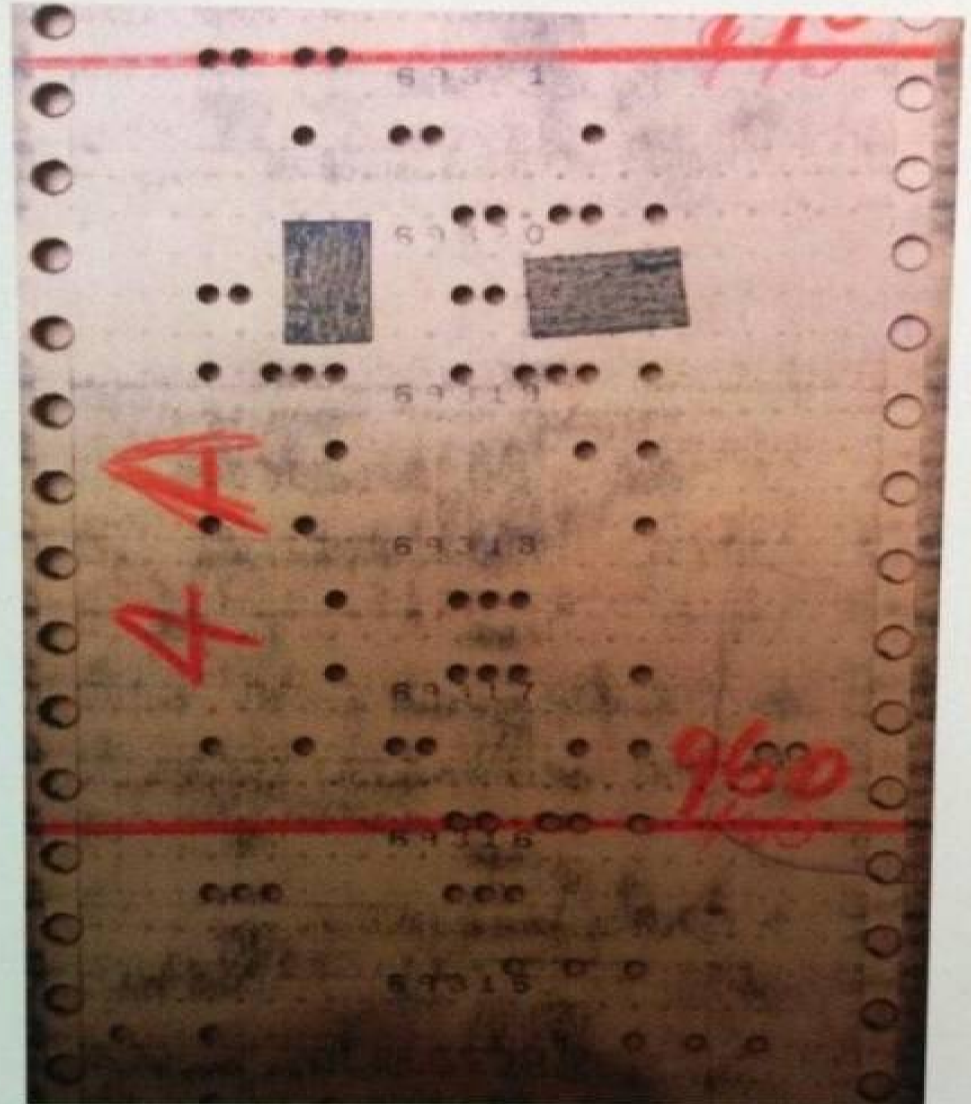
This Week on "Didja Know Dat?!"

The "Patch"



Small corrections to the programmed sequence could be done by patching over portions of the paper tape and re-punching the holes in that section.

Image courtesy of the Smithsonian Archives Center.

Why do CPU programmers celebrate Christmas and Halloween on the same day?

Because Oct-31 = Dec-25

Lecture Outline

- MIPS core processing blocks
- Basic programming in assembly
- Arithmetic programs

Administrative Stuff

- TA Office Hours (in Trailer 936)
  - Bay Yuan Hsu, bhsu@ucsb.edu,
    Thursdays 12:30 – 2:30 PM
  - Harmeet Singh, harmeetsingh@ucsb.edu,
    Thursdays 9:30 – 11:30 AM

- How did Lab# 2 go?
  - Too easy? Too hard? Just right?

Any Questions From Last Lecture?

The Simple Language of a CPU

- We have: variables, integers, addition, and assignment

- <u>Restrictions:</u>
  - Can only assign **integers** directly to variables
  - Can only add variables, always **two at a time** (no more)

EXAMPLE:

z = 5 + 7; has to be simplified to:

x = 5;

y = 7;

z = x + y;

What func is needed to implement this? ←←←

An adder: but how many bits?

Core Components

What we need in a CPU is:

- Some place to hold the statements (instructions to the CPU) as we operate on them
- Some *place* to tell us *which statement* is next
- Some *place* to hold all the *variables*
- Some *way* to do arithmetic on *numbers*

That's ALL that Processors Do!!

Processors just read a series of statements (instructions) forever.
No magic!

Core Components

What we need in a CPU is:

- Some place to **hold the statements** (instructions to the CPU) as we operate on them → MEMORY
- Some *place* to tell us *which statement* is **next** → PROGRAM COUNTER (PC)
- Some *place* to **hold all the variables** → REGISTERS
- Some *way* to **do arithmetic on** *numbers* → ARITHMETIC LOGIC UNIT (ALU)

…And one more thing:

- Some place to tell us which statement is **currently** being executed → INSTRUCTION REGISTER (IR)

Basic Interaction

- Copy instruction from **memory** at wherever the **program counter (PC)** says into the **instruction register (IR)**
- Execute it, possibly involving registers and the **arithmetic logic unit (ALU)**
- Update the **PC** to point to the next instruction
- Repeat

```
initialize();
while (true) {
    instruction_register =
        memory[program_counter];
    execute(instruction_register);
    program_counter++;
}
```

Instruction Register

?

Registers

```
x:  ?
y:  ?
z:  ?
```

Program Counter

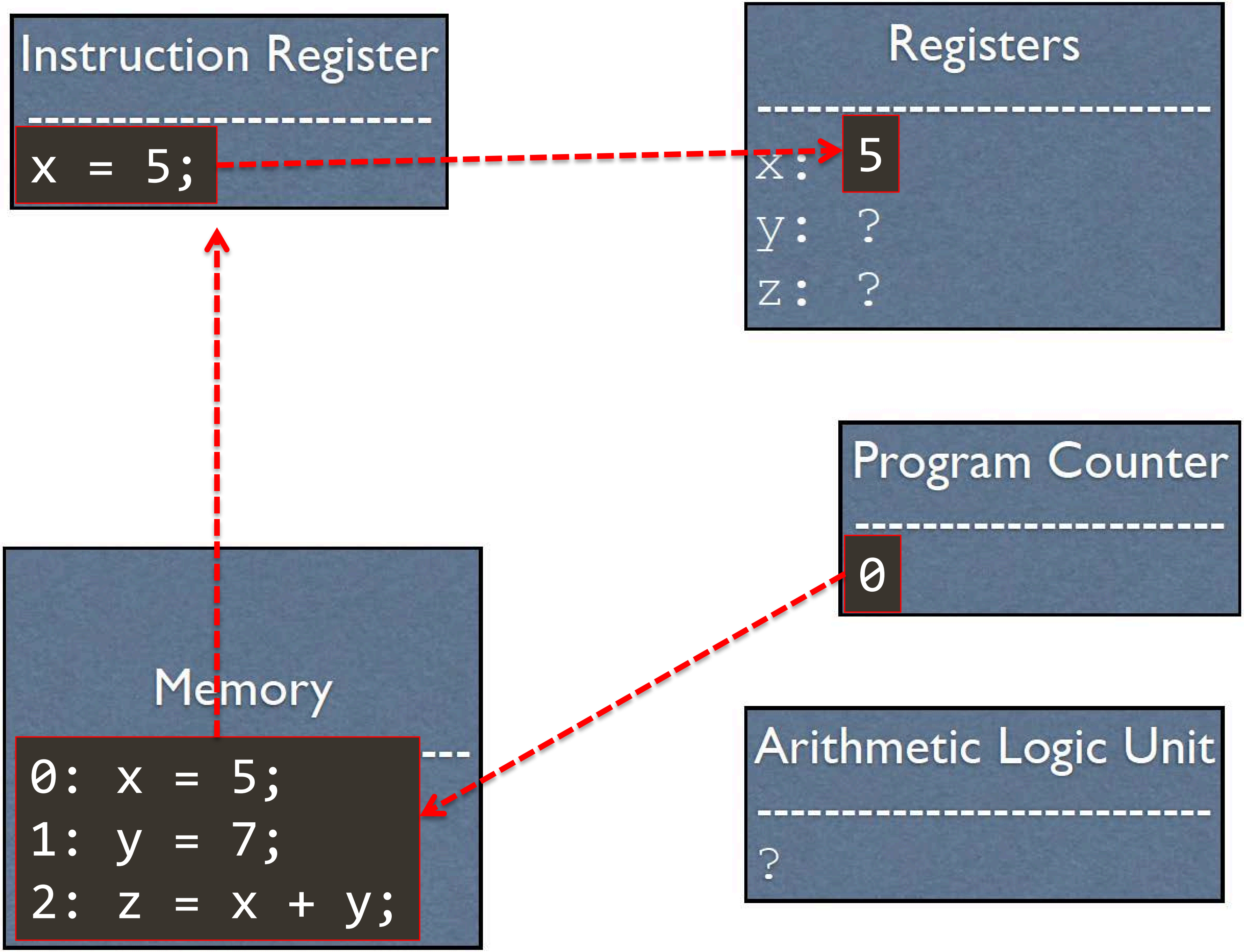
?

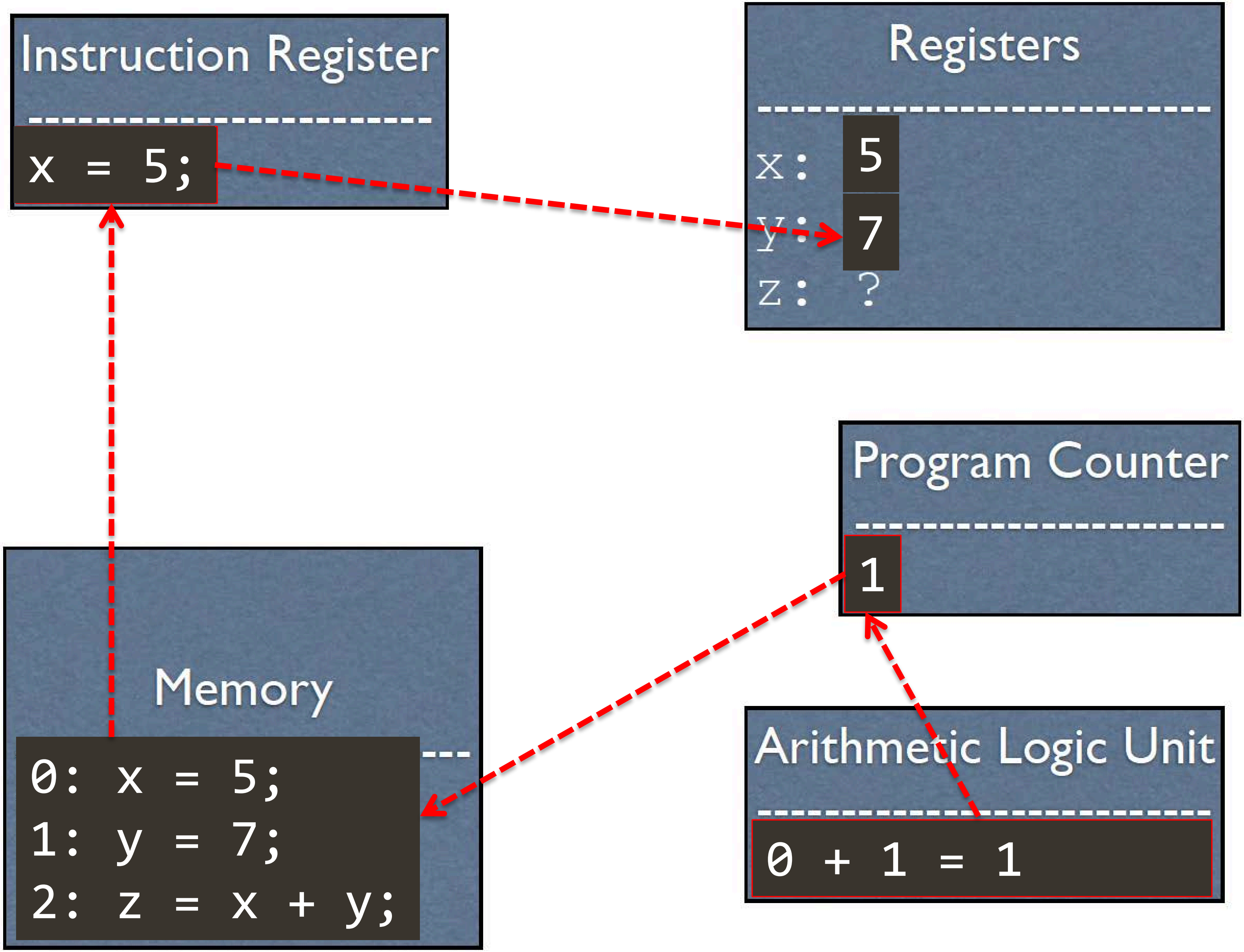
Memory

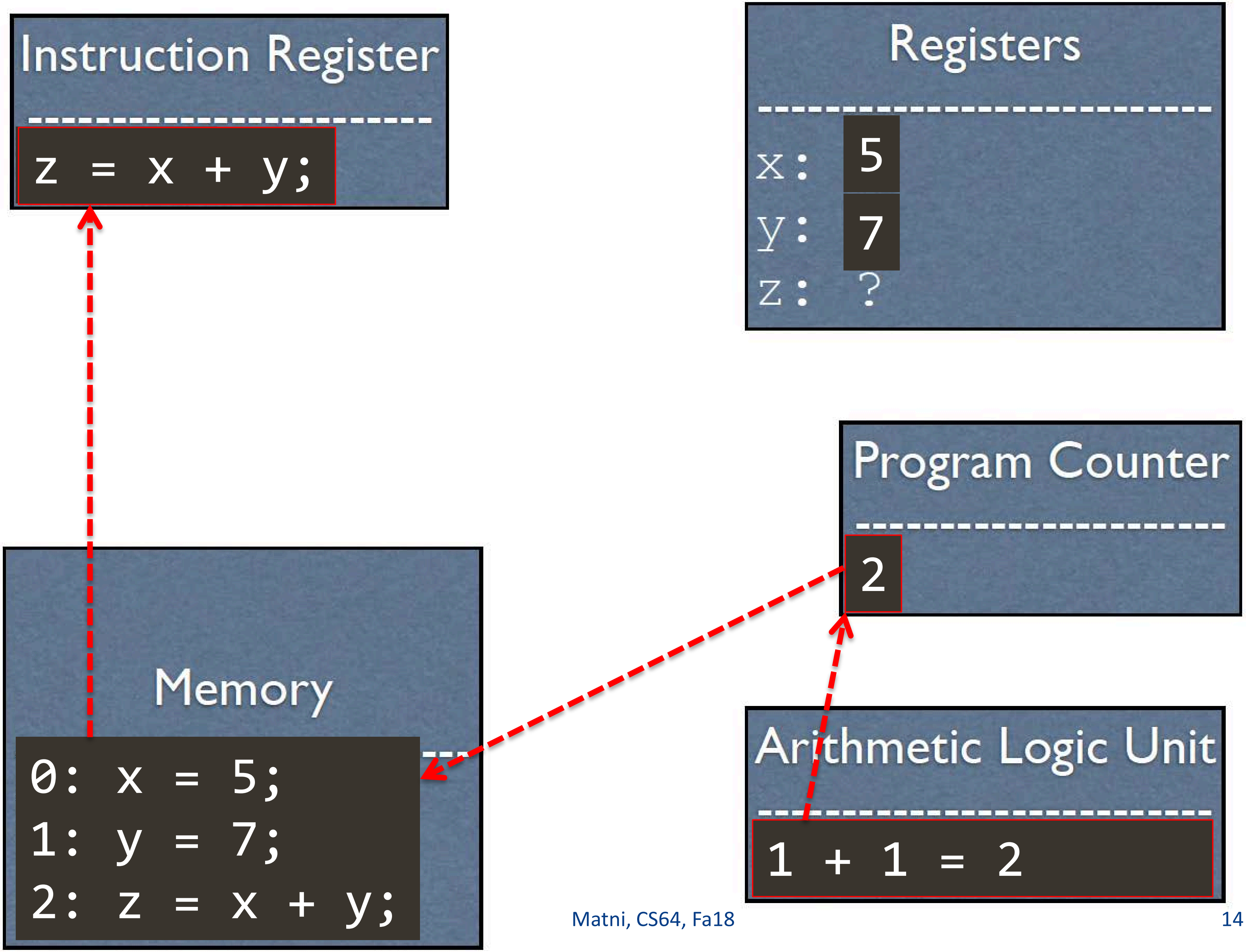
?

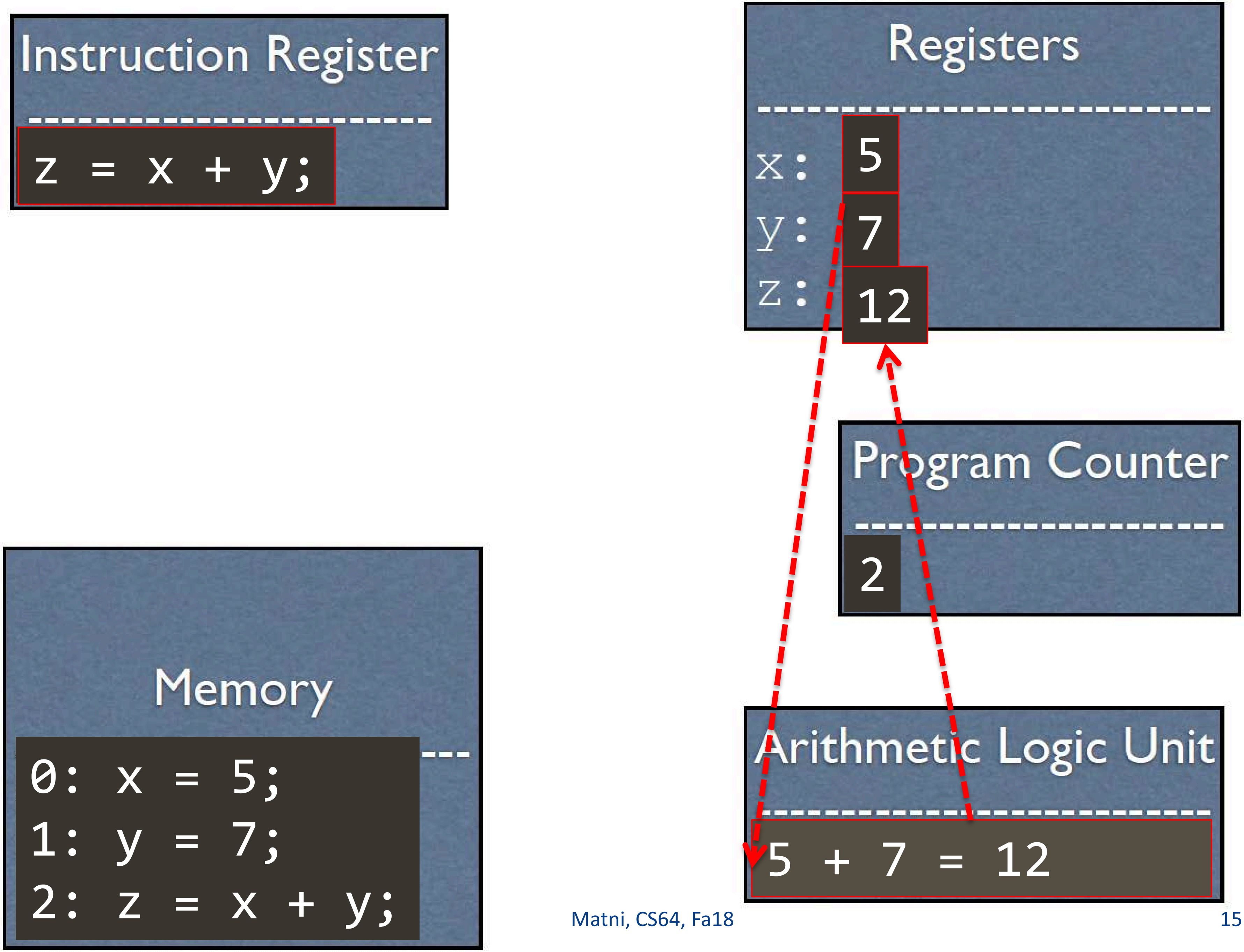
Arithmetic Logic Unit

?


Instruction Register
x = 5;
Registers
x: 5
y: ?
z: ?
Program Counter
0
Memory
0: x = 5;
1: y = 7;
2: z = x + y;
Arithmetic Logic Unit
?


Instruction Register
x = 5;
Registers
x: 5
y: 7
z: ?
Program Counter
1
Memory
0: x = 5;
1: y = 7;
2: z = x + y;
Arithmetic Logic Unit
0 + 1 = 1


Instruction Register
z = x + y;
Registers
x: 5
y: 7
z: ?
Program Counter
2
Memory
0: x = 5;
1: y = 7;
2: z = x + y;
Arithmetic Logic Unit
1 + 1 = 2


Instruction Register
z = x + y;
Registers
x: 5
y: 7
z: 12
Program Counter
2
Memory
0: x = 5;
1: y = 7;
2: z = x + y;
Arithmetic Logic Unit
5 + 7 = 12

Why MIPS?

- MIPS:
  - a **r**educed **i**nstruction **s**et **c**omputer (RISC) architecture developed by a company called MIPS Technologies (1981)
- Relevant in the *embedded systems* area of CS/CE
- All modern commercial processors share the same core concepts as MIPS, just with extra stuff
- ...but most importantly...

MIPS is Simpler…

… than other instruction sets for CPUs

So it's a great learning tool

- Dozens of instructions (as opposed to hundreds)
- Lack of redundant instructions or special cases
- 5 stage pipeline versus 24 stages

Note: Pipelining in CPUs

- Pipelining is a fundamental design in CPUs
- Allows multiple instructions to go on at once
  - a.k.a instruction-level parallelism

Basic five-stage pipeline

Instr. No. \ Clock cycle	1	2	3	4	5	6	7
1	IF	ID	EX	MEM	WB		
2		IF	ID	EX	MEM	WB	
3			IF	ID	EX	MEM	WB
4				IF	ID	EX	MEM
5					IF	ID	EX

(IF = Instruction Fetch, ID = Instruction Decode, EX = Execute, MEM = Memory access, WB = Register write back).

Code on MIPS

Original	MIPS

`x = 5;`
`y = 7;`
`z = x + y;`
	`li $t0, 5`
	`li $t1, 7`
	`add $t3, $t0, $t1`

Code on MIPS

Original	MIPS

`x = 5;`
`y = 7;`
`z = x + y;`
	`li $t0, 5`
	`li $t1, 7`
	`add $t3, $t0, $t1`

	load immediate: put the given value into a register **$t0**: temporary register **0**

Code on MIPS

Original	MIPS

`x = 5;`
`y = 7;`
`z = x + y;`
	`li $t0, 5`
	`li $t1, 7`
	`add $t3, $t0, $t1`

	load immediate: put the given value into a register **$t1**: temporary register **1**

Code on MIPS

Original	**MIPS**

`x = 5;`
`y = 7;`
`z = x + y;`
	`li $t0, 5`
	`li $t1, 7`
	`add $t3, $t0, $t1`

	add: add the rightmost registers, putting the result in the first register **$t3**: temporary register **3**

Available Registers in MIPS

- 32 registers in all
  - Refer to your MIPS Reference Card
- For the moment, let's only consider registers **$t0 thru $t9**

NAME	NUMBER	USE
$zero	0	The Constant Value 0
$at	1	Assembler Temporary
$v0-$v1	2-3	Values for Function Results and Expression Evaluation
$a0-$a3	4-7	Arguments
$t0-$t7	8-15	Temporaries
$s0-$s7	16-23	Saved Temporaries
$t8-$t9	24-25	Temporaries
$k0-$k1	26-27	Reserved for OS Kernel
$gp	28	Global Pointer
$sp	29	Stack Pointer
$fp	30	Frame Pointer
$ra	31	Return Address

Assembly

- The code that you see is MIPS assembly

```
li $t0, 5
li $t1, 7
add $t3, $t0, $t1
```

- Assembly is *almost* what the machine sees. For the most part, it is a **direct** translation to binary from here (known as **machine language/code**)

- An **assembler** takes assembly code and changes it into the actual 1's and 0's for machine code
  - Analogous to a compiler for HL code

Machine Code/Language

- What a CPU actually accepts as input
- What actually gets executed

- Each instruction is represented with **32 bits**
  - No more, no less

- There are **three** different ***instruction formats***: **R**, **I**, and **J**
  - These allow for instructions to take on different roles
  - R-Format is used when it's all about **registers**
  - I-Format is used when you involve **(immediate) numbers**
  - J-Format is used when you do code "**jumping**" (i.e. branching)

Instruction Registers

?

Registers

`$t0: ?`
`$t1: ?`
`$t2: ?`

Since all instructions are 32-bits, then they each occupy 4 Bytes of memory.

Memory is addressed in Bytes
(more on this later).

Program Counter

?

Memory

?

Arithmetic Logic Unit

?

Instruction Register

?

Registers

```
$t0: ?
$t1: ?
$t2: ?
```

Since all instructions are 32-bits, then they each occupy 4 Bytes of memory.

Memory is addressed in Bytes (more on this later).

Program Counter

0

Memory

```
0: li $t0, 5
4: li $t1, 7
8: add $t3, $t0, $t1
```

Arithmetic Logic Unit

?

Instruction Register

```
li $t0, 5
```

Registers

```
$t0: ?
$t1: ?
$t2: ?
```

Since all instructions are 32-bits, then they each occupy 4 Bytes of memory.

Memory is addressed in Bytes (more on this later).

Program Counter

```
0
```

Memory

```
0: li $t0, 5
4: li $t1, 7
8: add $t3, $t0, $t1
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
li $t0, 5
```

Registers

```
$t0: 5
$t1: ?
$t2: ?
```

Since all instructions are 32-bits, then they each occupy 4 Bytes of memory.

Memory is addressed in Bytes
(more on this later).

Program Counter

```
0
```

Memory

```
0: li $t0, 5
4: li $t1, 7
8: add $t3, $t0, $t1
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
li $t0, 5
```

Registers

```
$t0: 5
$t1: ?
$t2: ?
```

Since all instructions are 32-bits, then they each occupy 4 Bytes of memory.

Memory is addressed in Bytes (more on this later).

Program Counter

```
4
```

Memory

```
0: li $t0, 5
4: li $t1, 7
8: add $t3, $t0, $t1
```

Arithmetic Logic Unit

```
0 + 4 = 4
```

Instruction Register

```
li $t1, 7
```

Registers

```
$t0: 5
$t1: ?
$t2: ?
```

Since all instructions are 32-bits, then they each occupy 4 Bytes of memory.

Memory is addressed in Bytes (more on this later).

Program Counter

```
4
```

Memory

```
0: li $t0, 5
4: li $t1, 7
8: add $t3, $t0, $t1
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
li $t1, 7
```

Registers

```
$t0: 5
$t1: 7
$t2: ?
```

Since all instructions are 32-bits, then they each occupy 4 Bytes of memory.

Memory is addressed in Bytes
(more on this later).

Program Counter

```
4
```

Memory

```
0: li $t0, 5
4: li $t1, 7
8: add $t3, $t0, $t1
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
li $t1, 7
```

Registers

```
$t0: 5
$t1: 7
$t2: ?
```

Since all instructions are 32-bits, then they each occupy 4 Bytes of memory.

Memory is addressed in Bytes (more on this later).

Program Counter

```
8
```

Memory

```
0: li $t0, 5
4: li $t1, 7
8: add $t3, $t0, $t1
```

Arithmetic Logic Unit

```
4 + 4 = 8
```

Instruction Register

```
add $t3, $t0, $t1
```

Registers

```
$t0: 5
$t1: 7
$t2: ?
```

Since all instructions are 32-bits, then they each occupy 4 Bytes of memory.

Memory is addressed in Bytes (more on this later).

Program Counter

```
8
```

Memory

```
0: li $t0, 5
4: li $t1, 7
8: add $t3, $t0, $t1
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
add $t3, $t0, $t1
```

Registers

```
$t0: 5
$t1: 7
$t2: ?
```

Since all instructions are 32-bits, then they each occupy 4 Bytes of memory.

Memory is addressed in Bytes
(more on this later).

Program Counter

```
8
```

Memory

```
0: li $t0, 5
4: li $t1, 7
8: add $t3, $t0, $t1
```

Arithmetic Logic Unit

```
5 + 7 = 12
```

Instruction Register

```
add $t3, $t0, $t1
```

Registers

```
$t0: 5
$t1: 7
$t2: 12
```

Since all instructions are 32-bits, then they each occupy 4 Bytes of memory.

Memory is addressed in Bytes
(more on this later).

Program Counter

```
8
```

Memory

```
0: li $t0, 5
4: li $t1, 7
8: add $t3, $t0, $t1
```

Arithmetic Logic Unit

```
5 + 7 = 12
```

Adding More Functionality

- What about: display results???? *Yes, that's kinda important…*
- What would this entail?
  - Engaging with Input / Output part of the computer
  - i.e. talking to devices
    - **Q: What usually handles this?** **A: the operating system**

- So we need a way to tell
  the operating system to kick in

Talking to the OS

- We are going to be running on MIPS ***emulator*** called **SPIM**
  - Optionally, through a program called **QtSPIM** (GUI based)
  - *What is an emulator?*

- We're not actually running our commands on an actual MIPS (hardware) processor!!

  …we're letting software pretend it's hardware…

  …so, in other words… we're "faking it"

- Ok, so how might we print something onto std.out?

SPIM Routines

- MIPS features a `syscall` instruction, which triggers a ***software interrupt***, or ***exception***

- Outside of an emulator (i.e. in the real world), these instructions **pause the program** and tell the OS to go do something with I/O

- Inside the emulator, it tells the emulator to go *emulate* something with I/O

`syscall`

- So we have the OS/emulator's attention, but how does it know what we want?
- The OS/emulator has access to the CPU registers
- We put special values (codes) in the registers to indicate what we want
  - These are codes that can't be used for anything else, so they're understood to be just for `syscall`
  - So… is there a "code book"????

Yes! All CPUs come with manuals.
For us, we have the **MIPS Ref. Card**

(Finally) Printing an Integer

- For SPIM, if register **`$v0`** contains **1** and then we issue a **syscall**, then SPIM will *print whatever **integer** is stored in register **`$a0`*** ***← this is a specific rule using a specific code***
  - Note: $v0 is used for other stuff as well – more on that later…
  - When $v0=1, syscall is *expecting* an integer!

- Other values put into **$v0** indicate other types of I/O calls to **syscall**

  Examples:
  - $v0 = 3 means **double (or the mem address of one) in $a0**
  - $v0 = 4 means **string (or the mem address of one) in $a0**
  - We'll explore some of these later, but check **MIPS ref card** for all of them

(Finally) Printing an Integer

- Remember, the usual syntax to load immediate a value into a register is:

```
li <register>, <value>
```

Example: **li $v0, 1** # PUTS THE NUMBER 1 INTO REG. $v0

- You can move the value of one register into another too!
- E.g. To make sure that the register **$a0** has the value of what you want to print out (let's say it's in another register), use the **move** command:

```
move <to register>, <from register>
```

Example: **move $a0, $t0** # PUTS THE VALUE IN REG. $t0 INTO REG. $a0

Ok… So About Those Registers
MIPS has 32 registers, each is 32 bits

NAME	NUMBER	USE
$zero	0	The Constant Value 0
$at	1	Assembler Temporary
$v0-$v1	2-3	Values for Function Results and Expression Evaluation
$a0-$a3	4-7	Arguments
$t0-$t7	8-15	Temporaries
$s0-$s7	16-23	Saved Temporaries
$t8-$t9	24-25	Temporaries
$k0-$k1	26-27	Reserved for OS Kernel
$gp	28	Global Pointer
$sp	29	Stack Pointer
$fp	30	Frame Pointer
$ra	31	Return Address

Used for data

Program Files for MIPS Assembly

- The files have to be text
- Typical file extension type is **.asm**
- To leave comments,
  use **#** at the start of the line

Augmenting with Printing

```
# Main program
li $t0, 5
li $t1, 7
add $t3, $t0, $t1

# Print an integer to std.output
li $v0, 1
move $a0, $t3
syscall
```

We’re Not Quite Done Yet! Exiting an Assembly Program in SPIM

- If you are using SPIM, then you need to say when you are done as well
  - Most HLL programs do this for you automatically
- How is this done?
  - Issue a `syscall` with a special value in **$v0 = 10** (decimal)

Augmenting with Exiting

```
.text     # We always have to have this starting line
# Main program
li $t0, 5
li $t1, 7
add $t3, $t0, $t1

# Print to std.output
li $v0, 1
move $a0, $t3
syscall
# End program
li $v0, 10
syscall
```

MIPS Peculiarity:
NOR used a NOT

- How to make a NOT function using ***NOR*** instead
- Recall: NOR = NOT OR
- Truth-Table:

A	B	A NOR B
0	0	1
0	1	0
1	0	0
1	1	0

Note that:

0 NOR ***x*** = NOT ***x***

- So, in the absence of a NOT function,
  use a NOR with a 0 as one of the inputs!

Let’s Run This Program Already!

Using SPIM

- We’ll call it **simpleadd.asm**
- Run it on CSIL as: `$ spim –f simpleadd.asm`

DEMO !!!

- We’ll also run other arithmetic programs and explain them as we go along
  – TAKE NOTES!

YOUR TO-DOs

- Review ALL the demo code
  - Available via the class website

- Assignment #3
  - Lab tomorrow!
  - Due Friday

</LECTURE>