COMPUTER ORGANIZATION AND DESIGN
The Hardware/Software Interface
FOURTH EDITION

EECS 2021

Computer Organization
Fall 2014

Based on slides by the author and prof. Mary Jane Irwin of PSU.

Chapter Summary

- Stored-program concept
- Assembly language
- Number representation
- Instruction representation
- Supporting procedures in hardware
- MIPS addressing
- Some real-world stuff
- Fallacies and Pitfalls

Stored-Program Concept

- Program instructions are stored in the memory.
- Every cycle, an instruction is read from the memory (fetched).
- The instruction is examined to decide what to do (decode)
- Then we perform the operation stated in the instruction (execute)
- Fetch-Decode-Execute cycle.

Instruction Set

§2.1 Introduction

- The repertoire of instructions of a computer
- Different computers have different instruction sets
  - But with many aspects in common
- Early computers had very simple instruction sets
  - Simplified implementation
- Many modern computers also have simple instruction sets RISC vs. CISC

The MIPS Instruction Set

- Used as the example throughout the book
- Stanford MIPS commercialized by MIPS Technologies (www.mips.com)
- Large share of embedded core market
  - Applications in consumer electronics, network/storage equipment, cameras, printers, …
- Typical of many modern ISAs
  - See MIPS Reference Data tear-out card, and Appendixes B and E

Arithmetic Operations

- Add and subtract, three operands
  - Two sources and one destination

```
add a, b, c  # a gets b + c
```

- All arithmetic operations have this form
- ***Design Principle 1:* Simplicity favors regularity**
  - Regularity makes implementation simpler
  - Simplicity enables higher performance at lower cost

Arithmetic Example

- C code:

```
f = (g + h) - (i + j);
```

- Compiled MIPS code:

```
add t0, g, h   # temp t0 = g + h
add t1, i, j   # temp t1 = i + j
sub f, t0, t1  # f = t0 - t1
```


Register Operands

- Arithmetic instructions use **register operands**
- MIPS has a 32 × 32-bit register file
  - Use for frequently accessed data
  - Numbered 0 to 31
  - 32-bit data called a "word"
- Assembler names
  - $t0, $t1, …, $t9 for temporary values
  - $s0, $s1, …, $s7 for saved variables
- ***Design Principle 2:* Smaller is faster**
  - c.f. main memory: millions of locations

Register name	Number	Usage
$zero	0	constant 0
$at	1	reserved for assembler
$v0	2	expression evaluation and results of a function
$v1	3	expression evaluation and results of a function
$a0	4	argument 1
$a1	5	argument 2
$a2	6	argument 3
$a3	7	argument 4
$t0	8	temporary (not preserved across call)
$t1	9	temporary (not preserved across call)
$t2	10	temporary (not preserved across call)
$t3	11	temporary (not preserved across call)
$t4	12	temporary (not preserved across call)
$t5	13	temporary (not preserved across call)
$t6	14	temporary (not preserved across call)
$t7	15	temporary (not preserved across call)
$s0	16	saved temporary (preserved across call)
$s1	17	saved temporary (preserved across call)
$s2	18	saved temporary (preserved across call)
$s3	19	saved temporary (preserved across call)
$s4	20	saved temporary (preserved across call)
$s5	21	saved temporary (preserved across call)
$s6	22	saved temporary (preserved across call)
$s7	23	saved temporary (preserved across call)
$t8	24	temporary (not preserved across call)
$t9	25	temporary (not preserved across call)
$k0	26	reserved for OS kernel
$k1	27	reserved for OS kernel
$gp	28	pointer to global area
$sp	29	stack pointer
$fp	30	frame pointer
$ra	31	return address (used by function call)

Chapter 2 — Instructions: Language of the Computer — 9

Register Operand Example

- C code:

```
f = (g + h) - (i + j);
```

  - f, …, j in $s0, …, $s4
- Compiled MIPS code:

```
add $t0, $s1, $s2
add $t1, $s3, $s4
sub $s0, $t0, $t1
```

Chapter 2 — Instructions: Language of the Computer — 10

Memory Operands

- Main memory used for composite data
  - Arrays, structures, dynamic data
- To apply arithmetic operations
  - Load values from memory into registers
  - Store result from register to memory
- Memory is byte addressed
  - Each address identifies an 8-bit byte
- Words are aligned in memory
  - Address must be a multiple of 4
- MIPS is **Big Endian**
  - Most-significant byte at least address of a word
  - *c.f.* Little Endian: least-significant byte at least address

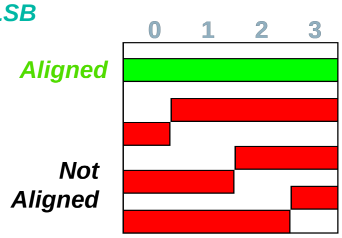
Chapter 2 — Instructions: Language of the Computer — 11

Memory Access

Another way to put it
Big Endian: leftmost byte is word address
Little Endian: rightmost byte is word address

little endian	***LSB***			***MSB***
Bytes address	**0**	**1**	**2**	**3**
big endian	***MSB***			***LSB***

Alignment restriction: requires that objects fall on address that is multiple of their size



Chapter 2 — Instructions: Language of the Computer — 12

Loading and Storing Bytes

- MIPS provides special instructions to move bytes

```
lb   $t0, 1($s3)  #load byte from memory
sb   $t0, 6($s3)  #store byte to  memory
```

- What 8 bits get loaded and stored?
  - load byte places the byte from memory in the rightmost 8 bits of the destination register
    - what happens to the other bits in the register?
  - store byte takes the byte from the rightmost 8 bits of a register and writes it to the byte in memory
    - leaving the other bytes in the memory word unchanged

Chapter 2 — Instructions: Language of the Computer — 13

Example

- Given following code sequence and memory state what is the state of the memory after executing the code?

```
add  $s3, $zero, $zero
lb   $t0, 1($s3)
sb   $t0, 6($s3)
```

	Memory	
24	0x 0 0 0 0 0 0 0 0	24
20	0x 0 0 0 0 0 0 0 0	20
16	0x 0 0 0 0 0 0 0 0	16
12	0x 1 0 0 0 0 0 1 0	12
8	0x 0 1 0 0 0 4 0 2	8
4	0x F F F F F F F F	4
0	0x 0 0 9 0 1 2 A 0	0
	Data	

- What value is left in $t0?

  $t0 = 0x00000090

- What word is changed in Memory and to what?

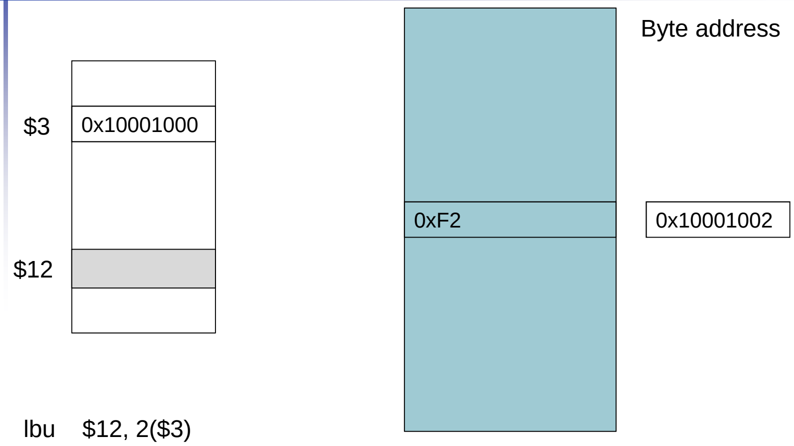
  mem(4) = 0xFFFF90FF

- What if the machine was little Endian? $t0 = 0x00000012

  mem(4) = 0xFF12FFFF

Chapter 2 — Instructions: Language of the Computer — 14

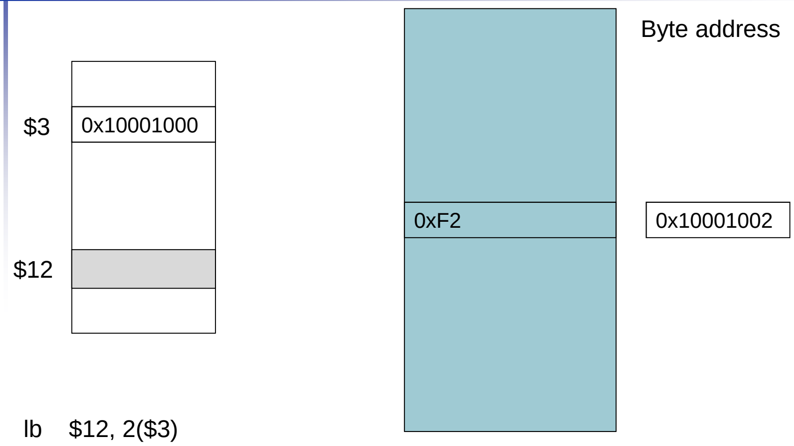
Example



lbu $12, 2($3)

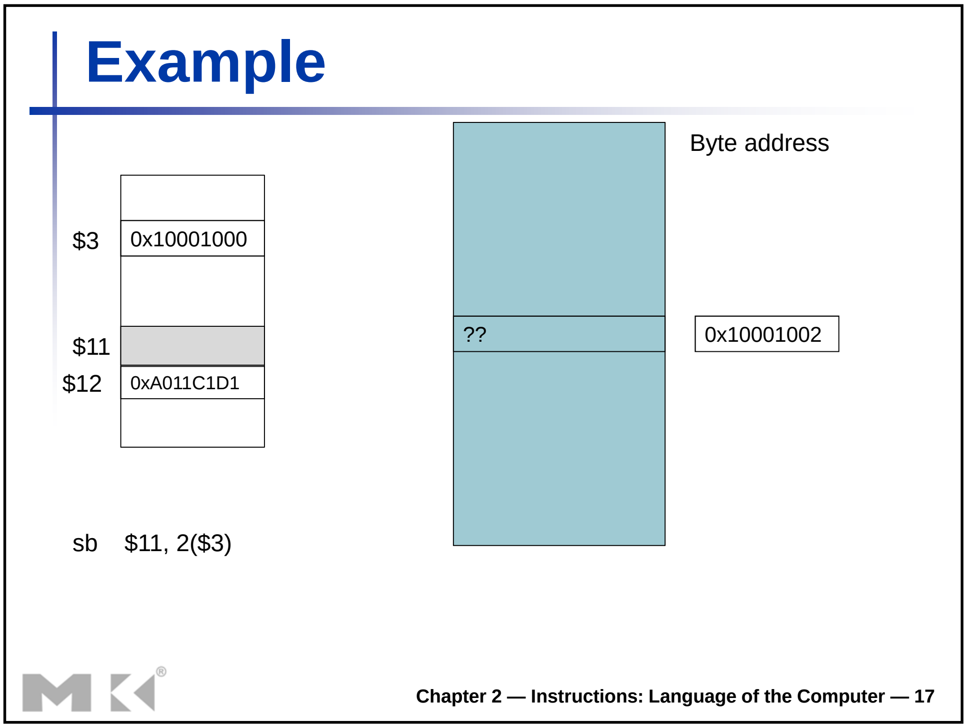
Chapter 2 — Instructions: Language of the Computer — 15

Example



lb $12, 2($3)

Chapter 2 — Instructions: Language of the Computer — 16


Example
Byte address
$3
0x10001000
$11
$12
0xA011C1D1
??
0x10001002
sb $11, 2($3)
Chapter 2 — Instructions: Language of the Computer — 17