Week 8, part B: ALU Instructions

Source: Computer History Museum

Arithmetic instructions

Instruction	Opcode/Function	Syntax	Operation
add	100000	$d, $s, $t	$d = $s + $t
addu	100001	$d, $s, $t	$d = $s + $t
addi	001000	$t, $s, i	$t = $s + SE(i)
addiu	001001	$t, $s, i	$t = $s + SE(i)
div	011010	$s, $t	lo = $s / $t; hi = $s % $t
divu	011011	$s, $t	lo = $s / $t; hi = $s % $t
mult	011000	$s, $t	hi:lo = $s * $t
multu	011001	$s, $t	hi:lo = $s * $t
sub	100010	$d, $s, $t	$d = $s - $t
subu	100011	$d, $s, $t	$d = $s - $t

Notes: “hi” and “lo” refer to the HI and LO registers (see register slide).
“SE” = “sign extend”.

R-type vs I-type arithmetic

R-Type

- `add, addu`
- `div, divu`
- `mult, multu`
- `sub, subu`

I-Type

- `addi`
- `addiu`

- In general, most instructions are R-type (meaning all operands are registers) and some are I-type (meaning they use an immediate/constant value in their operation).
- Can you recognize which of the following are R-type and I-type instructions? (Hint: “i” for “immediate”)

Assembly → Machine Code

Operation

`t3 = t1 + t2;`

Assembly

`add $t3, $t1, $t2`

Instruction	Opcode/Function	Syntax	Operation
`add`	100000	$d, $s, $t	$d = $s + $t

R-type instruction!

000000	01001	01010	01011	xxxxx	100000

Although we specify "don't care" bits as X values, in practice the assembler generally sets them to zero

Unsigned Instructions

- What is the difference between `add` or `addu`?
  - Both do exactly same thing! Add numbers.
- “`u`” stands for “`unsigned`”
  - Causes a “trap” (a.k.a exception) if there is overflow
  - Stops execution of current code.
  - addu ignores this overflow
- `mult` and `multu` are not the same!
  - Slight difference in operation. Use the right one!
  - Neither check for overflow.

Logical instructions

Instruction	Opcode/Function	Syntax	Operation
`and`	100100	$d, $s, $t	$d = $s & $t
`andi`	001100	$t, $s, i	$t = $s & ZE(i)
`nor`	100111	$d, $s, $t	$d = ~($s | $t)
`or`	100101	$d, $s, $t	$d = $s | $t
`ori`	001101	$t, $s, i	$t = $s | ZE(i)
`xor`	100110	$d, $s, $t	$d = $s ^ $t
`xori`	001110	$t, $s, i	$t = $s ^ ZE(i)

Note: ZE = zero extend (pad upper bits with 0 value).

Assembly → Machine Code II

Operation

```
t2 = t1 & 42;
```

Assembly

```
andi $t2, $t1, 42
```

Instruction	Opcode/Function	Syntax	Operation
`andi`	001100	$t, $s, i	$t = $s & ZE(i)

I-type instruction!

001100	01001	01010	0000000000101010

Shift instructions

Instruction	Opcode/Function	Syntax	Operation
`sll`	000000	$d, $t, a	$d = $t << a
`sllv`	000100	$d, $t, $s	$d = $t << $s
`sra`	000011	$d, $t, a	$d = $t >> a
`srav`	000111	$d, $t, $s	$d = $t >> $s
`srl`	000010	$d, $t, a	$d = $t >>> a
`srlv`	000110	$d, $t, $s	$d = $t >>> $s

- Order is **$d, $t, $s** or **$d, $t, a** (not $d, $s, $t as before!)
- `srl` = "shift right logical"
- `sra` = "shift right arithmetic".
- The "`v`" denotes a variable number of bits, specified by `$s`.
- `a` is **shift amount**, and is stored in `shamt` when encoding the R-type machine code instructions.

Data movement instructions

Instruction	Opcode/Function	Syntax	Operation
`mfhi`	010000	$d	$d = hi
`mflo`	010010	$d	$d = lo
`mthi`	010001	$s	hi = $s
`mtlo`	010011	$s	lo = $s

- These are instructions for operating on the HI and LO registers described earlier (for multiplication and division)

lui – load upper immediate

Instruction	Opcode/Function	Syntax	Operation
`lui`	001111	$t, i	$t = i << 16

- Load 16-bit immediate into upper half of the register.
- The lower 16 bits of the register are set to zero.

```
iiiiiiiiiiiiiiii0000000000000000
```

ALU instructions in RISC

R type

- add, div, mult, sub
- addu, divu, multu, subu
- or, and, nor, xor

I type

- addi
- addiu
- andi, ori, xori

- Most ALU instructions are R-type instructions.
  - The six-digit codes in the tables are therefore the function codes (opcodes a
  - Except the few I-type instructions (addi, andi, ori, etc.)

ALU instructions in RISC

- Not all R-type instructions have an I-type equivalent.
  - We have `addi` but not `subi`
  - We have `ori` but not `nori`
  - `div` but not `divi`
- RISC principle: an operation doesn't need an instruction if it can be performed through multiple existing operations.
  - `addi $t0, -1` → "`subi`" `$t0, 1`
  - `addi` + `div` → "`divi`"

Pseudoinstructions

- Pseudo instructions look like assembly instructions…
- …but don't have a dedicated machine code instruction.
- Provided by the assembler
  - Mapping ASM to machine code is more like a many-to-one mapping…
- If a temporary register is needed, use $at

Pseudoinstructions

- Move data from $t4 to $t5?
  - `move $t5,$t4` →

```
add $t5,$t4,$zero
```

- Multiply and store in $s3?
  - `mul $s1, $t4, $t5` →

```
mult $t4,$t5
mflo $s1
```

- Load a 32-bit immediate?
  - `li $s0,0x1234ABCD` →

```
lui $s0,$s0,0x1234
ori $s0,$s0,0xABCD
```

Time to write our first assembly program

Making an assembly program

- Assembly language programs typically have structure similar to simple Python or C programs:
  - They set aside registers to store data.
  - They have sections of instructions that manipulate this data.
- It is always good to decide at the beginning which registers will be used for what purpose!
  - More on this later ☺

Compute result = $a^2 + 2b + 10$

- Set up values in registers
  - a → \$t0, b → \$t1
- temp = 10
- temp = temp + b
- temp = temp + b (again!)
- result = a*a
- result = result + temp

```
addi $t0, $zero, 7
addi $t1, $zero, 9

addi $t6, $zero, 10

add $t6, $t6, $t1
add $t6, $t6, $t1

mult $t0, $t0
mflo $t4


add $t4, $t4, $t6
```

Formatting Assembly Code

- Start file with .text
  - (we'll see other options later)
- Follow this with:
- .globl main
  - Makes the main label visible to the OS
- main:
  - Tells OS which line of code should run first.
- Write instructions, up to 3 columns per line
  - label: <instr> <params> # comments
  - Labels and comments as needed
- At the end of the program, tell the OS to finish:

```
li $v0, 10
syscall
```

```
.text

.globl main
main:
        <code>

        li $v0, 10
        syscall
```

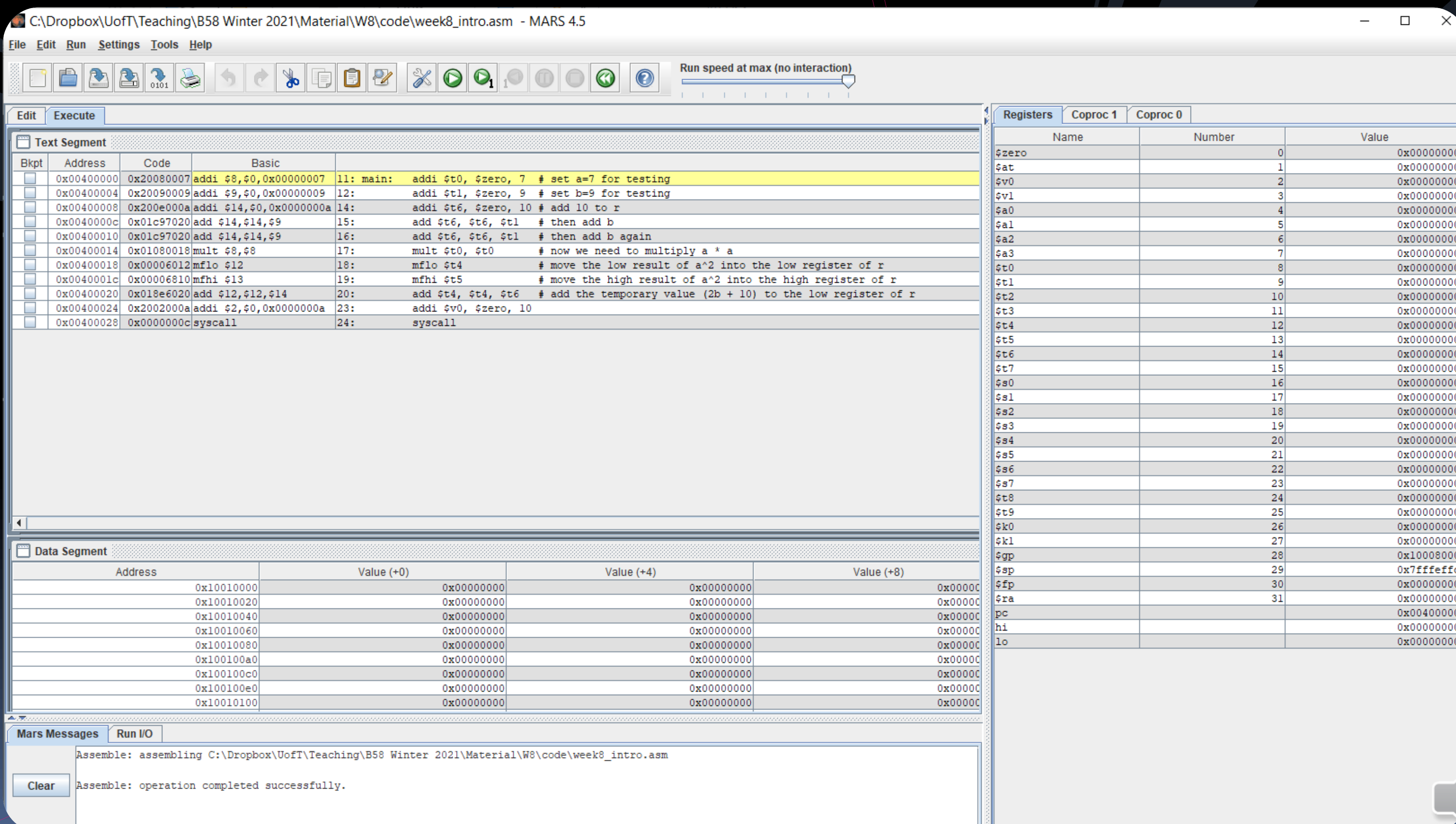
```
# Compute the following result: r = a^2 + 2b + 10
.text

.globl main
main:  addi $t0, $zero, 7   # set a=7 for testing
       addi $t1, $zero, 9   # set b=9 for testing
# $t0 will be a,   $t1 will be b,   $t5 will be r
# $t6 will be temp
       addi $t6, $zero, 10  # add 10 to r
       add $t6, $t6, $t1    # then add b
       add $t6, $t6, $t1    # then add b again
       mult $t0, $t0        # multiply a * a
       mflo $t4             # move the low result of a^2
                            # into the register for r
       add $t4, $t4, $t6    # add the temporary value
                            # (2b + 10) to the result

       addi $v0, $zero, 10  # end program
       syscall
```

How can we run this?

- We don't have a MIPS CPU handy.
- We'll use a simulator instead.
- A program that simulates the operation of the MIPS CPU on your own computer,

Simulating MIPS

The MARS Simulator



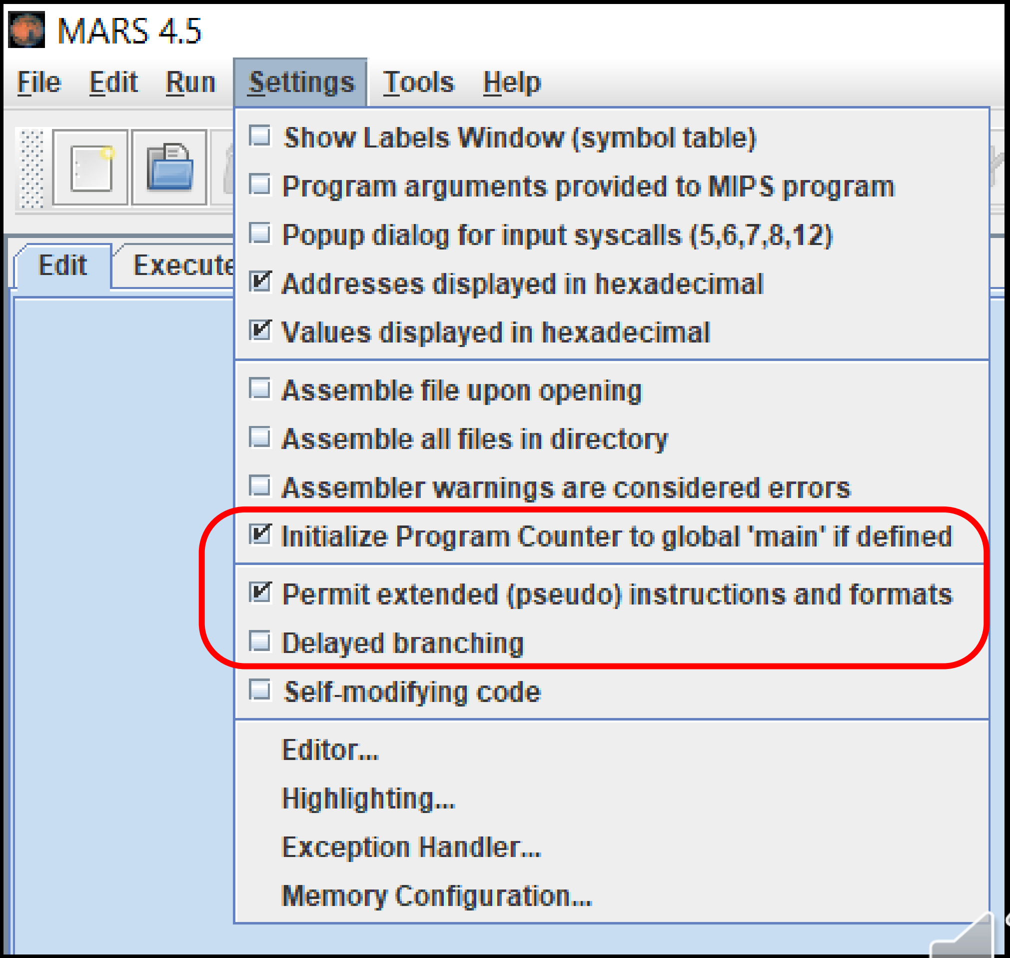
MARS Simulator

- MARS Simulator official site:
  - http://courses.missouristate.edu/kenvollmar/mars/
  - As with Logisim, you will need Java.
- Official version sometimes freezes during debugging.
- Download alternative MARS jar file from Quercus module on assembly

MARS Settings

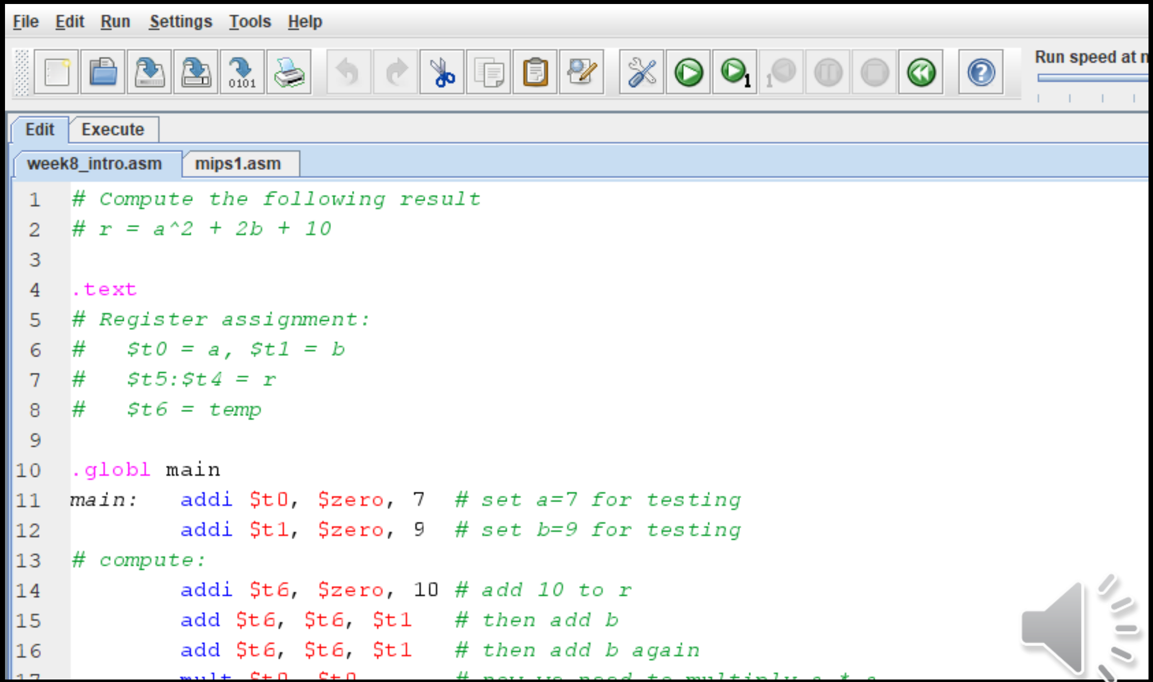
Make sure:

- delayed branching is turned off
- permit extended instruction is on
- Initialize program counter to global 'main' is on



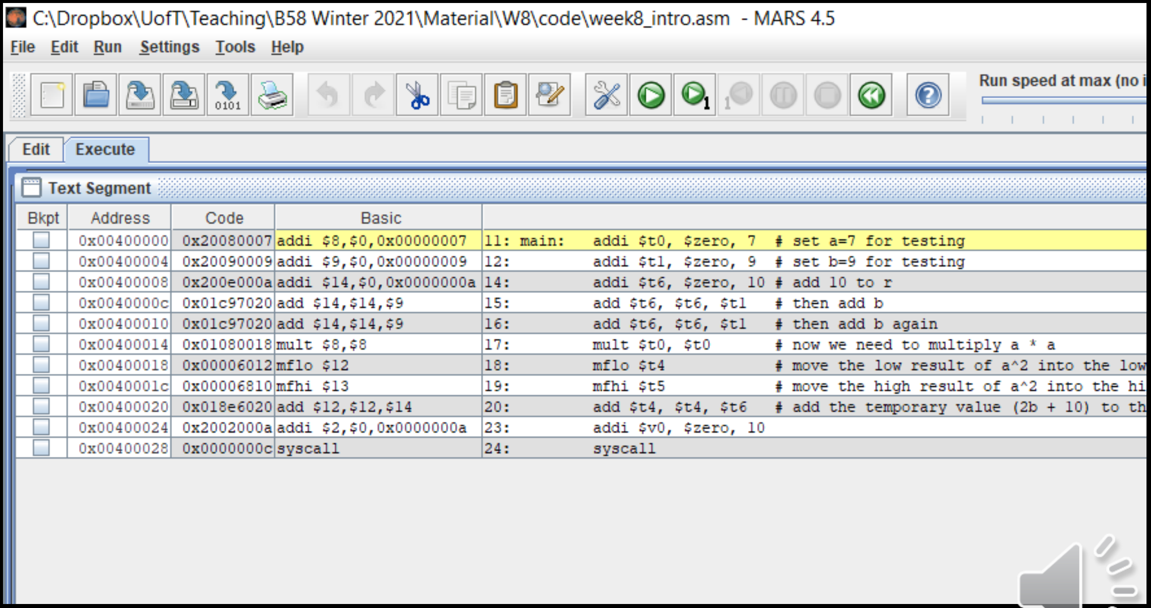
MARS HowTo

- MARS works like a simple IDE
  - Write assembly program in code editor
  - Save it to an .asm or .s file (doesn't matter)



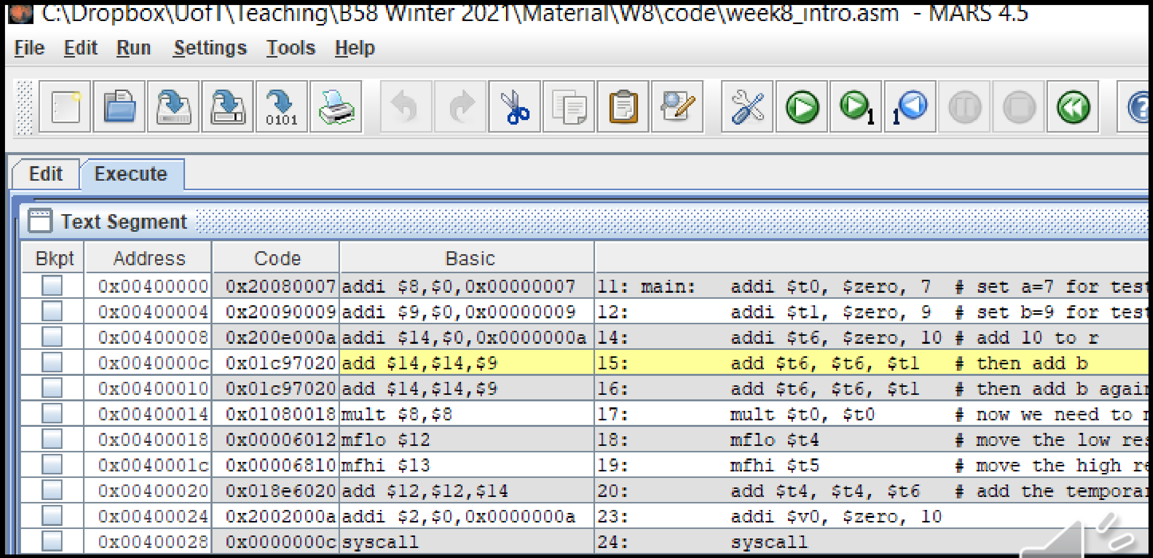
MARS HowTo

- MARS works like a simple IDE
  - Assemble the program (F3 or Run→Assemble)
  - Mars will switch to execute view



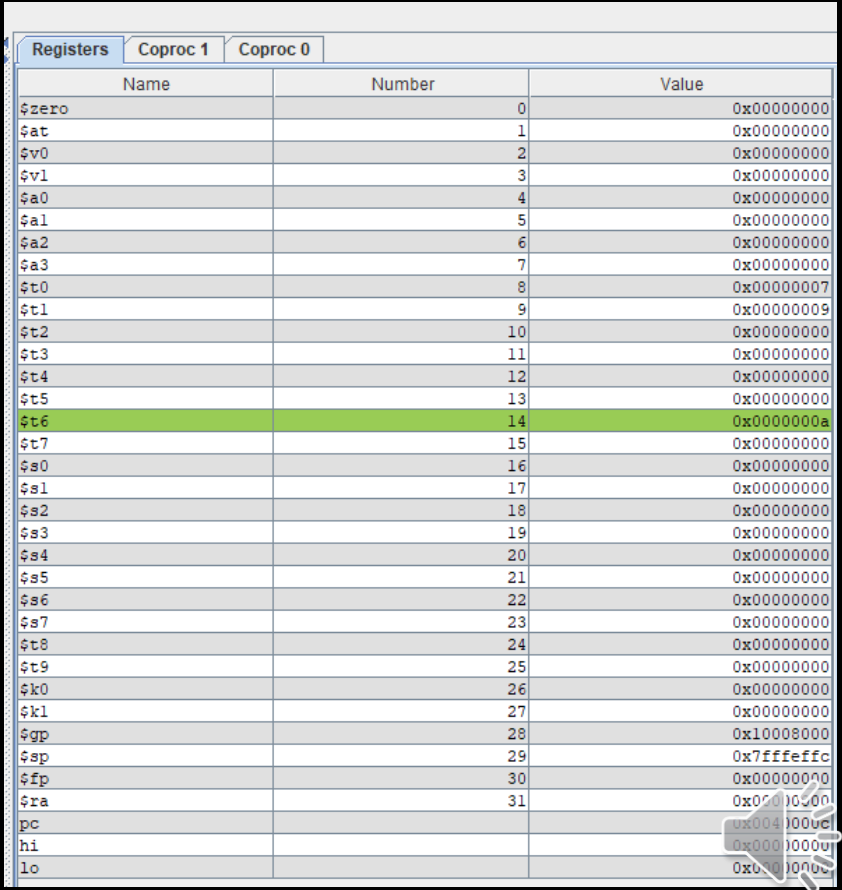
MARS HowTo

- MARS works like a simple IDE
  - Run the whole program (F5 or Run→Go)
  - Or execute line by line (F7 or Run→Step)



MARS HowTo

- MARS works like a simple IDE
  - Check the register window to see what is going on.



Registers | Coproc 1 | Coproc 0

Name	Number	Value
$zero	0	0x00000000
$at	1	0x00000000
$v0	2	0x00000000
$v1	3	0x00000000
$a0	4	0x00000000
$a1	5	0x00000000
$a2	6	0x00000000
$a3	7	0x00000000
$t0	8	0x00000007
$t1	9	0x00000009
$t2	10	0x00000000
$t3	11	0x00000000
$t4	12	0x00000000
$t5	13	0x00000000
$t6	14	0x0000000a
$t7	15	0x00000000
$s0	16	0x00000000
$s1	17	0x00000000
$s2	18	0x00000000
$s3	19	0x00000000
$s4	20	0x00000000
$s5	21	0x00000000
$s6	22	0x00000000
$s7	23	0x00000000
$t8	24	0x00000000
$t9	25	0x00000000
$k0	26	0x00000000
$k1	27	0x00000000
$gp	28	0x10008000
$sp	29	0x7fffeffc
$fp	30	0x00000000
$ra	31	0x00000000
pc		0x0040000c
hi		0x00000000
lo		0x00000000

Get MARS

- You need it for labs.
- And for practice.
- Code from lectures is available on OneDrive.
- Try to execute it on MARS.
- See how it works.
- Play with it yourself.
- Learn!

r = (2a + 5) * (7b)

```
.text
.globl main
# $t0 = a, $t1 = b, $t4 = r
# $t7 = left side, $t8 = right side
main:  addi $t0, $zero, 7  # load up some values to test
       addi $t1, $zero, 9
# calculate left side
calc_left:    add $t7, $t0, $t0   # ls <- 2a
              addi $t7, $t7, 5    # ls <- ls + 5

# calculate right side
calc_right:   addi $t8, $zero, 7  # rs <- 7
              mult $t8, $t1       # multiply 7 * b
              mflo $t8            # put result back into rs

# multiply left * right and put result into r
mulitply:     mult $t7, $t8
              mflo $t4
```

Implement c = max(a,b)?

- Most code does not simply execute linearly from start to finish.
- For example, how would we implement:

```
if (a>b)
        c = a;
    else
        c = b;
```

- Move to next part!