

ARCOS Group

uc3m | Universidad **Carlos III** de Madrid

Lesson 3 (I)

Fundamentals of assembler programming

Computer Structure
Bachelor in Computer Science and Engineering

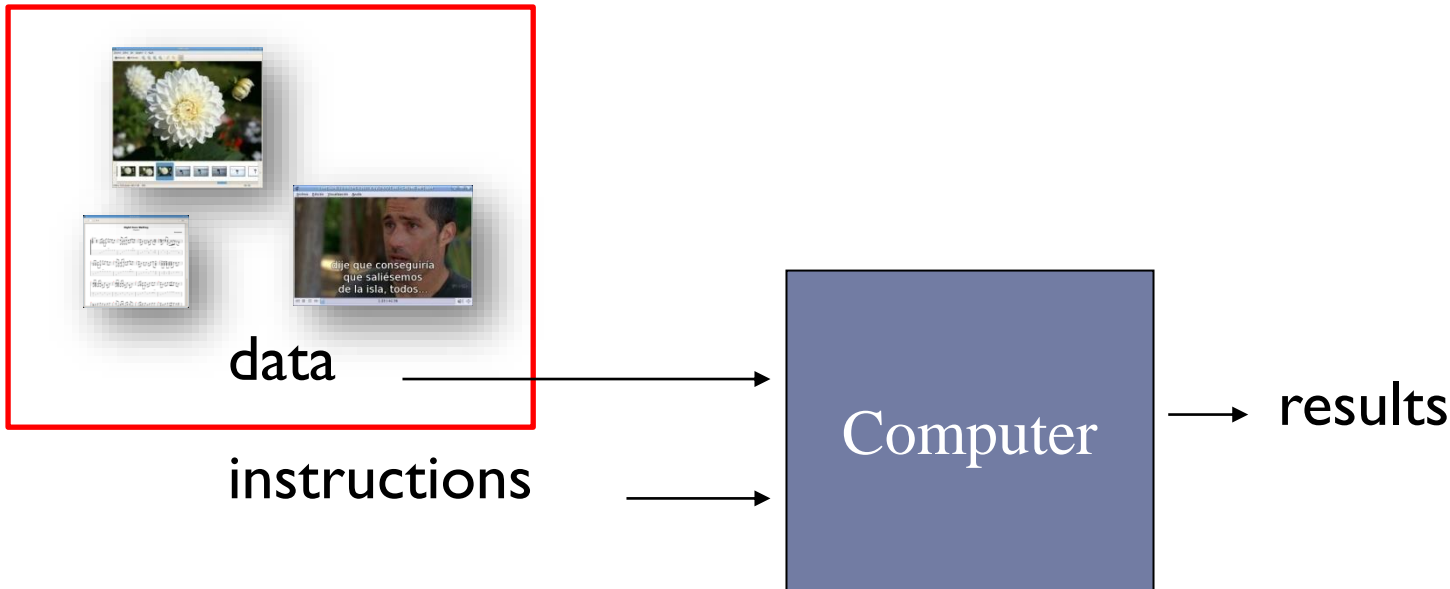


Contents

- ▶ **Basic concepts on assembly programming**
 - ▶ Motivations and goals
 - ▶ MIPS32 introduction
- ▶ MIPS32 assembly language, memory model and data representation
- ▶ Instruction formats and addressing modes
- ▶ Procedure calls and stack convention

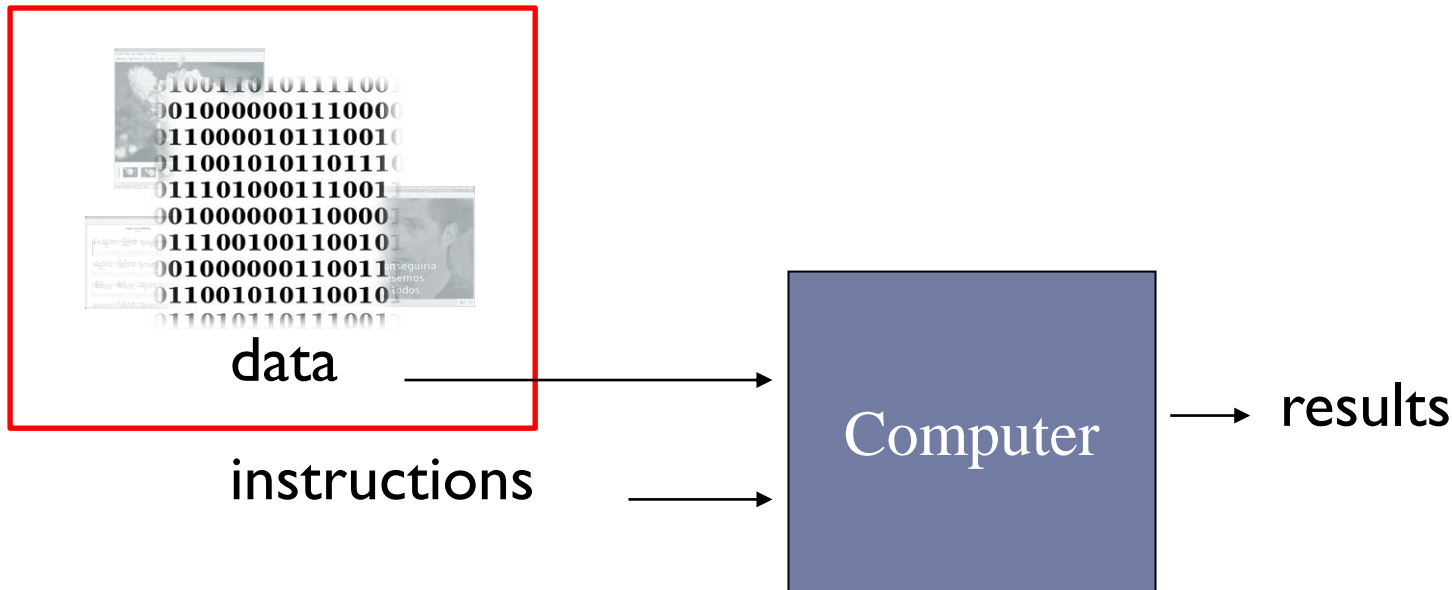
Types of information: instructions and data

► Data representation...



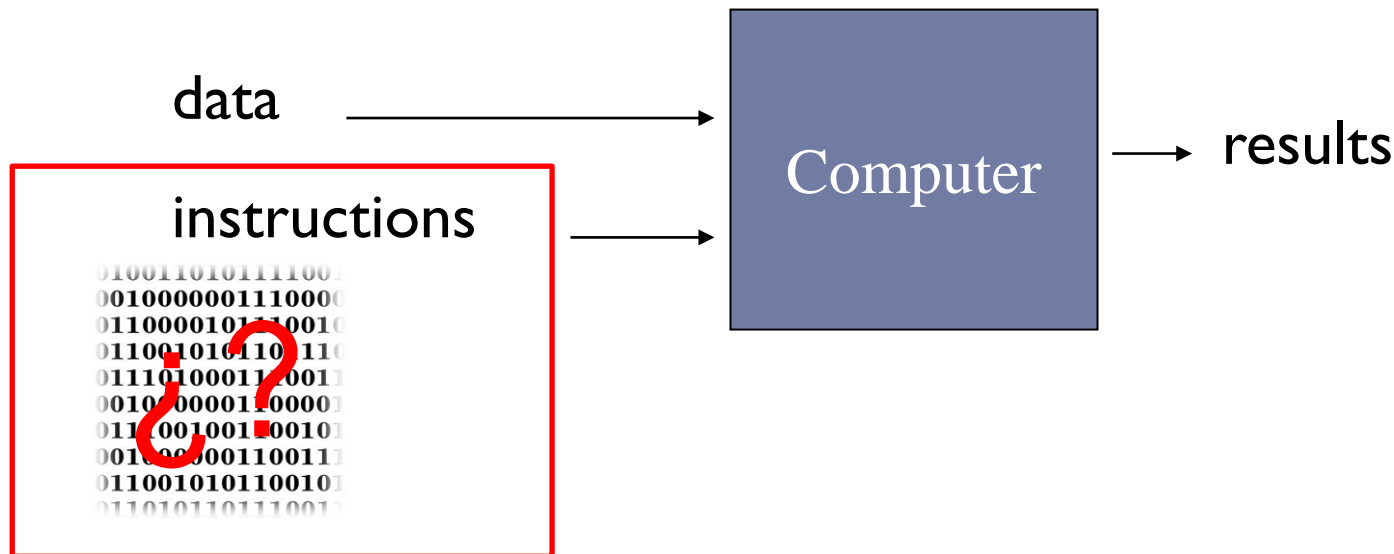
Types of information: instructions and data

► Binary data representation.



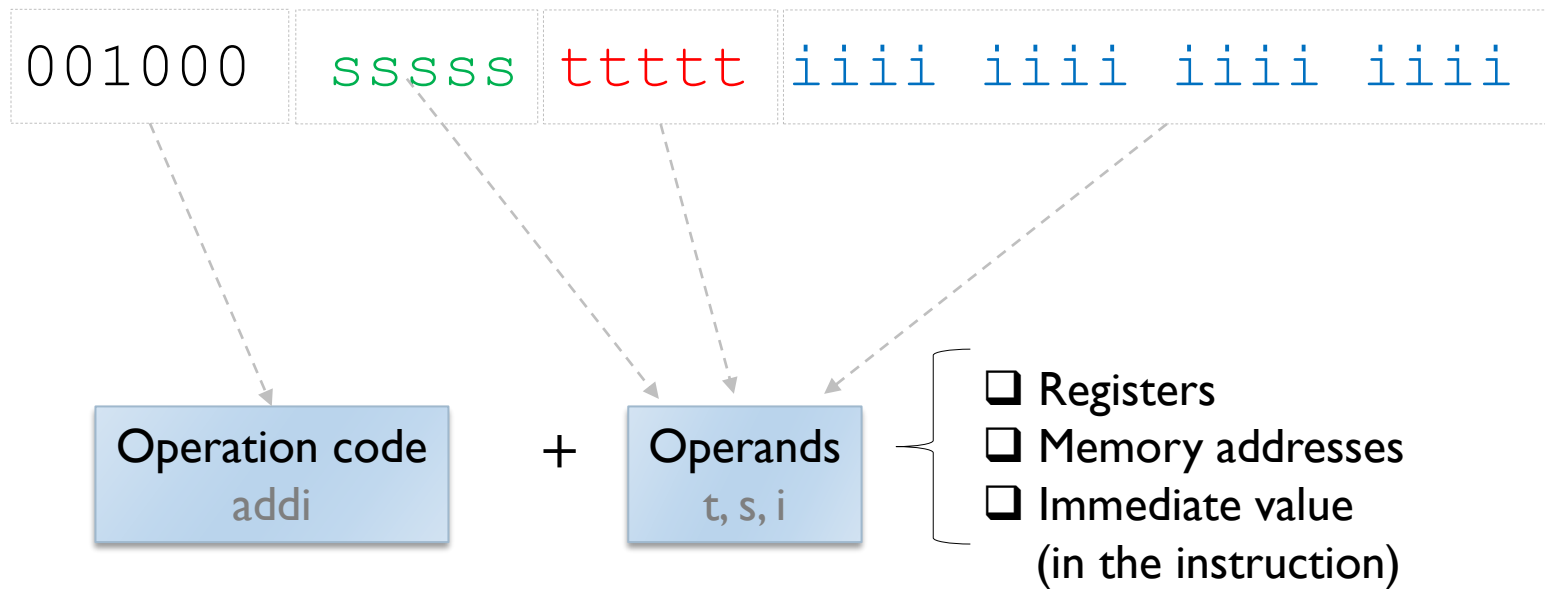
Types of information: instructions and data

- ▶ What about the instructions?



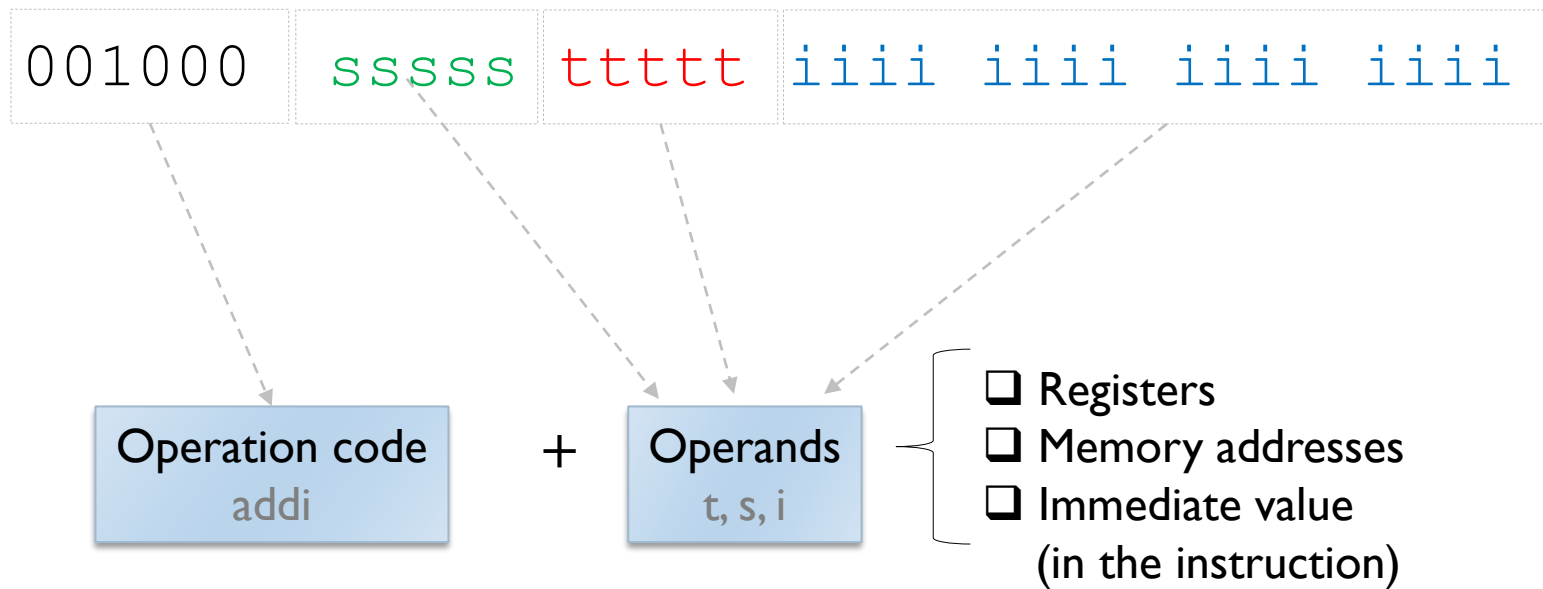
Machine instruction

- ▶ Machine instruction: elementary operation that can be executed directly by the processor.
- ▶ Example of instruction in MIPS:
 - ▶ Sum of a register (s) with an immediate value (i) and the result of the sum is stored in register (t).



Properties of machine instructions

- ▶ Perform a **single, simple task**
- ▶ Operate on a **fixed number of operands**
- ▶ **Include all** the **information necessary** for its **execution**



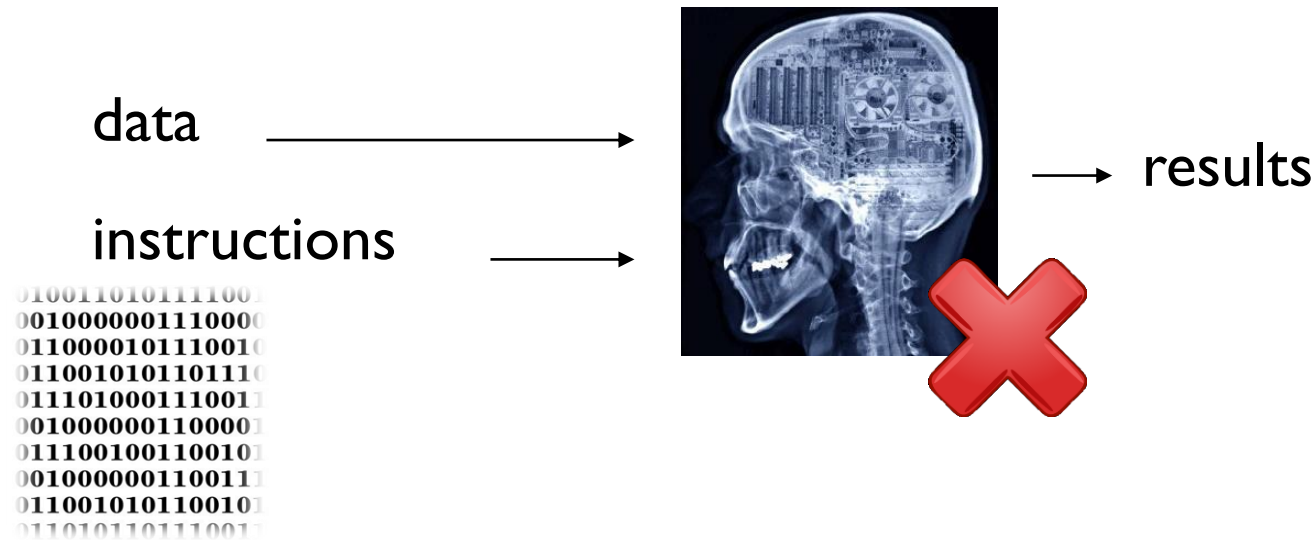
Information contained in a machine instruction

- ▶ The **operation to be performed**.
- ▶ Where the **operands** are located:
 - ▶ In registers
 - ▶ In memory
 - ▶ In the instruction itself (immediate)
- ▶ Where to leave the **results** (as operand)
- ▶ A reference to the **next instruction** to be executed
 - ▶ Implicitly: the following instruction
 - ▶ A program is a consecutive sequence of machine instructions.
 - ▶ Explicitly in branching instructions (as operand)



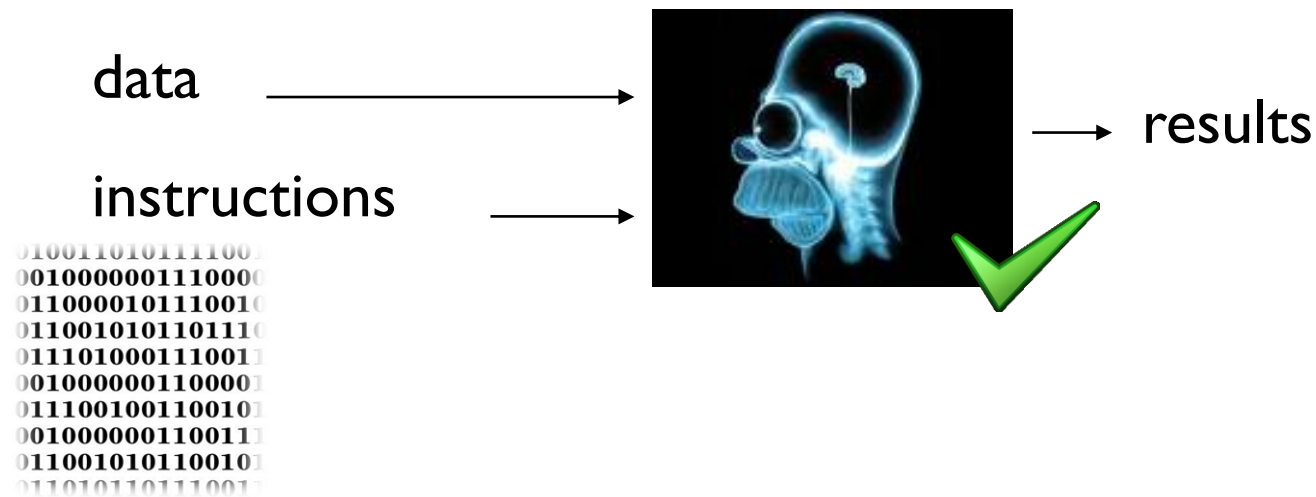
Machine instructions

- ▶ There are not complex instructions...



Machine instructions

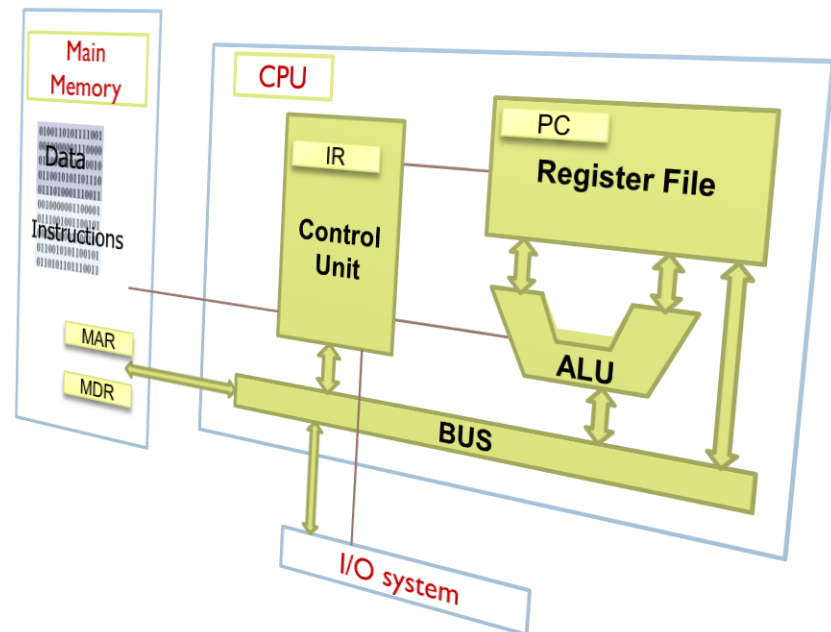
- ▶ ... but very simple tasks...



Machine instructions

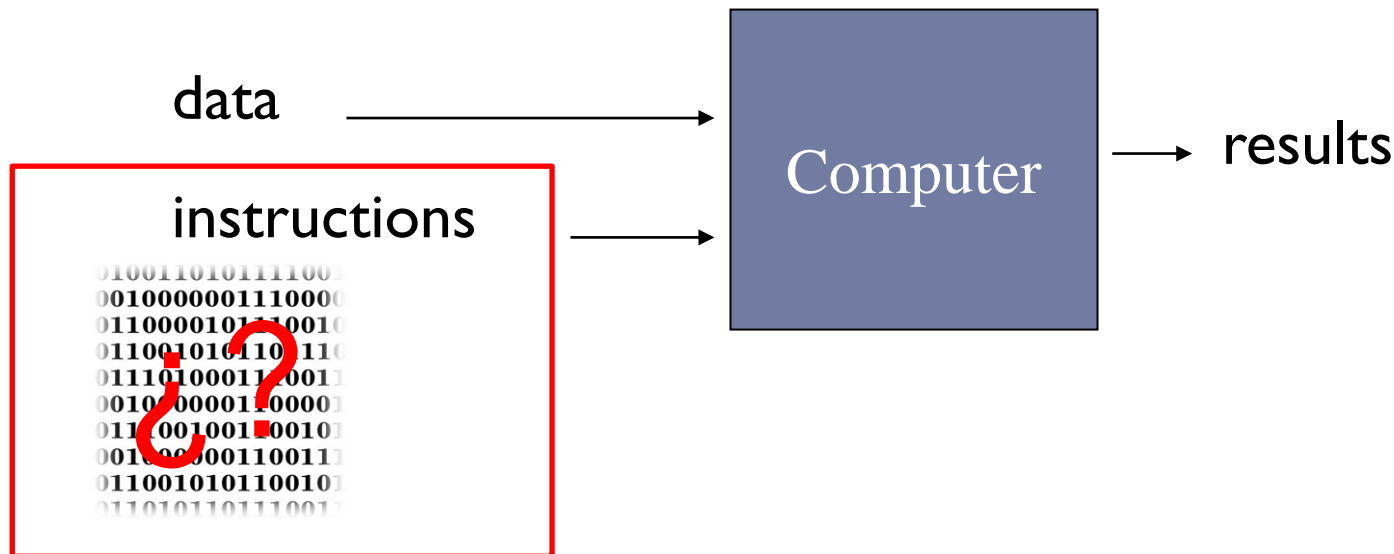
- ▶ ... performed by the processor:

- ▶ Data transfers
- ▶ Arithmetic
- ▶ Logical
- ▶ Conversion
- ▶ Input/Output
- ▶ System Control
- ▶ Flow control



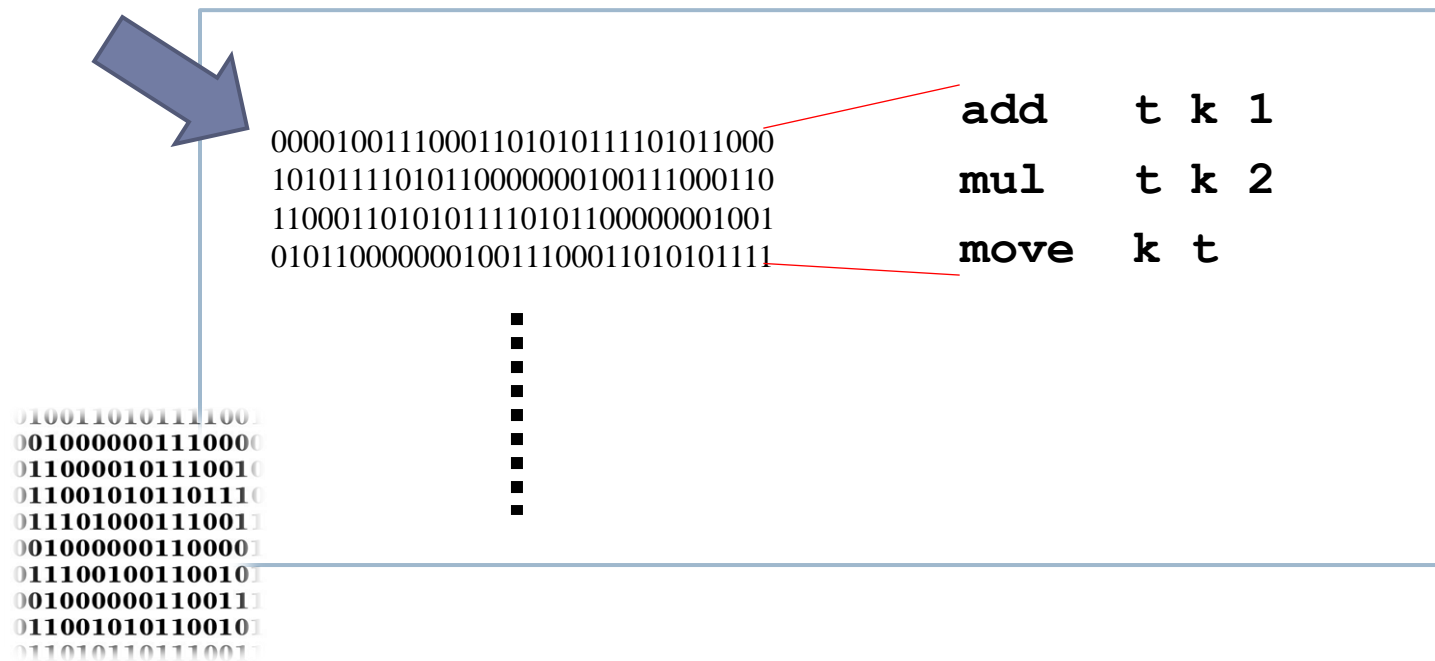
Types of information: instructions and data

- ▶ What about the instructions?



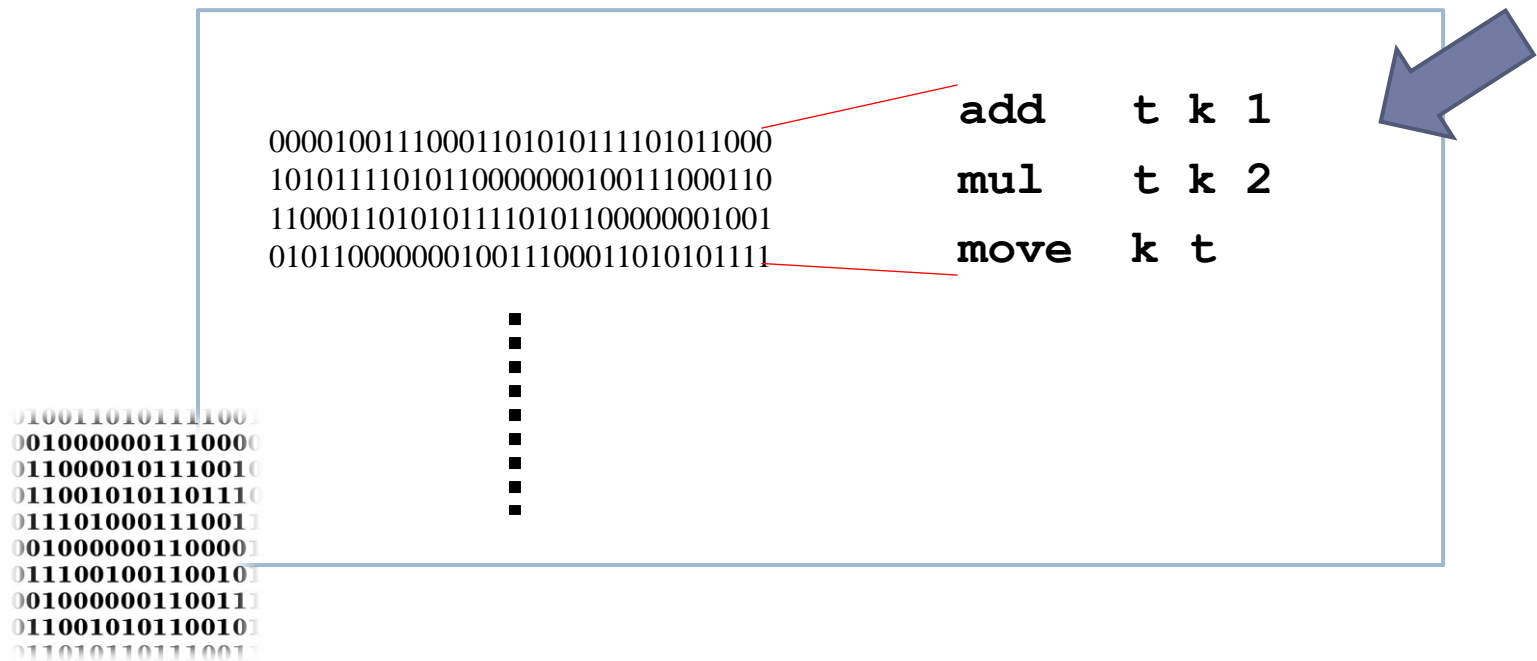
Definition of program

- **Program:** Ordered sequence of machine instructions that are executed by default in order.



Assembly language definition

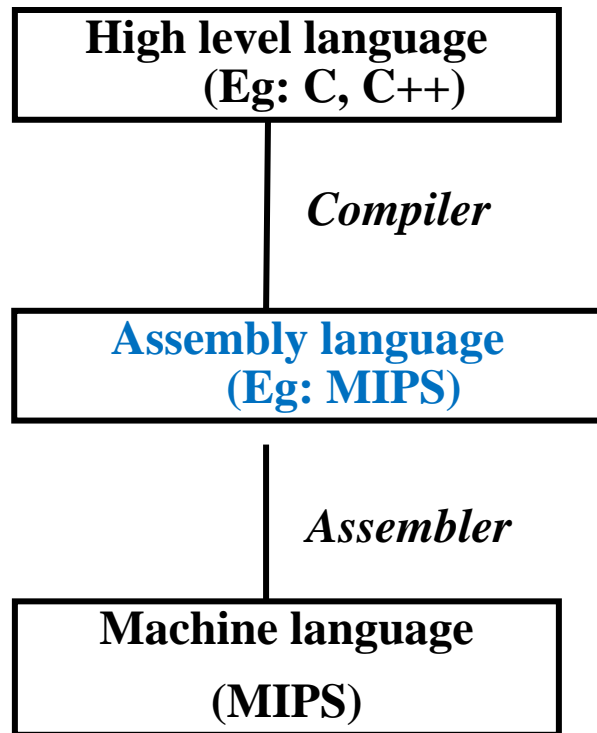
- **Assembly language:** programmer-readable language that is **the most direct representation of architecture-specific machine code**.



Assembly language definition

- ▶ **Assembly language:** programmer-readable language that is the most direct representation of architecture-specific machine code.
 - ▶ Uses symbolic codes to represent instructions
 - ▶ `add` – addition
 - ▶ `lw` – Load a memory data
 - ▶ Uses symbolic codes for data and references
 - ▶ `$t0` – register
 - ▶ There is an assembly instruction per machine instruction
 - ▶ `add $t1, $t2, $t3`

Languages levels



```
temp = v[k];  
v[k] = v[k+1];  
v[k+1] = temp;
```

```
lw    $t0, 0($2)  
lw    $t1, 4($2)  
sw    $t1, 0($2)  
sw    $t0, 4($2)
```

```
0000 1001 1100 0110 1010 1111 0101 1000  
1010 1111 0101 1000 0000 1001 1100 0110  
1100 0110 1010 1111 0101 1000 0000 1001  
0101 1000 0000 1001 1100 0110 1010 1111
```


Instruction sets

- ▶ **Instruction Set Architecture (ISA)**
 - ▶ Instruction set of a processor
 - ▶ Boundary between hardware and software
- ▶ **Examples:**
 - ▶ 80x86
 - ▶ ARM
 - ▶ MIPS
 - ▶ RISC-V
 - ▶ PowerPC
 - ▶ Etc.

Characteristics of an instruction set (1 / 2)

- ▶ **Operations:**
 - ▶ Arithmetic, logic, transfer, control, control, etc.
- ▶ **Operands:**
 - ▶ Registers, memory, the instruction itself
- ▶ **Type and size of operands:**
 - ▶ bytes: 8 bits
 - ▶ integers: 16, 32, 64 bits
 - ▶ floating-point numbers: single precision, double precision, etc.
- ▶ **Memory addressing:**
 - ▶ Most of them use byte addressing
 - ▶ They provide instructions for accessing multi-byte elements from a given position

Characteristics of an instruction set (2/2)

- ▶ **Addressing modes:**

- ▶ They specify where and how to access operands (register, memory or the instruction itself)

- ▶ **Flow control instructions:**

- ▶ Unconditional jumps
- ▶ Conditional jumps
- ▶ Procedure calls

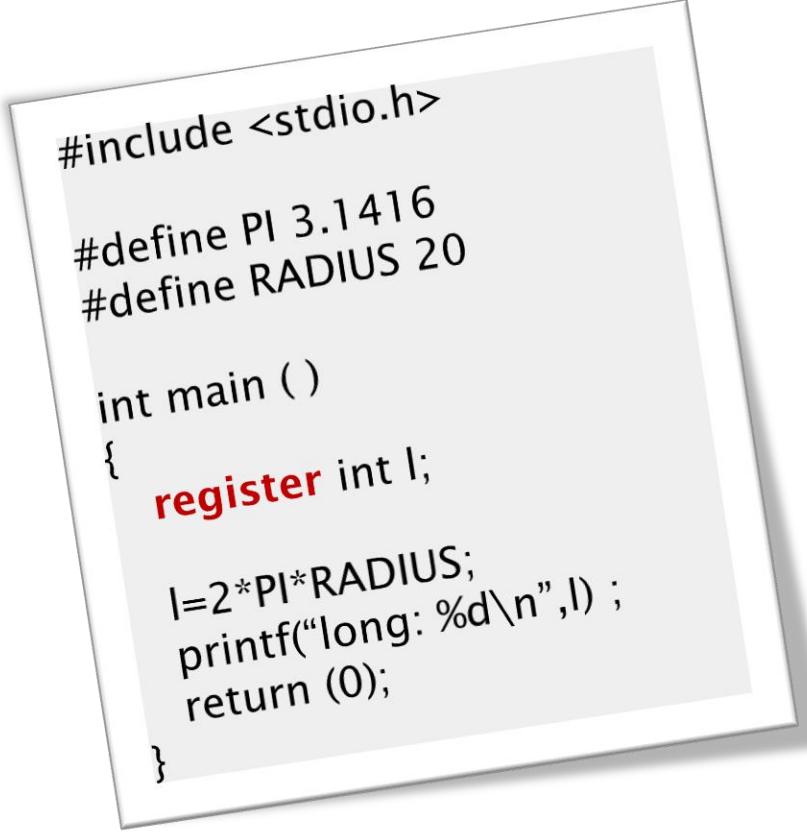
- ▶ **Format and coding of the instruction set:**

- ▶ Fixed or variable length instructions
 - ▶ 80x86: variable (from 1 up to 18 bytes)
 - ▶ MIPS, ARM: fixed

Programming model of a computer

- ▶ A computer offers a programming model that consists of:
 - ▶ **Instruction set (assembly language)**
 - ▶ *ISA: Instruction Set Architecture*
 - ▶ An instruction includes:
 - Operation code
 - Other elements: registers, memory address, numbers
 - ▶ **Storing elements**
 - ▶ Registers
 - ▶ Memory
 - ▶ Registers of I/O controllers
 - ▶ **Execution modes**

Motivation to learn assembly



```
#include <stdio.h>

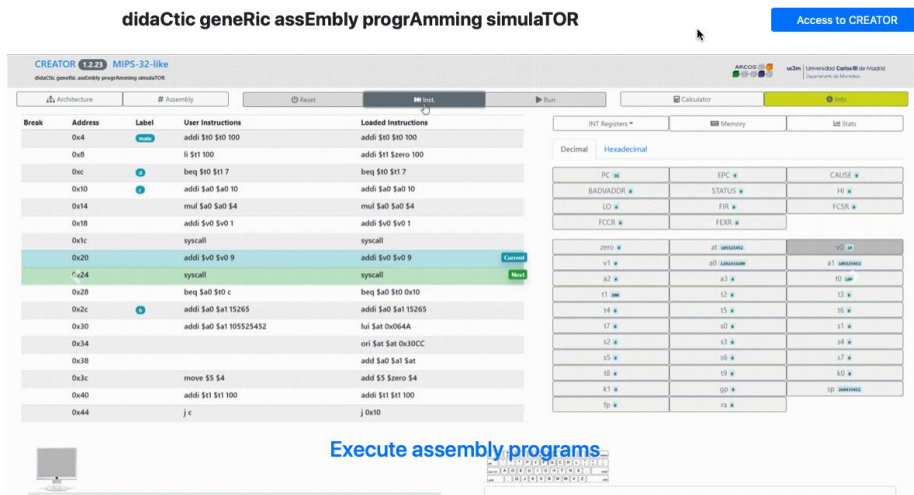
#define PI 3.1416
#define RADIUS 20

int main ()
{
    register int l;

    l=2*PI*RADIUS;
    printf("long: %d\n",l) ;
    return (0);
}
```

- ▶ Understand how high level languages are executed
 - ▶ C, C++, Java, ...
- ▶ Analyze the execution time of high level instructions.
- ▶ Useful in specific domains:
 - ▶ Compilers
 - ▶ Operating Systems
 - ▶ Games
 - ▶ Embedded systems
 - ▶ Etc.

Motivation to use CREATOR simulator

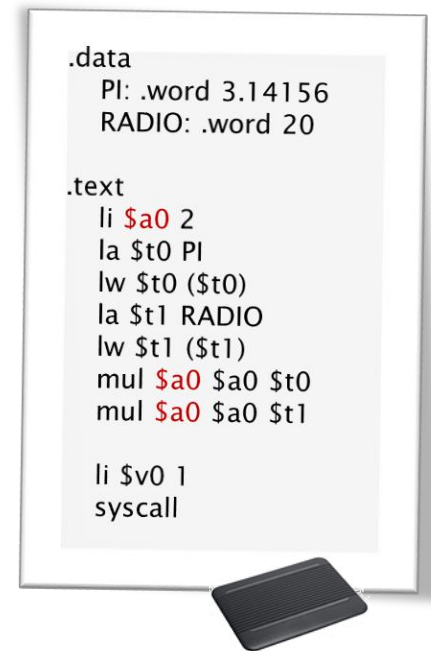


<https://creatorsim.github.io/>

- ▶ CREATOR: didaCtic geneRic assEmbly progrAmming simulaTOR
- ▶ CREATOR can simulate MIPS32 and RISC-V architectures
- ▶ CREATOR can be executed from Firefox, Chrome, Edge or Safari

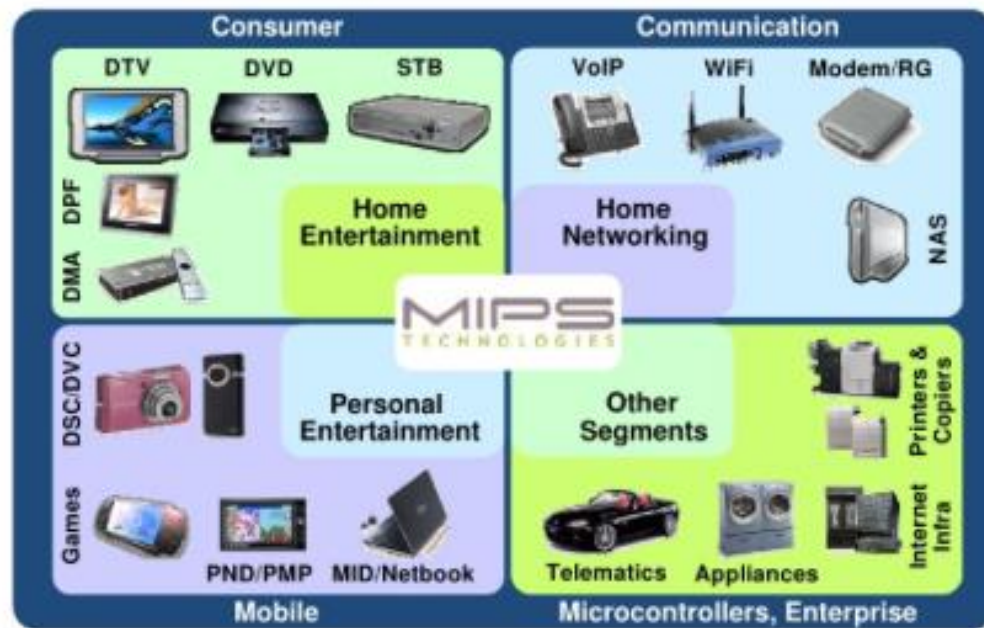
Goals

- ▶ Know how the elements of a high-level assembly language are represented.:
 - ▶ Data types (int, char, ...)
 - ▶ Control structures (if, while, ...)
- ▶ Be able to write small programs in assembler



Example assembler: MIPS 32

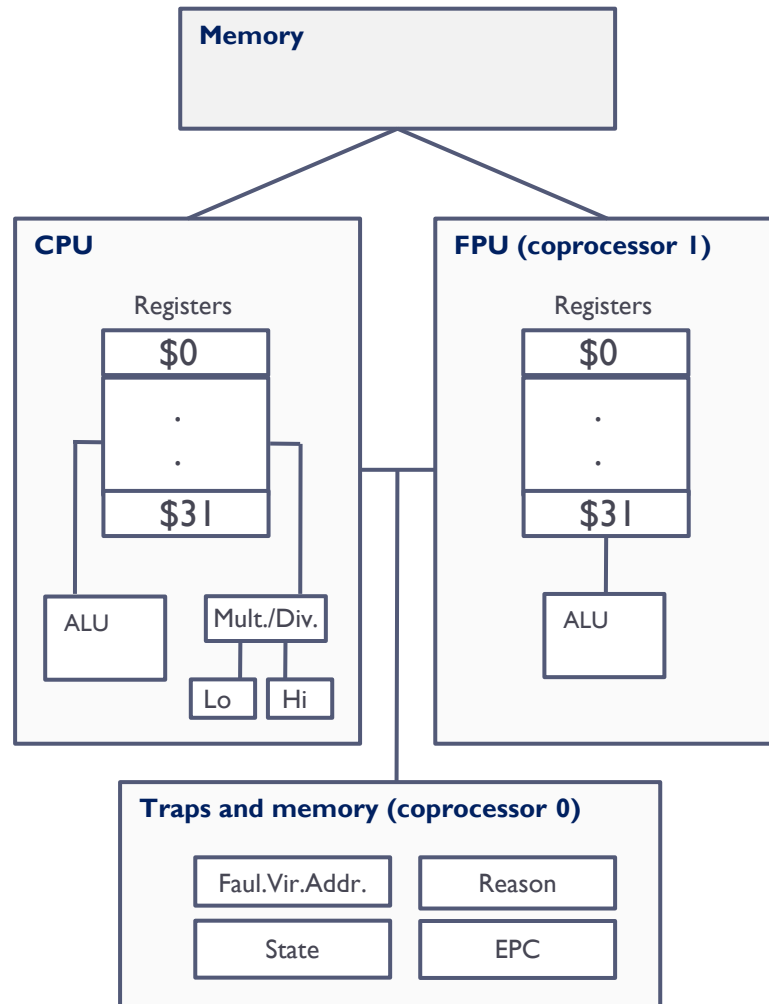
- RISC (Reduced Instruction Set Computer) Processor
- Examples of RISC processors:
 - MIPS, ARM, RISC-V



Contents

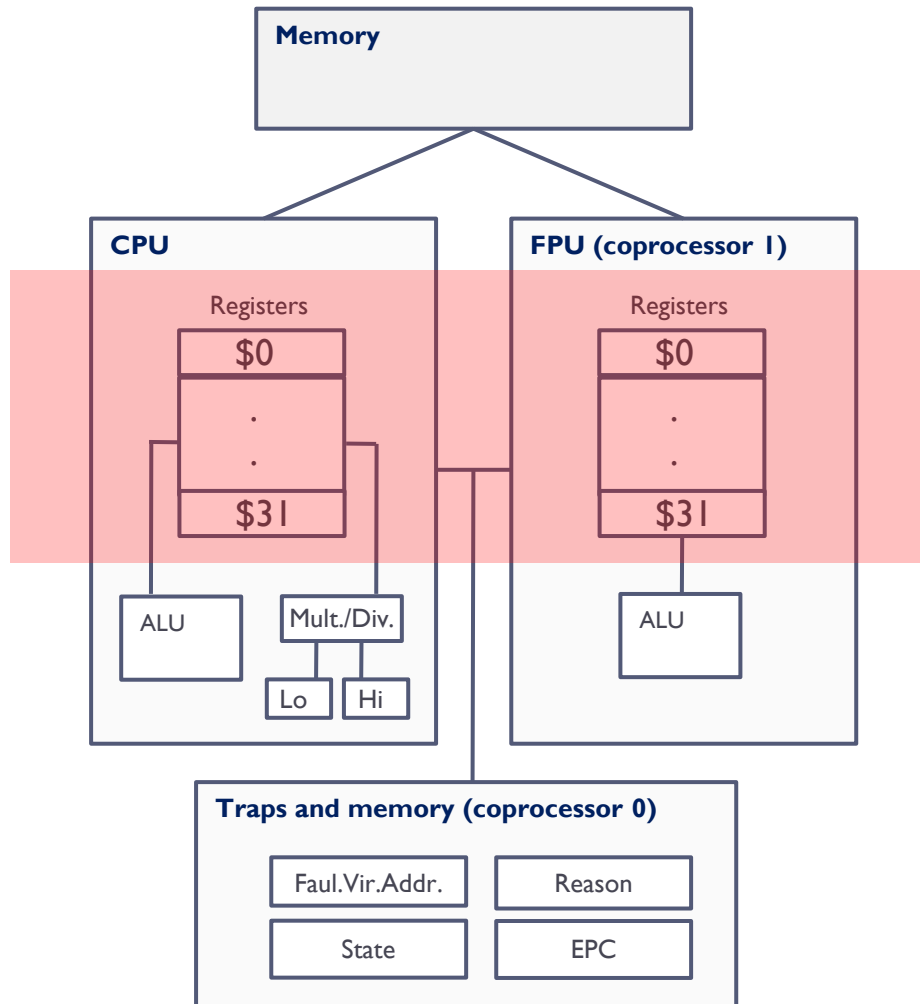
- ▶ **Basic concepts on assembly programming**
 - ▶ Motivations and goals
 - ▶ **MIPS32 introduction**
- ▶ MIPS32 assembly language, memory model and data representation
- ▶ Instruction formats and addressing modes
- ▶ Procedure calls and stack convention

MIPS architecture



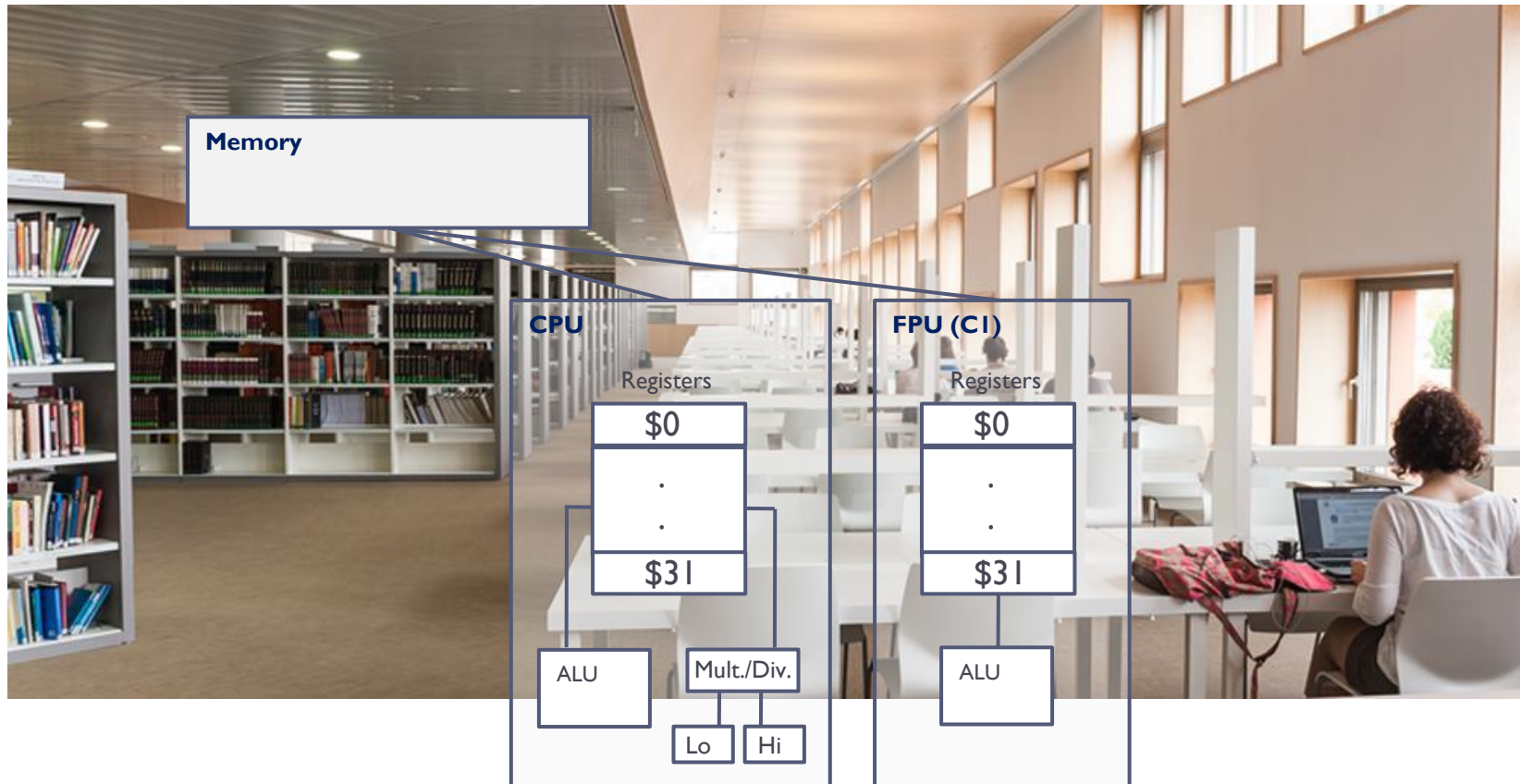
- ▶ **MIPS 32**
 - ▶ 32 bits processor
 - ▶ RISC type
 - ▶ CPU + auxiliary coprocessors
- ▶ **Coprocessor 0**
 - ▶ exceptions, interrupts and virtual memory system
- ▶ **Coprocessor 1**
 - ▶ FPU (floating point unit)

MIPS architecture



- ▶ **MIPS 32**
 - ▶ 32 bits processor
 - ▶ RISC type
 - ▶ CPU + auxiliary coprocessors
- ▶ **Coprocessor 0**
 - ▶ exceptions, interrupts and virtual memory system
- ▶ **Coprocessor 1**
 - ▶ FPU (floating point unit)

MIPS architecture



Register File (integers)

Symbolic name	Number	Usage
\$zero	\$0	Constant 0
\$at	\$1	Reserved for assembler
\$v0, \$v1	\$2, \$3	Results of functions
\$a0, ..., \$a3	\$4, ..., \$7	Function arguments
\$t0, ..., \$t7	\$8, ..., \$15	Temporary (NO preserved across calls)
\$s0, ..., \$s7	\$16, ..., \$23	Saved temporary (preserved across calls)
\$t8, \$t9	\$24, \$25	Temporary (NO preserved across calls)
\$k0, \$k1	\$26, \$27	Reserved for operating system
\$gp	\$28	Pointer to global area
\$sp	\$29	Stack pointer
\$fp	\$30	Frame pointer
\$ra	\$31	Return address (used by function calls)

- ▶ There are 32 registers
 - ▶ Size: 4 bytes (1 word)
 - ▶ Used a \$ at the beginning
- ▶ Use convention:
 - ▶ Reserved
 - ▶ Arguments
 - ▶ Results
 - ▶ Temporary
 - ▶ Pointers

Register File (floating point)

Symbolic name	Usage
\$f0...\$f3	Results (like \$v...)
\$f4...\$f11	Temporals (like \$t...)
\$f12...\$f15	Arguments (like \$a...)
\$f16...\$f19	Temporals (like \$t...)
\$f20...\$f31	Reserved (like \$sv...)

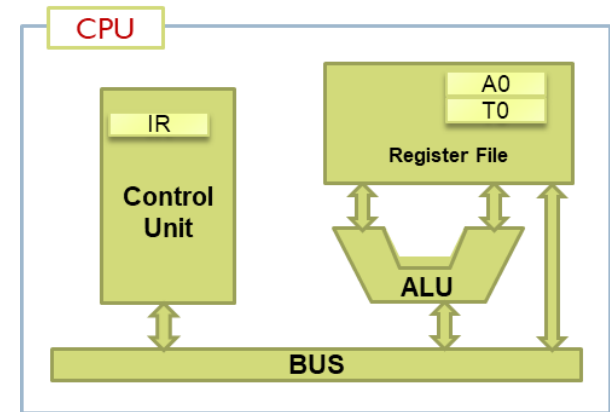
- ▶ There are 32 registers
 - ▶ Size: 4 bytes (1 word)
 - ▶ Used a \$ at the beginning
- ▶ Can be used:
 - ▶ Simple precision (32 registers)
 - ▶ Double precision (16 registers)
 - ▶ Two consecutive registers are combined into a single double
 - ▶ E.g.: \$f0' = (\$f0, \$f1)

Data transfer

- ▶ Copy data:
 - ▶ Between registers
 - ▶ Between registers and memory (later)

- ▶ Examples:

- ▶ Immediate load
(store a value in a register)
 - ▶ `li $t0 5` `# $t0 ← 5`
- ▶ Register to register
 - ▶ `move $a0 $t0` `# $a0 ← $t0`



```
move $a0 $t0    # BR[$a0] = BR[$t0]
li     $t0 1     # BR[$t0] = IR(li,$t0,1)
```

CREATOR

didaCtic geneRiC assEmbly progrAMming simulaTOR

Register
File

CREATOR 1.2.23 MIPS-32-like
didaCtic geneRiC assEmbly progrAMming simulaTOR

Architecture # Assembly Reset Inst. Run Calculator Info

Break	Address	Label	User Instructions	Loaded Instructions
	0x4	start	addi \$t0 \$t0 100	addi \$t0 \$t0 100
	0x8		li \$t1 100	addi \$t1 \$zero 100
	0xc		beq \$t0 \$t1 7	beq \$t0 \$t1 7
	0x10		addi \$a0 \$a0 10	addi \$a0 \$a0 10
	0x14		mul \$a0 \$a0 \$4	mul \$a0 \$a0 \$4
	0x18		addi \$v0 \$v0 1	addi \$v0 \$v0 1
	0x1c		syscall	syscall
	0x20		addi \$v0 \$v0 9	addi \$v0 \$v0 9
	0x24		syscall	syscall
	0x28		beq \$a0 \$t0 c	beq \$a0 \$t0 0x10
	0x2c		addi \$a0 \$a1 15265	addi \$a0 \$a1 15265
	0x30		addi \$a0 \$a1 105525452	lui \$at 0x064A
	0x34			ori \$at \$at 0x30CC
	0x38			add \$a0 \$a1 \$at
	0x3c		move \$5 \$4	add \$5 \$zero \$4
	0x40		addi \$t1 \$t1 100	addi \$t1 \$t1 100
	0x44		j c	j 0x10

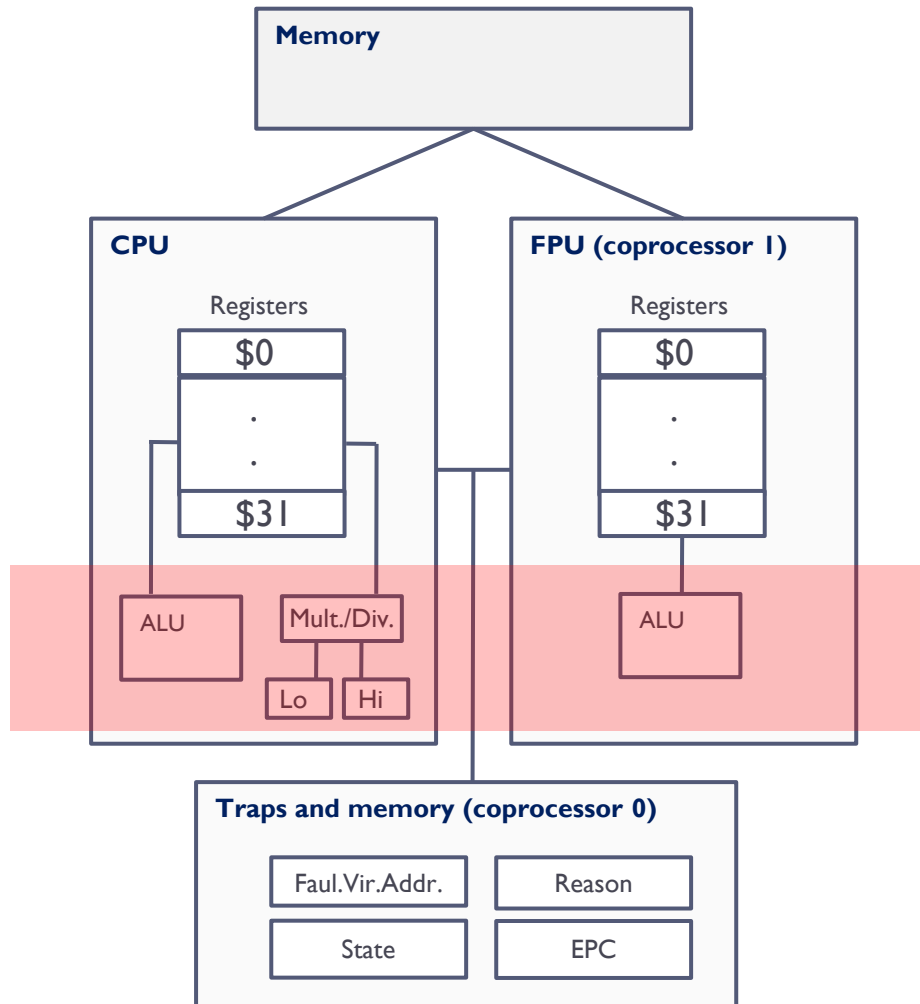
INT Registers Memory Mem Stats

Decimal Hexadecimal

PC	EPC	CAUSE
BADVADDR	STATUS	HI
LO	FIR	FCSR
PCR	FEXR	
zero	at 105525452	v0 9
v1	a0 105525452	a1 105525452
a2	a3	t0 100
t1 100	t2	t3
t4	t5	t6
t7	s0	s1
s2	s3	s4
s5	s6	s7
t8	t9	k0
k1	gp	sp 105525452
fp	ra	

<https://creatorsim.github.io/>

MIPS architecture



- ▶ **MIPS 32**
 - ▶ 32 bits processor
 - ▶ RISC type
 - ▶ CPU + auxiliary coprocessors
- ▶ **Coprocessor 0**
 - ▶ exceptions, interrupts and virtual memory system
- ▶ **Coprocessor 1**
 - ▶ FPU (floating point unit)

Arithmetic instructions

- ▶ Integer operations (ALU) or floating-point operations (FPU)

- ▶ Examples (ALU):

- ▶ Addition

`add $t0, $t1, $t2` $\$t0 = \$t1 + \$t2$ Add with overflow

`addi $t0, $t1, 5` $\$t0 = \$t1 + 5$ Add with overflow

`addu $t0, $t1, $t2` $\$t0 = \$t1 + \$t2$ Add without overflow

- ▶ Subtraction

`sub $t0, $t1, 1`

- ▶ Multiplication

`mul $t0, $t1, $t2`

- ▶ Division

`div $t0, $t1, $t2` $\$t0 = \$t1 / \$t2$ Integer division

`rem $t0, $t1, $t2` $\$t0 = \$t1 \% \$t2$ Remainder

Example

```
int a = 5;  
int b = 7;  
int c = 8;  
int d;
```

```
d = a * (b + c)
```



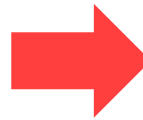
```
li $t0, 5  
li $t1, 7  
li $t2, 8
```

```
add $t1, $t1, $t2  
mul $t3, $t1, $t0
```

Example

```
int a = 5;  
int b = 7;  
int c = 8;  
int d;
```

```
d = -(a * (b - 10) + c)
```



```
li $t0, 5  
li $t1, 7  
li $t2, 8  
li $t3, 10  
  
sub $t4, $t1, $t3  
mul $t4, $t4, $t0  
add $t4, $t4, $t2  
li $t5, -1  
mul $t4, $t4, $t5
```

Types of arithmetic operations

- ▶ Pure binary or two's complement arithmetic

- ▶ Examples:

- ▶ Signed sum (ca2)
`add $t0 $t1 $t2`
- ▶ Immediate signed sum
`addi $t0 $t1 -5`
- ▶ Unsigned sum (binary)
`addu $t0 $t1 $t2`
- ▶ Immediate unsigned sum
`addiu $t0 $t1 2`

- ▶ Without **overflow**:

```
li $t0 0x7FFFFFFF
li $t1 5
addu $t0 $t0 $t1
```

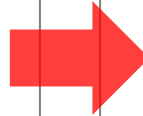
- ▶ With **overflow**:

```
li $t0 0x7FFFFFFF
li $t1 1
add $t0 $t0 $t1
```

Exercise

```
li $t1 5  
li $t2 7  
li $t3 8
```

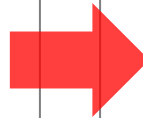
```
li    $t0 10  
sub   $t4 $t2 $t0  
mul   $t4 $t4 $t1  
add   $t4 $t4 $t3  
li    $t0 -1  
mul   $t4 $t4 $t0
```



Exercise (solution)

```
li $t1 5  
li $t2 7  
li $t3 8
```

```
li    $t0 10  
sub   $t4 $t2 $t0  
mul   $t4 $t4 $t1  
add   $t4 $t4 $t3  
li    $t0 -1  
mul   $t4 $t4 $t0
```



```
li $t1 5  
li $t2 7  
li $t3 8
```

```
addi   $t4 $t2 -10  
mul    $t4 $t4 $t1  
add    $t4 $t4 $t3  
mul    $t4 $t4 -1
```

Arithmetic: IEEE 754

- ▶ IEEE 754 floating point arithmetic on the FPU

- ▶ Examples:

- ▶ Simple precision add

`add.s $f0 $f1 $f4`

$f_0 = f_1 + f_4$

- ▶ Double precision add

`add.d $f0 $f2 $f4`

$(f_0, f_1) = (f_2, f_3) + (f_4, f_5)$

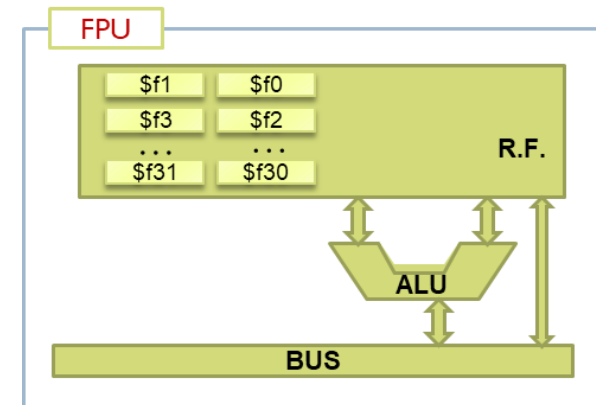
- ▶ Load the float value 8.0 in register \$f4:

`li.s $f4, 8.0`

- ▶ Load the double value 12.4 in registers (\$f2, \$f3):

`li.d $f2, 12.4`

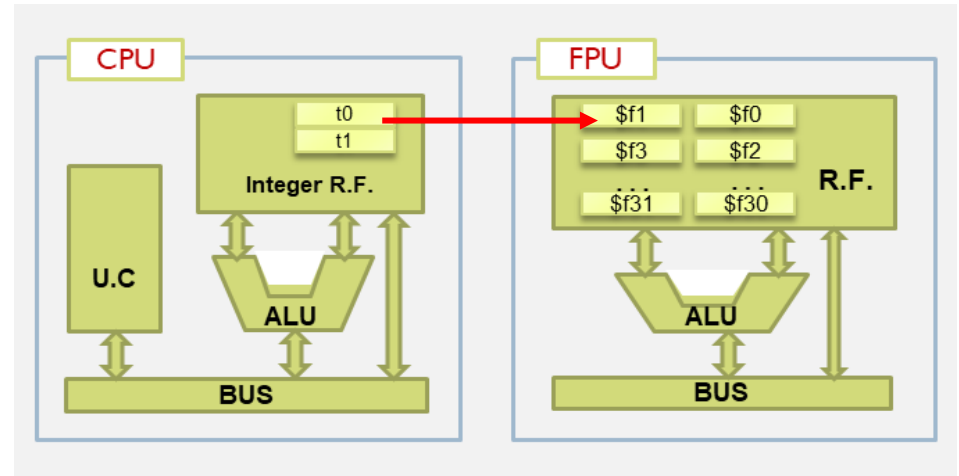
- ▶ Others: `add.s`, `sub.s`, `mul.s`, `div.s`, `abs.s`, `bclt`, `bclt`, ...



Data transfer: IEEE 754

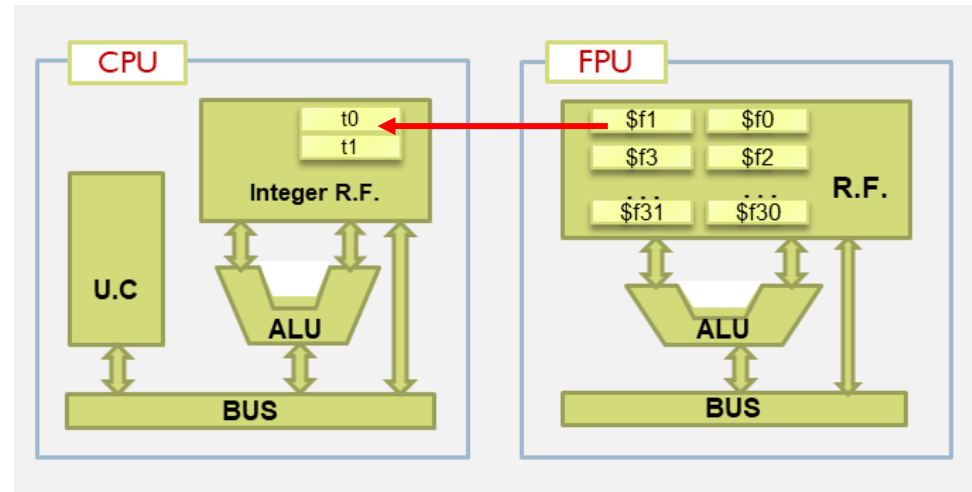
`mtc1 $t0 $f1`

- Move To Coprocessor 1 (FPU)



`mfc1 $t0 $f1`

- Move From Coprocessor 1 (FPU)



Conversion operations

▶ `cvt.s.w $f2 $f1`

▶ Convert from integer (\$f1) to single precision (\$f2)

▶ `cvt.w.s $f2 $f1`

▶ Convert from single precision (\$f1) to integer (\$f2)

▶ `cvt.d.w $f2 $f0`

▶ Convert from integer (\$f0) to double precision (\$f2)

▶ `cvt.w.d $f2 $f0`

▶ Convert from double precision (\$f0) to integer (\$f2)

▶ `cvt.d.s $f2 $f0`

▶ Convert from single precision (\$f0) to double (\$f2)

▶ `cvt.s.d $f2 $f0`

▶ Convert from double precision (\$f0) to single (\$f2)

Example



```
float PI      = 3,1415;
```

```
int  radio = 4;
```

```
float longitud;
```

```
longitud = PI * radio;
```

```
.text  
.globl main  
main:
```

```
li.s    $f0 3.1415  
li      $t0 4
```

Example



```
float PI    = 3,1415;
```

```
int  radio = 4;
```

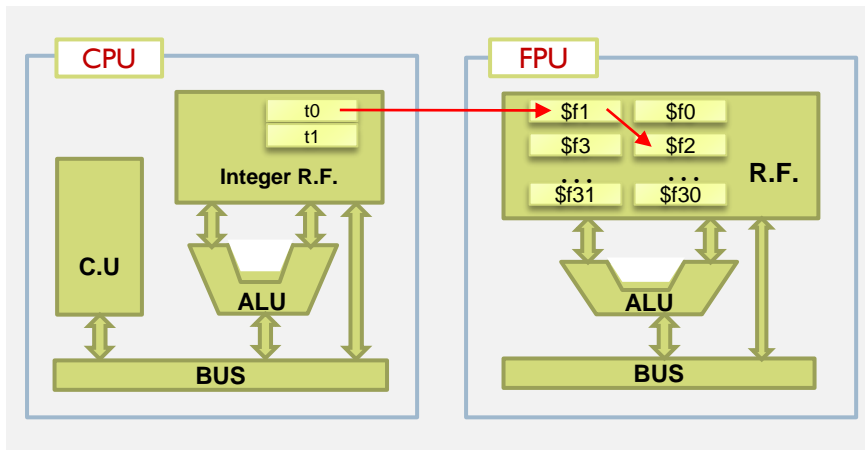
```
float longitud;
```

```
longitud = PI * radio;
```

```
.text
.globl main
main:
```

```
li.s    $f0 3.1415
li      $t0 4
```

```
mtc1    $t0 $f1    # 4ca2
cvt.s.w $f2 $f1    # 4ieee754
mul.s   $f0 $f2 $f1
```



Logical instructions

► Boolean operations:

► NOT

`not $t0 $t1` ($\$t0 = ! \$t1$)

NOT	10
<hr/>	
	01

► AND

`and $t0 $t1 $t2` ($\$t0 = \$t1 \& \$t2$)

	1100
AND	1010
<hr/>	
	1000

► OR

`or $t0 $t1 $t2` ($\$t0 = \$t1 \mid \$t2$)
`ori $t0 $t1 80` ($\$t0 = \$t1 \mid 80$)

	1100
OR	1010
<hr/>	
	1110

► XOR

`xor $t0 $t1 $t2` ($\$t0 = \$t1 \wedge \$t2$)

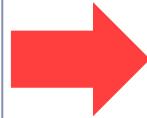
	1100
XOR	1010
<hr/>	
	0110

Example

```
li $t0, 5
```

```
li $t1, 8
```

```
and $t2, $t1, $t0
```



What is the value of \$t2?

Example (solution)

```
li $t0, 5
```

```
li $t1, 8
```

```
and $t2, $t1, $t0
```

What is the value of \$t2?

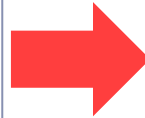


and

000	0101	\$t0
<u>000</u>	<u>.....</u>	<u>1000</u>	\$t1
000	0000	\$t2

Exercise

```
li $t0, 5  
li $t1, 0x007FFFFFFF  
  
and $t2, $t1, $t0
```

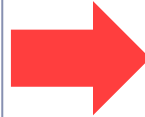


What does an "and" with
0x007FFFFFFF allow to do?

Exercise (solution)

```
li $t0, 5  
li $t1, 0x007FFFFFFF
```

```
and $t2, $t1, $t0
```



What does an "and" with
0x007FFFFFFF allow to do?

Obtain the 23 least
significant bits

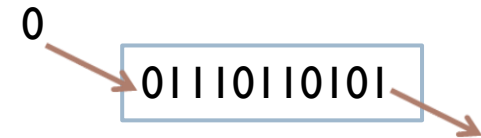
The constant used for bit
selection is called a **mask**.

Shift instructions

- ▶ Bits movement

- ▶ Examples:

- ▶ Shift right **logical**
`srl $t0 $t0 4` ($\$t0 = \$t0 \gg 4$ bits)



- ▶ Shift left **logical**
`sll $t0 $t0 5` ($\$t0 = \$t0 \ll 5$ bits)



- ▶ Shift right **arithmetic**
`sra $t0 $t0 2` ($\$t0 = \$t0 \gg 2$ bits)



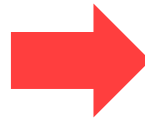
Example

```
li $t0, 5
```

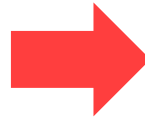
```
li $t1, 6
```

```
sra $t0, $t1, 1
```

```
srl $t0, $t1, 1
```



- What is the value of \$t0?



- What is the value of \$t0?

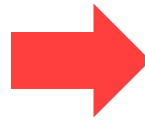
Example (solution)

```
li $t0, 5
```

```
li $t1, 6
```

```
sra $t0, $t1, 1
```

```
srl $t0, $t1, 1
```



- What is the value of \$t0?

000 0110 \$t1

shift one bit to right (/2)

000 0011 \$t0



- What is the value of \$t0?

000 0110 \$t1

Shift one bit to left (x2)

000 1100 \$t0

Rotations

- ▶ Bits movement

- ▶ Example:

- ▶ Rotate left
`rol $t0 $t0 4` rotate 4 bits

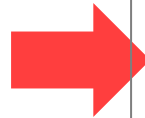


- ▶ Rotate right
`ror $t0 $t0 5` rotate 5 bits



Exercise (solution)

Make a program that detects the sign of a stored number \$t0 and leaves in \$t1 a 1 if it is negative and a 0 if it is positive.



```
li    $t0 -3  
  
move  $t1 $t0  
rol   $t1 $t1 1  
and   $t1 $t1 0x00000001
```

Comparison instructions

▶ **seq \$t0, \$t1, \$t2**

if (\$t1 == \$t2) \$t0 = 1; else \$t0 = 0 # set if equal

▶ **sneq \$t0, \$t1, \$t2**

if (\$t1 != \$t2) \$t0 = 1; else \$t0 = 0 # set if no equal

▶ **sge \$t0, \$t1, \$t2**

if (\$t1 >= \$t2) \$t0 = 1; else \$t0 = 0 # set if greater or equal

▶ **sgt \$t0, \$t1, \$t2**

if (\$t1 > \$t2) \$t0 = 1; else \$t0 = 0 # set if greater than

▶ **sle \$t0, \$t1, \$t2**

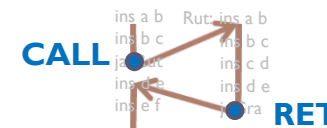
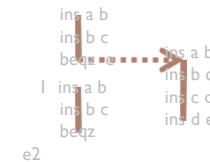
if (\$t1 <= \$t2) \$t0 = 1; else \$t0 = 0 # set if less or equal

▶ **slt \$t0, \$t1, \$t2**

if (\$t1 < \$t2) \$t0 = 1; else \$t0 = 0 # set if less than

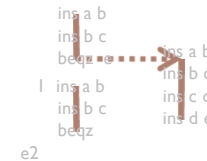
Branch instructions

- ▶ Change the sequence of instructions to be executed
- ▶ Several types:
 - ▶ Conditional branches:
 - ▶ Branch if value match condition
 - ▶ E.g.: `bne $t0 $t1 etiqueta1`
 - ▶ Unconditional branches:
 - ▶ Always branch
 - ▶ E.g.: `j etiqueta2`
 - ▶ Function calls:
 - ▶ Branch with return
 - ▶ E.g.: `jal subrutina1 jr $ra`



Branch instructions

- ▶ Change the sequence of instructions to be executed
- ▶ Several types:
 - ▶ Conditional branches:
 - ▶ Branch if value match condition
 - ▶ E.g.: `bne $t0 $t1 etiqueta1`



- ▶ `beq $t0 $t1 etiq1 # go to etiq1 if $t1 = $t0`
- ▶ `bne $t0 $t1 etiq1 # go to etiq1 if $t1 != $t0`
- ▶ `beqz $t1 etiq1 # go to etiq1 if $t1 = 0`
- ▶ `bnez $t1 etiq1 # go to etiq1 if $t1 != 0`
- ▶ `bgt $t0 $t1 etiq1 # go to etiq1 if $t1 > $t0`
- ▶ `bge $t0 $t1 etiq1 # go to etiq1 if $t1 >= $t0`
- ▶ `blt $t0 $t1 etiq1 # go to etiq1 if $t1 < $t0`
- ▶ `ble $t0 $t1 etiq1 # go to etiq1 if $t1 <= $t0`

Control flow structures

if...(1/2)

```
int b1 = 4;  
int b2 = 2;
```



```
if (b2 == 8) {  
    b1 = 0;  
}  
...
```

```
li    $t0 4 # b1  
li    $t1 2 # b2  
li    $t2 8  
bneq  $t1 $t2 end1  
li    $t0 0  
end1: ...
```

Control flow structures

if-else ...(2/2)

```
int a = 1;
int b = 2;

if (a < b)
{
    // action 1
}
else
{
    // action 2
}
```



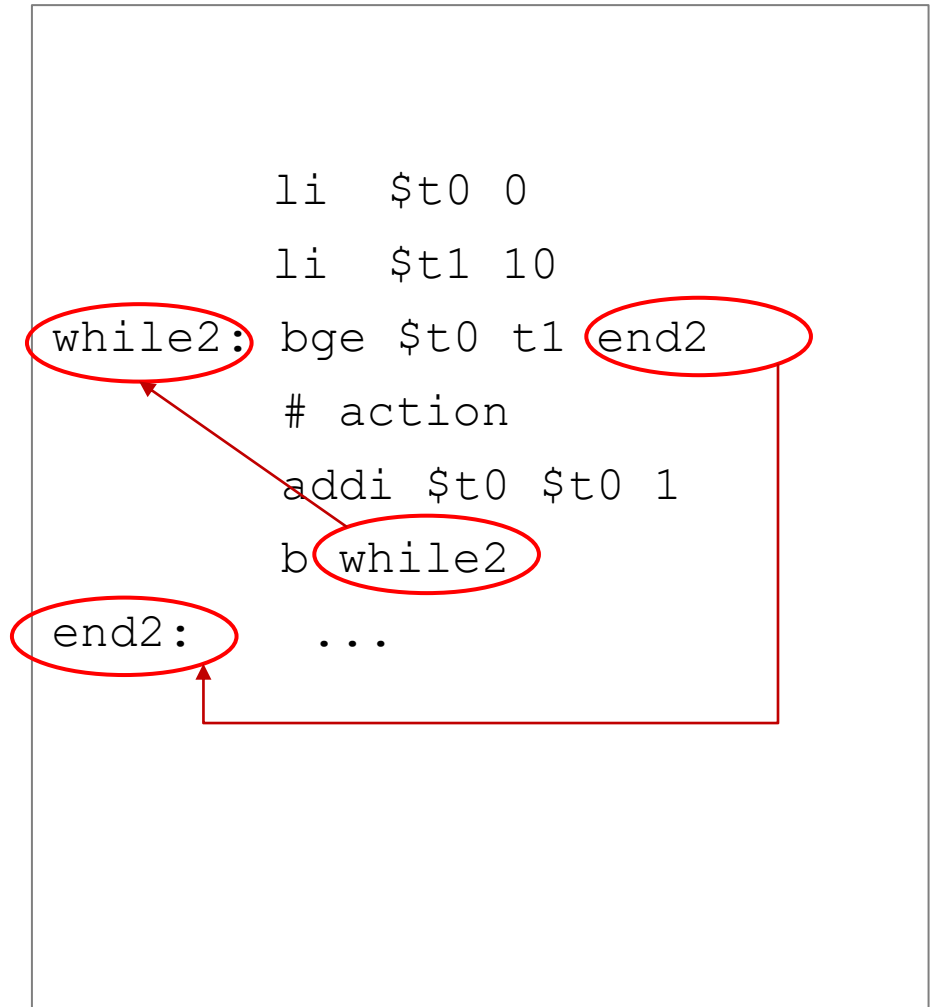
```
li $t1 1
li $t2 2

blt $t1 $t2 then1
else1: ...
    # action 2
b end1
then1: ...
    # action 1
end1: ...
```

Control flow structures

while

```
int i;  
  
i=0;  
while (i < 10)  
{  
    /* action */  
    i = i + 1 ;  
}
```



Exercise

- Calculate $1 + 2 + 3 + \dots + 10$ and result in \$t1

```
i=0;
s=0;
while (i < 10)
{
    s = s + i;
    i = i + 1;
}
```

Exercise (solution)

- Calculate $1 + 2 + 3 + \dots + 10$ and result in $\$t1$

```
i=0;
s=0;
while (i < 10)
{
    s = s + i;
    i = i + 1;
}
```

```
li    $t0 0
li    $t1 0
li    $t2 10
while: bge    $t0 t2 end
      add    $t1 $t1 $t0
      addi   $t0 $t0 1
      b      while
end:   ...
```

Exercise

- Calculate the number of 1's of a register (\$t0). Result in \$t3.

```
i = 0;
n = 45;  # number
s=0;
while (i < 32)
{
    b = last bit of n
    s = s + b;
    shift n 1 bit to right
    i = i + 1 ;
}
```

Exercise (solution)

- Calculate the number of 1's of a register (\$t0). Result in \$t3.

```
i = 0;
n = 45;  # number
s=0;
while (i < 32)
{
    b = last bit of n
    s = s + b;
    shift n 1 bit to right
    i = i + 1 ;
}
```

```
i = 0;
n = 45;  # number
s = 0;
while (i < 32)
{
    b = n & 1;
    s = s + b;
    n = n >> 1;
    i = i + 1 ;
}
```


Exercise (solution)

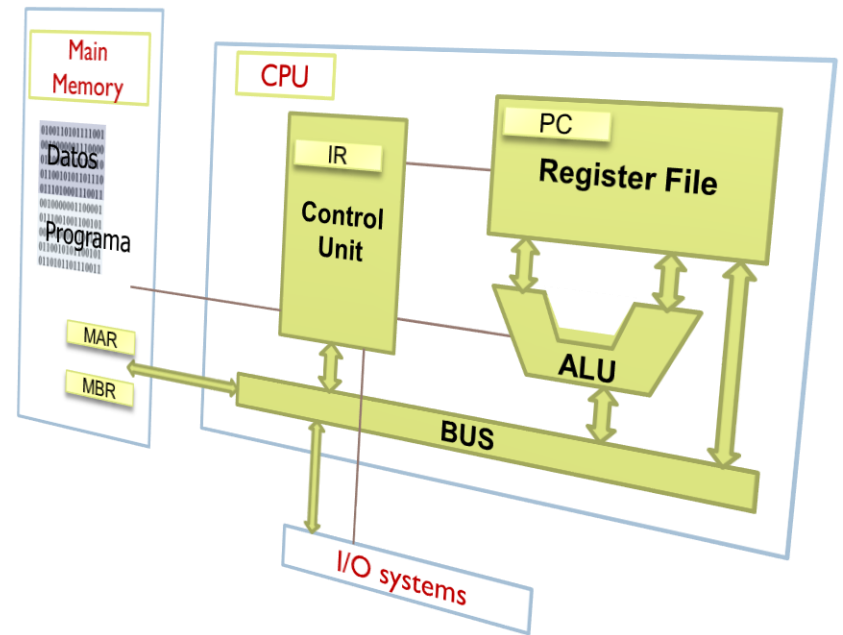
- Calculate the number of 1's of a register (\$t0). Result in \$t3

```
i = 0;
n = 45;  # number
s=0;
while (i < 32)
{
    b = last bit of n
    s = s + b;
    shift n 1 bit to right
    i = i + 1 ;
}
```

```
li    $t0 0      #i
li    $t1 45     #n
li    $t2 32
li    $t3 0      #s
while1: bge    $t0 t2 end1
        and    $t4 $t1 1
        add    $t3 $t3 $t4
        srl    $t1 $t1 1
        addi   $t0 $t0 1
        b      while1
end1:   ...
```

Types of instructions

- ▶ Data transfer
- ▶ Arithmetic
- ▶ Logical
- ▶ Shifting
- ▶ Rotation
- ▶ Comparison
- ▶ Branches
- ▶ Conversion
- ▶ Input/output
- ▶ System calls



Typical faults

1) Poorly designed program

- ▶ Does not do what is requested
- ▶ Incorrectly does what is requested

2) Programming directly in assembler

- ▶ Do not code in pseudo-code the algorithm to be implemented

3) Write unreadable code

- ▶ Do not tabulate the code
- ▶ Do not comment the assembly code or make reference to the algorithm initially proposed.

Example

- Calculate the number of 1's of a `int` in C/Java

Another solution :

```
int count[256] = {0,1,1,2,1,2,2,3,1, . . . 8};  
int i;  
int c = 0;  
  
for (i = 0; i <4; i++) {  
    c = count[n & 0xFF];  
    s = s + c;  
    n = n >> 8;  
}  
printf("There is %d\n", c);
```

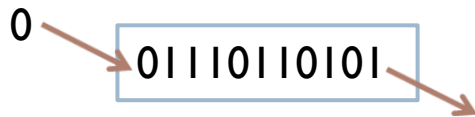
Example

- ▶ Obtain the 16 first bits of a register (\$t0) and store them in the 16 last bits of other register (\$t1)

Solution

- Obtain the 16 first bits of a register (\$t0) and store them in the 16 last bits of other register (\$t1)

```
srl  $t1,  $t0,  16
```



Shift 16 bits to right

Compilation process

High level language

```
#include <stdio.h>

#define PI 3.1416
#define RADIO 20

int main ( )
{
    int l;

    l=2*PI*RADIO;
    printf("long: %d\n",l) ;
    return (0);
}
```



Assembly language

```
.data
PI: .word 3.14156
RADIO: .word 20

.text
li $a0 2
la $t0 PI
lw $t0 ($t0)
la $t1 RADIO
lw $t1 ($t1)
mul $a0 $a0 $t0
mul $a0 $a0 $t1

li $v0 1
syscall
```



Binary language

```
0100110101111001
0010000001110000
0110000101110010
0110010101101110
0111010001110011
0010000001100001
0111001001100101
0010000001100111
0110010101100101
0110101101110011
```

Example

- ▶ Determine if the number stored in \$t2 is even. If \$t2 is even the program stores 1 in \$t1, else stores 0 in \$t1

Solution

- Determine if the number stored in \$t2 is even. If \$t2 is even the program stores 1 in \$t1, else stores 0 in \$t1

```
        li    $t2    9
        li    $t1    2
        rem   $t1    $t2    $t1    # remainder
        beq   $t1    $0    then    # cond.
else:    li    $t1    0
        b     end                # uncond.
then:    li    $t1    1
end:     ...
```

Example

- ▶ Determine if the number stored in \$t2 is even. If \$t2 is even the program stores 1 in \$t1, else stores 0 in \$t1. In this case, analyze the last bit

Solution

- Determine if the number stored in \$t2 is even. If \$t2 is even the program stores 1 in \$t1, else stores 0 in \$t1. In this case, analyze the last bit

```
        li    $t2 9
        li    $t1 1
        and   $t1 $t2 $t1    # get the last bit
        beq   $t1 $0 then    # cond.
else:    li    $t1 0
        b     end            # uncond.
then:    li    $t1 1
end:     ...
```

Example

- ▶ Calculate a^n
 - ▶ a in \$t0
 - ▶ n in \$t1
 - ▶ Result in \$t2

```
a=8
n=4;
i=0;
p = 1;
while (i < n)
{
    p = p * a
    i = i + 1 ;
}
```

Solution

- ▶ Calculate a^n
 - ▶ a in \$t0
 - ▶ n in \$t1
 - ▶ Result in \$t2

```
a=8
n=4;
i=0;
p = 1;
while (i < n)
{
    p = p * a
    i = i + 1 ;
}
```

```
li    $t0 8
li    $t1 4
li    $t2 1
li    $t4 0

while: bge    $t4 $t1 end
mul    $t2 $t2 $t0
addi   $t4 $t4 1
b      while
end:    move   $t2 $t4
```