Assembler Arithmetic
an [illegible] ess

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Overview

- Variables in Assembly
- Addition and Subtraction in Assembly
- Memory Access in A

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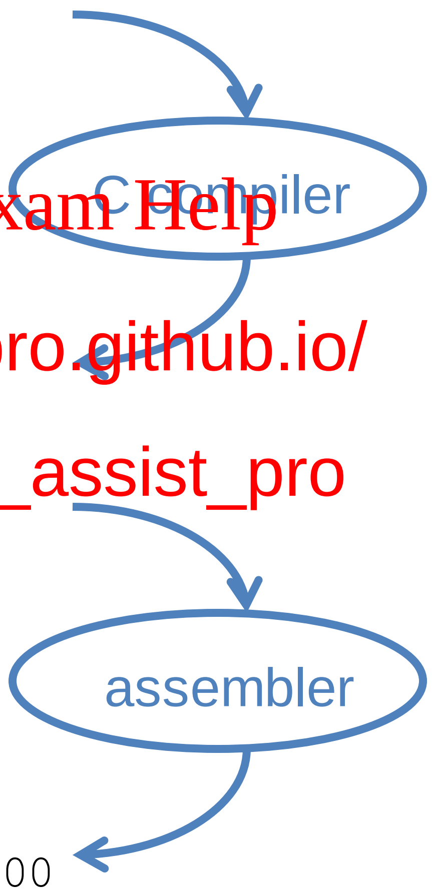
Below Your Program

- High-level language program (in C)

```
swap (int v[], int k) {
    int temp = v[k];
    v[k] = v[k+1];
    v[k+1] = temp;
}
```



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- Assembly language pr

```
swap:  sll
       add    $2, $4,$2
       lw     $15, 0($2)
       lw     $16, 4($2)
       sw     $16, 0($2)
       sw     $15, 4($2)
       jr     $31
```

- Machine (object) code (for MIPS)

```
000000 00000 00101 0001000010000000
000000 00100 00010 0001000000100000
 . . .
```

Operators / Operands in High-level Languages

Operators: +, -, *, /, % ;

- 7/4==1, 7%4==3

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Operands:

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- Variables: fahr, celsius
- Constants: 0, 1000, -17, 15.4

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Statement: Variable = Expression ;

- celsius = 5*(fahr-32)/9;
- a = b+c+d-e;

Assembly Design: Key Concepts

- Assembly language is directly supported in hardware
- It is kept very simple!
  - Limit on the type of
  - Limit the set of **oper** imum

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The MIPS Instruction Set

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- Microprocessor without Interlocked Pipelined Stages (MIPS)

ple in this course (Quickguide)

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MARS: Free MIPS Simulator

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- Download the ________
- Run the software java –jar pMARS.jar

How do I learn MIPS assembly?

- Try it out with MARS!

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Assem https://eduassistpro.github.io/ Register

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Assembly Variables: Registers

C and Java

- Operands are **variables and constants**
- Declare as many as you

MIPS

- Variables are replaced by **registers**
- tions can only rmed on these!
- number built directly into the hardware

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Why? Keep the Hardware Simple!

Assembly Variables: Registers

- MIPS has a register file of 32 registers
- Why 32? Smaller is faster
- Each MIPS register is 32 bits = 4 bytes = a word

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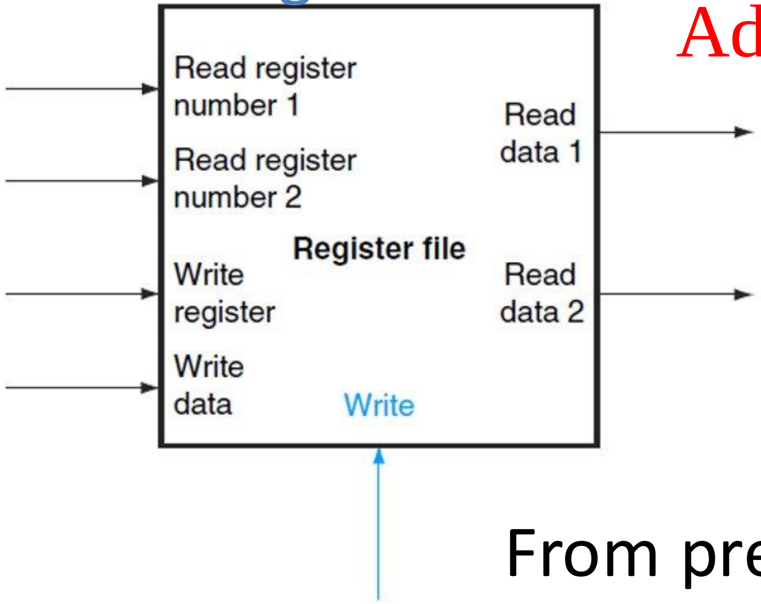
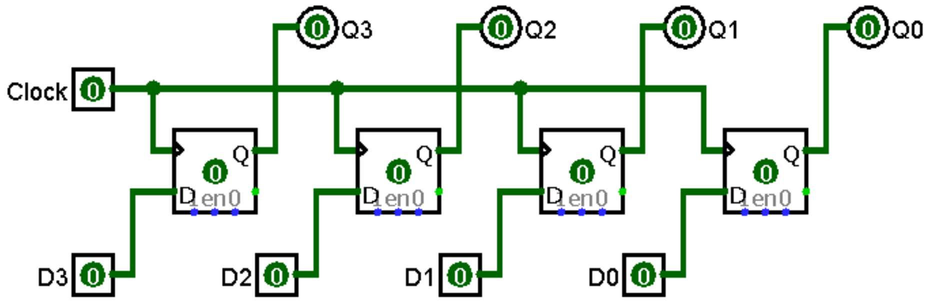
Register File



General) Register



From previous lecture on "Register and Memory"

Assembly Variables: Registers

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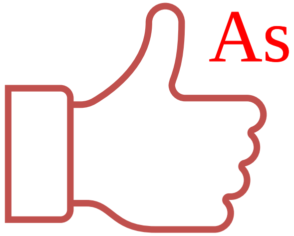
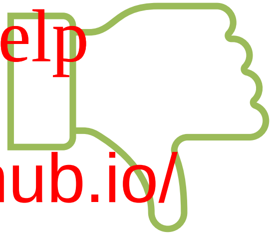


Good

Register file is small and inside of the core, so they are very fast



Bad

Since registers are implemented in the hardware, there are a predetermined number of them

MIPS code must be very carefully put together to efficiently use registers

Assembly Variables: Registers

- Registers are numbered from 0 to 31

  `$0, $1, $2, … $30, $31`

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- Each register also has a **name** to make it easier to code:

  `$16 - $23` ➔ https://eduassistpro.github.io/

  (s correspond to saved temporar)

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  `$8 - $15` ➔ `$t0 - $t7`

  (t correspond to temporary variables)

We will come back to s and t when we talk about "procedure"

In general, **use register names** to make your code more readable

Assembly Variables: Registers

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$1, $26, $27 are reserved for assembler and operation system

Comments

Assembly code is hard to read!

Another way to **make your code more readable**: comments!

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C and Java	MIPS
/* comment can span many lines */ // comment, to the end of a line	# from hash mark to end of line is a comment and will be ignored

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Assembly Instructions

C and Java

Each statement could r
multiple operations

$a = b + c - d ;$

Is equivalent to two small operations

$a = b + c ;$

$a = a - d ;$

MIPS

tement
n instruction), executes
ne of a short list of
simple commands

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Addit action

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Addition and Subtraction

- **Syntax of Instructions:**

    Operation Destination, Source1, Source2

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    Operation: by name (

    i.e., something easy to remember: acronym, abbreviation, or similar

    Destination: operand

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    Source1: 1st operand for operation

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    Source2: 2nd operand for operation

- Syntax is rigid:
    - Most of them use 1 operator + 3 operands ***(commas are optional)***
    - Why? Keep Hardware simple via regularity

Addition and Subtraction

Try with Mars

Addition

```
// C and Java
a = b + c ;
```

```
# MIPS
0 $s1 $s2
```

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registers $s0,$s … iables a, b, c

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Subtraction

```
// C and Java
d = e - f;
```

```
# MIPS
sub $s3,$s4,$s5
```

registers $s3,$s4,$s5 are associated with variables d, e, f

Addition and Subtraction

Each Instruction, executes exactly one simple commands

C and Java

```
a = b + c + d -
```

Break into multiple instructions

MIPS

```
s0, $s1, $s2
b + c

, $s0, $s3
# a = a + d

sub $s0, $s0, $s4
# a = a - e
```

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A single line of C may break up into several lines of MIPS.

Immediates

- **Immediates** are numerical constants.
- Special instructions for immediates: addi
- Syntax is similar to a pt that ***last*** argument is a number (decima stead of a register.

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```
// C and Java
f = g + 10 ;
```

```
addi $s0 $s1 10
addi $s0 $s1 -10
```

- There is no subi (use a negative immediate instead)

Register Zero

- MIPS defines **register zero** (`$0` or `$zero`) ***always*** be 0.
- The number zero appears very often in code.
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- Use this register, it'
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```
add   $6 $0 $5              5 to $6
addi  $6 $0 77              # copy 77 to $6
```

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- Register zero cannot be overwritten

```
addi  $0 $0 5               # will do nothing
```

Register Zero

- What if you want to negate a number?

```
sub $6 $0 $5    #$6 = 0 - $5
```

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Data ctions

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Data Transfer Instructions

- **MIPS arithmetic instructions only operate on registers**
- What about large data structures like arrays? **Memory**!
  - Add two numbers in
    - Load values from me
    - Store result from register to memor
- Use **Data transfer instructions** to transfer data between registers and memory. We need to specify
  - Register: specify this by number (0 - 31)
  - Memory address: more difficult

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Memory Address

Memory is a linear array of byte

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the memory has its own

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ss

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We can access the content by supplying the memory address

The processor can read or write the content of the memory

Memory Address

- **Memory Address Syntax: Offset(AddrReg)**
  - **AddrReg:** **A register which contains a pointer to a memory location**
  - **Offset**: **A numerical offset in bytes** (optional)

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```
8($t0)
```

specifies the memory add 0 plus 8 bytes

- We might access a location with an offset from a base pointer
- The resulting memory address is the sum of these two values

Memory Address

```
// An array of 8 integers in C/Java
int arr[8]={56,26,88,45,-45,77,98,13} ;
```

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```
# Assume $s0 has the address 0x1000

0($s0)   # 0x1000, to access arr[0]
4($s0)   # 0x1004, to access arr[1]
```

4-bit address example

Address	Content
	…
0x1000	56
0x1004	26
0x1008	88
0x100C	45
0x1010	−45
0x1014	77
0x1018	98
0x101C	13
	…

Data Transfer: Memory to Register

- **Load Instruction Syntax: lw DstReg, Offset(AddrReg)**
  - **lw**: Load a **Word**
  - **DstReg**: register tha
  - **Offset**: numerical of
  - **AddrReg**: register containing poin ory

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```
lw $t0, 8($s0)
# load one word from memory at
address stored in $s0 with an offset 8 and
store the content in $t0
```

Address	Content
	…
0x1000	56
0x1004	26
0x1008	88
0x100C	45
0x1010	-45
0x1014	77
0x1018	98
0x101C	13
	…

Data Transfer: Register to Memory

- **Store instruction syntax: sw DataReg, Offset(AddrReg)**
  - sw: Store a **word**
  - **DstReg**: register
  - **Offset**: numerica
  - **AddrReg**: register containing

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```
sw $t0, 4($s0)
```

Store one word (32 bits) to memory address $s0 + 4

Address	Content
	...
0x1000	56
0x1004	26
0x1008	88
0x100C	45
0x1010	−45
0x1014	77
0x1018	98
0x101C	13
	...

Byte vs. word

- Machines address memory as **bytes**
- **Both lw and sw access one word at a time**
- The sum of the base address and the offset ***must be a*** be word aligned)

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```
sw $t0, 0
sw $t0, 4($s0)
sw $t0, 8($s0)
          .
          .
```

Address	Content
	...
0x1000	56
0x1004	26
0x1008	88
0x100C	45
0x1010	-45
0x1014	77
0x1018	98
0x101C	13
	...

Byte vs. word

Try with Mars

```
// C and Java
A[12] = h + A[8] ;
```

Index 8 requires offset of 32
Index 12 reuqires offset of 48

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```
# MIPS
# assume h is stored in $s0 and th dress of A is in $s1
lw  $s2 32($s1)   # load A[8] to $s2
add $s3 $s0, $s2 # $s3 = $s0 + $s2
sw  $s3 48($s1)   # store result to A[12]
```

Register vs. Memory

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- MIPS arithmetic instructions can read 2 registers, operate on them, and write 1 per instruction

write 1 operand per instruction, and no operation

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Why not keep all variables in memory?

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- Smaller is faster

What if more variables than registers?

- Compiler tries to keep most frequently used variable in registers
- Writing less common to memory: ***spilling***

Pointers vs. Values

- **A register can hold *any* 32-bit value.**
  - a (signed) `int`,
  - an `unsigned int`
  - a pointer (memory a
  - etc.

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```
lw $t2, 0($t0)        # $t0 must contain?
```

```
add $t3, $t4, $t5     # what can you say about $t4 and $t5?
```

Review and Information

Registers:

- The variables in assembly
- Saved Temporary Variables, Temporary Variables, Register Zero

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Instructions:

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- Addition and Subtraction: add, addi, sub
- Data Transfer: lw, sw

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References

- Textbook: 2.1, 2.2, 2.3, A.10
- [MARS Tutorial]