Assembler Arithmetic and Memory Access

Overview

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

Below Your Program

- High-level language program (in C)

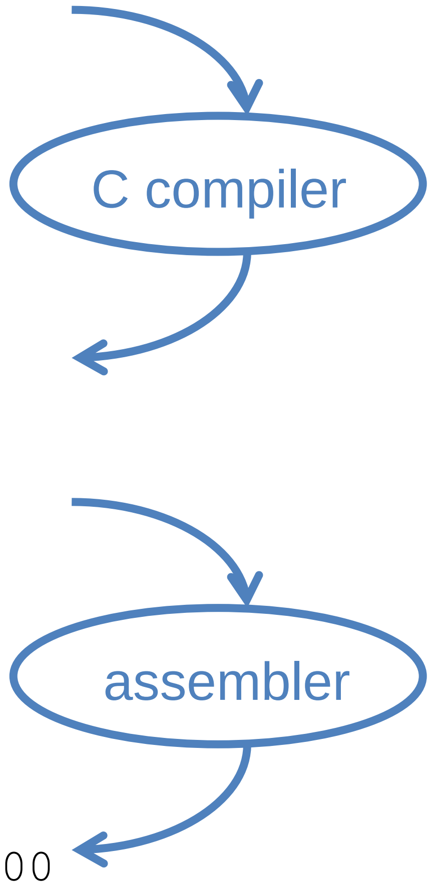
```
swap (int v[], int k) {
    int temp = v[k];
    v[k] = v[k+1];
    v[k+1] = temp;
}
```

- Assembly language program (for MIPS)

```
swap:  sll    $2, $5, 2
       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
 . . .
```



Parameter could also be written as int* v because it is a pointer to an integer, i.e., v is a memory address telling us where an array of integers can be found.

Operators / Operands in High-level Languages

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

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

Operands:

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

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 **operands**
  - Limit the set of **operations** to absolute minimum

The MIPS Instruction Set

MIPS Technology

- Microprocessor without Interlocked Pipelined Stages (MIPS)
- Used MIPS32 as the example in this course (Quickguide)

MARS: Free MIPS Simulator

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

How do I learn MIPS assembly?

- Try it out with MARS!

Assembly Variables: Registers

C and Java

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

MIPS

- Variables are replaced by **registers**
- Operations can only be performed on these!
- Limited number built directly into the hardware

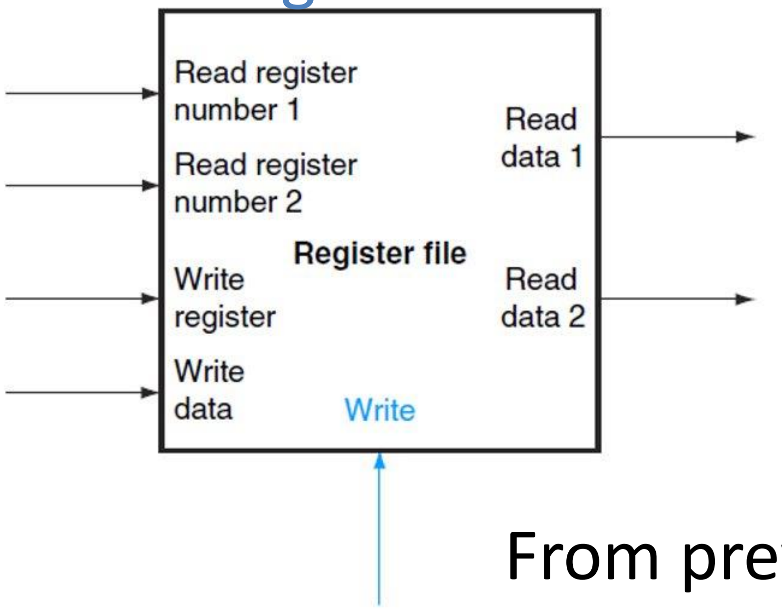
Why? Keep the Hardware Simple!

Assembly Variables: Register

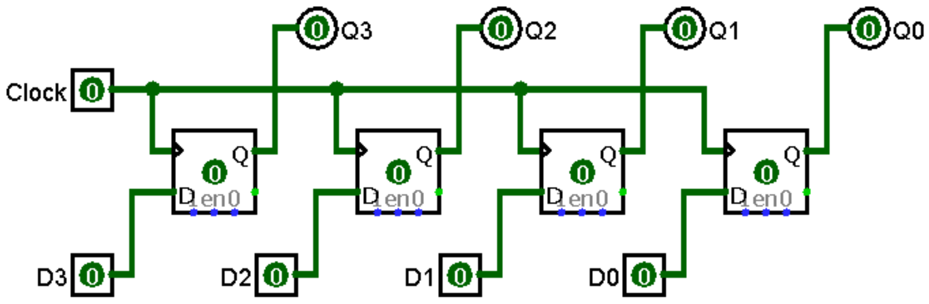
Assembly Variables: Registers

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

Register File

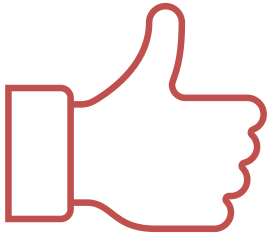


4-bit (General) Register



From previous lecture on "Register and Memory"

Assembly Variables: Registers



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`

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

  `$16 - $23` ➔ `$s0 - $s7`

  (s correspond to saved temporary variables)

  `$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

Register	Name	Used For
0	zero	Always returns 0
1	at	Reserved for use by assembler
2-3	v0, v1	Value returned by subroutine
4-7	a0-a3	First few parameters for subroutine
8-15	t0-t7	Temporary: can use without saving
24, 25	t8, t9	Temporary: can use without saving
16-23	s0-s7	If used, *must* save on stack (or other)
26, 27	k0, k1	Used by interrupt / trap handler
28	gp	A global pointer (extern/static vars...)
29	sp	Stack pointer
30	s8/fp	Frame pointer
31	ra	Subroutine return address

For the moment focus only on blue.

$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!

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

Assembly Instructions

C and Java

Each statement could represent multiple operations

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

Is equivalent to two small operations

```
a = b + c ;
a = a – d ;
```

MIPS

Each statement (called an Instruction), executes exactly one of a short list of simple commands

Addition and Subtraction

Addition and Subtraction

- **Syntax of Instructions:**

  Operation Destination, Source1, Source2

  Operation: by name (Mnemonic)

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

  Destination: operand getting result

  Source1: 1st operand for operation

  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

```
add $s0 $s1 $s2
```

registers `$s0,$s1,$s2` are associated with variables `a, b, c`

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 - e;
```

Break into
multiple instructions

MIPS

```
add $s0, $s1, $s2
# a = b + c

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

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

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 add instruction, except that ***last*** argument is a number (decimal or hexadecimal) instead of a register.

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

```
# MIPS
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.
- Use this register, it's very handy!

```
add   $6 $0 $5        # copy $5 to $6
addi  $6 $0 77        # copy 77 to $6
```

- Register zero cannot be overwritten

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

Register Zero

- What if you want to negate a number?

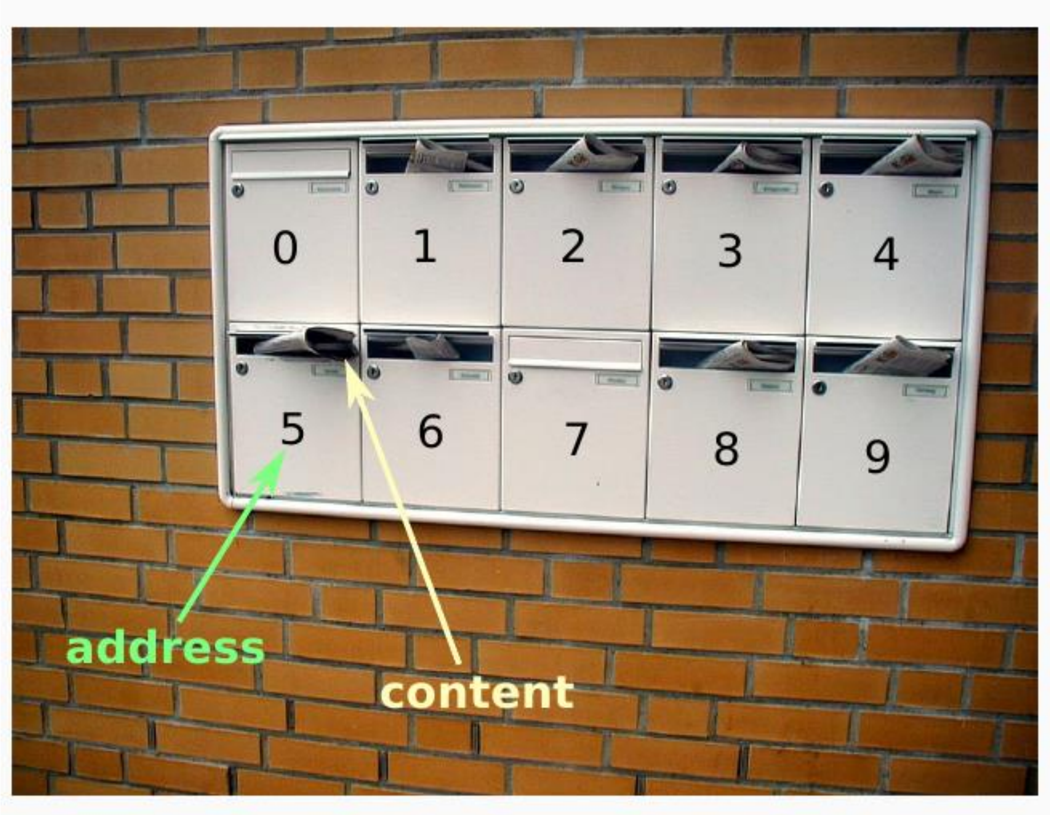
```
sub $6 $0 $5              # $6 = 0 - $5
```

Data Transfer Instructions

Data Transfer Instructions

- **MIPS arithmetic instructions only operate on registers**
- What about large data structures like arrays? **Memory**!
  - Add two numbers in memory
    - Load values from memory into registers
    - Store result from register to memory
- 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

Memory Address



Memory is a linear array of byte

Each byte in the memory has its own unique address

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)

```
8($t0)
# specifies the memory address in $t0 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} ;
```

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

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

16-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 that will receive value
  - **Offset**: numerical offset in bytes
  - **AddrReg**: register containing pointer to memory

```
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 containing the data
  - **Offset**: numerical offset in bytes
  - **AddrReg**: register containing memory

```
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 multiple of 4*** (to be word aligned)

```
sw $t0, 0($s0)
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

```
# MIPS
# assume h is stored in $s0 and the base address 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

Operations with registers are faster than memory

- MIPS arithmetic instructions can read 2 registers, operate on them, and write 1 per instruction
- MIPS data transfer only read or write 1 operand per instruction, and no operation

Why not keep all variables in memory?

- 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 address),
  - etc.

```
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

Instructions:

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

References

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