inst.eecs.berkeley.edu/~cs61c

CS61C : Machine Structures

Lecture #6 – Intro MIPS; Load & Store

2007-7-3

Scott Beamer, Instructor

Interesting Research on Social Sites by Danah Boyd

facebook xanga.com LiveJournal myspace.com YouTube

www.danah.org

Review

- The operations a CPU can perform are defined by its ISA (Instruction Set Architecture)
- In MIPS Assembly Language:
  - One Instruction (simple operation) per line
  - Simpler is better, smaller is faster
- MIPS Registers (32 of them, each 32-bit)
  - So far you know about $t0 - $t7 and $s0-$s7
  - Registers have no type, the operation tells CPU how to treat it

Comments in Assembly

- Another way to make your code more readable: comments!
- Hash (#) is used for MIPS comments
  - anything from hash mark to end of line is a comment and will be ignored
- Note: Different from C.
  - C comments have format
    `/* comment */`
    so they can span many lines

Assembly Instructions

- In assembly language, each statement (called an Instruction), executes exactly one of a short list of simple commands
- Unlike in C (and most other High Level Languages), each line of assembly code contains at most 1 instruction
- Instructions are related to operations (=, +, -, *, /) in C or Java
- Ok, enough already…gimme my MIPS!

MIPS Addition and Subtraction (1/4)

- Syntax of Instructions:

  1 2,3,4

  where:

  1) operation by name

  2) operand getting result ("destination")

  3) 1st operand for operation ("source1")

  4) 2nd operand for operation ("source2")
- Syntax is rigid:
  - 1 operator, 3 operands
  - Why? Keep Hardware simple via regularity

Addition and Subtraction of Integers (2/4)

- Addition in Assembly
  - Example: `add $s0,$s1,$s2` (in MIPS)

    Equivalent to: `a = b + c` (in C)

  where MIPS registers `$s0,$s1,$s2` are associated with C variables `a, b, c`
- Subtraction in Assembly
  - Example: `sub $s3,$s4,$s5` (in MIPS)

    Equivalent to: `d = e - f` (in C)

  where MIPS registers `$s3,$s4,$s5` are associated with C variables `d, e, f`

Addition and Subtraction of Integers (3/4)

- How do the following C statement?

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

- Break into multiple instructions

```
add $t0, $s1, $s2 # temp = b + c
add $t0, $t0, $s3 # temp = temp + d
sub $s0, $t0, $s4 # a = temp - e
```

- Notice: A single line of C may break up into several lines of MIPS.
- Notice: Everything after the hash mark on each line is ignored (comments)

Addition and Subtraction of Integers (4/4)

- How do we do this?

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

- Use intermediate temporary register

```
add $t0,$s1,$s2     # temp = g + h
add $t1,$s3,$s4     # temp = i + j
sub $s0,$t0,$t1     # f=(g+h)-(i+j)
```

Register Zero

- One particular immediate, the number zero (0), appears very often in code.
- So we define register zero (`$0` or `$zero`) to always have the value 0; eg

```
add $s0,$s1,$zero   (in MIPS)
f = g               (in C)
```

where MIPS registers `$s0,$s1` are associated with C variables `f, g`

- defined in hardware, so an instruction

```
add $zero,$zero,$s0
```

will not do anything!

Immediates

- Immediates are numerical constants.
- They appear often in code, so there are special instructions for them.
- Add Immediate:

```
addi $s0,$s1,10     (in MIPS)
f = g + 10          (in C)
```

where MIPS registers `$s0,$s1` are associated with C variables `f, g`

- Syntax similar to `add` instruction, except that last argument is a number instead of a register.

Immediates

- There is no Subtract Immediate in MIPS: Why?
- Limit types of operations that can be done to absolute minimum
  - if an operation can be decomposed into a simpler operation, don't include it
  - `addi ..., -X = subi ..., X` => so no `subi`
- `addi $s0,$s1,-10` (in MIPS)

```
f = g - 10          (in C)
```

where MIPS registers `$s0,$s1` are associated with C variables `f, g`

Peer Instruction

A. Types are associated with declaration in C (normally), but are associated with instruction (operator) in MIPS.

B. Since there are only 8 local (`$s`) and 8 temp (`$t`) variables, we can't write MIPS for C exprs that contain > 16 vars.

C. If `p` (stored in `$s0`) were a pointer to an array of `int`s, then `p++;` would be `addi $s0 $s0 1`

	ABC
1:	FFF
2:	FFT
3:	FTF
4:	FTT
5:	TFF
6:	TFT
7:	TTF
8:	TTT

Administrivia

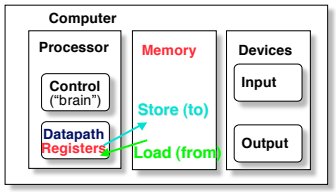
- WLA is a great resource
  - wla.berkeley.edu
- Assignments
  - HW2 due 7/5 @ 11:59pm
  - HW3 due 7/8 @ 11:59pm (to be posted today)
  - Proj1 due 7/12 @ 11:59pm (to be posted today)

Assembly Operands: Memory

- C variables map onto registers; what about large data structures like arrays?
- 1 of 5 components of a computer: memory contains such data structures
- But MIPS arithmetic instructions only operate on registers, never directly on memory.
- Data transfer instructions transfer data between registers and memory:
  - Memory to register
  - Register to memory

Anatomy: 5 components of any Computer

Registers are in the datapath of the processor; if operands are in memory, we must transfer them to the processor to operate on them, and then transfer back to memory when done.



These are "data transfer" instructions…

Data Transfer: Memory to Reg (1/4)

- To transfer a word of data, we need to specify two things:
  - Register: specify this by # ($0 - $31) or symbolic name ($s0,…, $t0, …)
  - Memory address: more difficult
    - Think of memory as a single one-dimensional array, so we can address it simply by supplying a pointer to a memory address.
    - Other times, we want to be able to offset from this pointer.

Remember: "Load FROM memory"

Data Transfer: Memory to Reg (2/4)

- To specify a memory address to copy from, specify two things:
  - A register containing a pointer to memory
  - A numerical offset (in bytes)
- The desired memory address is the sum of these two values.
- Example: `8($t0)`
  - specifies the memory address pointed to by the value in `$t0`, plus 8 bytes

Data Transfer: Memory to Reg (3/4)

- Load Instruction Syntax:

  1 2,3(4)

  - where
    1) operation name
    2) register that will receive value
    3) numerical offset in bytes
    4) register containing pointer to memory
- MIPS Instruction Name:
  - `lw` (meaning Load Word, so 32 bits or one word are loaded at a time)

Data Transfer: Memory to Reg (4/4)

Data flow

Example: `lw $t0,12($s0)`

This instruction will take the pointer in `$s0`, add 12 bytes to it, and then load the value from the memory pointed to by this calculated sum into register `$t0`

- Notes:
  - `$s0` is called the base register
  - 12 is called the offset
  - offset is generally used in accessing elements of array or structure: base reg points to beginning of array or structure

Data Transfer: Reg to Memory

- Also want to store from register into memory
  - Store instruction syntax is identical to Load's
- MIPS Instruction Name:

`sw` (meaning Store Word, so 32 bits or one word are loaded at a time)

Data flow

- Example: `sw $t0,12($s0)`

This instruction will take the pointer in `$s0`, add 12 bytes to it, and then store the value from register `$t0` into that memory address

- Remember: "Store INTO memory"

Pointers v. Values

- Key Concept: A register can hold any 32-bit value. That value can be a (signed) `int`, an `unsigned int`, a pointer (memory address), and so on
- If you write `add $t2,$t1,$t0` then `$t0` and `$t1` better contain values
- If you write `lw $t2,0($t0)` then `$t0` better contain a pointer
- Don't mix these up!

Addressing: Byte vs. word

- Every word in memory has an address, similar to an index in an array
- Early computers numbered words like C numbers elements of an array:
  - `Memory[0], Memory[1], Memory[2], …`

Called the "address" of a word

- Computers needed to access 8-bit bytes as well as words (4 bytes/word)
- Today machines address memory as bytes, (i.e., "Byte Addressed") hence 32-bit (4 byte) word addresses differ by 4
  - `Memory[0], Memory[4], Memory[8], …`

Compilation with Memory

- What offset in `lw` to select `A[5]` in C?
- 4x5=20 to select `A[5]`: byte v. word
- Compile by hand using registers:

```
g = h + A[5];
```

  - `g`: `$s1`, `h`: `$s2`, `$s3`:base address of `A`
- 1st transfer from memory to register:

```
lw $t0,20($s3)     # $t0 gets A[5]
```

  - Add 20 to `$s3` to select `A[5]`, put into `$t0`
- Next add it to `h` and place in `g`

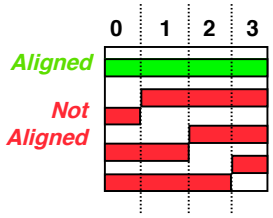
```
add $s1,$s2,$t0    # $s1 = h+A[5]
```

Notes about Memory

- Pitfall: Forgetting that sequential word addresses in machines with byte addressing do not differ by 1.
  - Many an assembly language programmer has toiled over errors made by assuming that the address of the next word can be found by incrementing the address in a register by 1 instead of by the word size in bytes.
  - So remember that for both `lw` and `sw`, the sum of the base address and the offset must be a multiple of 4 (to be word aligned)

More Notes about Memory: Alignment

- MIPS requires that all words start at byte addresses that are multiples of 4 bytes



- Called Alignment: objects must fall on address that is multiple of their size.

Role of Registers vs. Memory

- What if more variables than registers?
  - Compiler tries to keep most frequently used variable in registers
  - Less common in memory: spilling
- Why not keep all variables in memory?
  - Smaller is faster: registers are faster than memory
  - Registers more versatile:
    - MIPS arithmetic instructions can read 2, operate on them, and write 1 per instruction
    - MIPS data transfer only read or write 1 operand per instruction, and no operation

Example

- We want to accomplish the following:

```
int x = 5;
*p = *p + x + 10;
```

- In MIPS (assuming $s0 holds p)

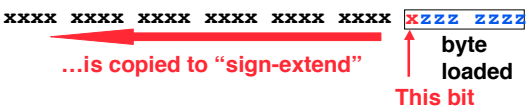
```
addi $s1,$0,5      # x = 5
lw   $t0,0($s0)    # temp = *p
add  $t0,$t0,$s1   # temp += x
addi $t0,$t0,10    # temp += 10
sw   $t0,0($s0)    # *p = temp
```


Loading, Storing bytes 1/2

- In addition to word data transfers (`lw`, `sw`), MIPS has byte data transfers:
- load byte: `lb`
- store byte: `sb`
- same format as `lw`, `sw`

Loading, Storing bytes 2/2

- What do with other 24 bits in the 32 bit register?
  - `lb`: sign extends to fill upper 24 bits



- Normally don't want to sign extend chars
- MIPS instruction that doesn't sign extend when loading bytes:

load byte unsigned: `lbu`

"And in conclusion…"

- In MIPS Assembly Language:
  - Registers replace C variables
  - One Instruction (simple operation) per line
  - Simpler is better, smaller is faster
- Memory is byte-addressable, but `lw` and `sw` access one word at a time.
  - One can store & load (signed and unsigned) bytes too
- A pointer (used by `lw` & `sw`) is just a mem address, so we can add to it or subtract from it (via offset).
- New Instructions:
  `add, addi, sub, lw, sw, lb, sb, lbu`
- New Registers:
  C Variables: `$s0 - $s7`
  Temporary Variables: `$t0 - $t9`
  Zero: `$zero`