CS61C - Machine Structures

Lecture 4 - C/Assembler Arithmetic and Memory Access

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Overview

° C operators, operands

° Variables in Assembly: Registers

° Comments in Assembly

° Addition and Subtraction in Assembly

° Memory Access in Assembly

Review C Operators/Operands (1/2)

° Operators: `+`, `-`, `*`, `/`, `%` (mod);
  `¥7/4==1`, `7%4==3`

° Operands:
- **Variables:** `lower`, `upper`, `fahr`, `celsius`
- **Constants:** `0`, `1000`, `-17`, `15.4`

° Assignment Statement:

Variable = expression

- **Examples:**

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


C Operators/Operands (1/2)

° In C (and most High Level Languages) variables declared first and given a type
- **Example:**

```
int fahr, celsius;
char a, b, c, d, e;
```

° Each variable can ONLY represent a value of the type it was declared as (cannot mix and match `int` and `char` variables).

Assembly Design: Key Concepts

° Keep it simple!
- Limit what can be a variable and what can't
- 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

Assembly Variables: Registers (1/4)

° Unlike HLL, assembly cannot use variables
- Why not? Keep Hardware Simple

° Assembly Operands are registers
- limited number of special locations built directly into the hardware
- operations can only be performed on these!

° Benefit: Since registers are directly in hardware, they are very fast

Assembly Variables: Registers (2/4)

- Drawback: Since registers are in hardware, there are a predetermined number of them
  - Solution: MIPS code must be very carefully put together to efficiently use registers
- 32 registers in MIPS
  - Why 32? Smaller is faster
- Each MIPS register is 32 bits wide
  - Groups of 32 bits called a word in MIPS

Assembly Variables: Registers (3/4)

- Registers are numbered from 0 to 31
- Each register can be referred to by number or name
- Number references:

  `$0, $1, $2,   $30, $31`

Assembly Variables: Registers (4/4)

- By convention, each register also has a name to make it easier to code
- For now:

  `$16 - $22 Ł $s0 - $s7`

  (correspond to C variables)

  `$8 - $15 Ł $t0 - $t7`

  (correspond to temporary variables)
- In general, use names to make your code more readable

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

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 (2/4)

° **Addition in Assembly**

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

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

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

° **Subtraction in Assembly**

- **Example:** `sub $s3,$s4,$s5` **(in MIPS)**

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

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

Addition and Subtraction (3/4)

° **How do the following C statement?**

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

° **Break into multiple instructions**

```
add $s0, $s1, $s2 # a = b + c
add $s0, $s0, $s3 # a = a + d
sub $s0, $s0, $s4 # a = a - 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 (4/4)

° **How do we do this?**

```
¥f = (g + h) - (i + j);
```

° **Use intermediate temporary register**

```
add $s0,$s1,$s2     # f = g + h
add $t0,$s3,$s4     # t0 = i + j
 # need to save i+j, but can t use
 # f, so use t0
sub $s0,$s0,$t0     # f=(g+h)-(i+j)
```


Administrivia

° **Project 1 due Midnight**

° **Lab 3: Your first MIPS program!**

° **HW 2 (due Mon 9/11) and HW3 (9/18) online and available**

° **Reading assignment:**

- **P&H 3.1-3.3, 3.5, 3.8 (page 145)**

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 registers `$s0,$s1` **are associated with variables** `f, g`

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

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.**

° **This is defined in hardware, so an instruction like**

```
addi $0,$0,5
```

will not do anything.

° **Use this register, it’s very handy!**

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

Data Transfer: Memory to Reg (1/4)

° To transfer a word of data, we need to specify two things:

- Register: specify this by number (0 - 31)
- 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.

Data Transfer: Memory to Reg (2/4)

° To specify a memory address to copy from, specify two things:

- A register which contains 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

° Instruction Name:

¥`lw` (meaning Load Word, so 32 bits or one word are loaded at a time)

Data Transfer: Memory to Reg (4/4)

° 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: base reg points to beginning of array

Data Transfer: Reg to Memory (1/2)

° Also want to store value from a register into memory

° Store instruction syntax is identical to Load instruction syntax

° Instruction Name:

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

Data Transfer: Reg to Memory (2/2)

° **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 the memory address pointed to by the calculated sum

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), etc.**

° **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, hence word addresses differ by 4**

`¥Memory[0], Memory[4], Memory[8], ...`

Compilation with Memory

° **What offset in `lw` to select `A[8]` in C?**

° **4x8=32 to select `A[8]`: byte v. word**

° **Compile by hand using registers:**
`g = h + A[8];`

- g: `$s1`, h: `$s2`, `$s3`:**base address of A**

° **1st transfer from memory to register:**

`lw $t0,32($s3) # $t0 gets A[8]`

- **Add 32 to `$s3` to select `A[8]`, put into `$t0`**

° **Next add it to h and place in g**
`add $s1,$s2,$t0   # $s1 = h+A[8]`

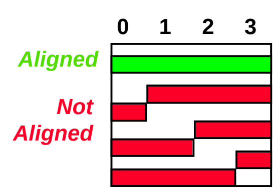
Notes about Memory

° **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 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
  - Writing less common to 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

"And in Conclusion..." (1/2)

- 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.
- A pointer (used by `lw` and `sw`) is just a memory address, so we can add to it or subtract from it (using offset).

"And in Conclusion..."(2/2)

- New Instructions:

  `add, addi,`

  `sub`

  `lw, sw`
- New Registers:

  C Variables: `$s0` - `$s7`

  Temporary Variables: `$t0` - `$t9`

  Zero: `$zero`