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CS61C : Machine Structures

Lecture 5 – Introduction to MIPS Assembly language : Arithmetic

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China MIPS HPC! ⇒
China is making a new high-performance supercomputer, Dawning 6000, using a MIPS processor! Quadrillion ops/sec!

en.wikipedia.org/wiki/MIPS_architecture#MIPS-based_supercomputers/

Review

- **Pointers and arrays are virtually same**

- **C knows how to increment pointers**

- **C is an efficient language, with little protection**
    - **Array bounds not checked**
    - **Variables not automatically initialized**

- **Use handles to change pointers**

- **Dynamically allocated heap memory must be manually deallocated in C.**
    - **Use malloc() and free() to allocate and deallocate memory from heap.**

- **(Beware) The cost of efficiency is more overhead for the programmer.**
    - **"C gives you a lot of extra rope but be careful not to hang yourself with it!"**

Assembly Language

- **Basic job of a CPU: execute lots of *instructions*.**

- **Instructions are the primitive operations that the CPU may execute.**

- **Different CPUs implement different sets of instructions. The set of instructions a particular CPU implements is an *Instruction Set Architecture* (*ISA*).**

  - **Examples: Intel 80x86 (Pentium 4), IBM/Motorola PowerPC (old Macintosh), MIPS, Intel IA64, ...**

Book: Programming From the Ground Up

"A new book was just released which is based on a new concept - teaching computer science through assembly language (Linux x86 assembly language, to be exact). This book teaches how the machine itself operates, rather than just the language. I've found that the key difference between mediocre and excellent programmers is whether or not they know assembly language. *Those that do tend to understand computers themselves at a much deeper level.* Although [almost!] unheard of today, this concept isn't really all that new -- there used to not be much choice in years past. Apple computers came with only BASIC and assembly language, and there were books available on assembly language for kids. This is why the old-timers are often viewed as 'wizards': they **had** to know assembly language programming."

-- **slashdot.org** comment, 2004-02-05
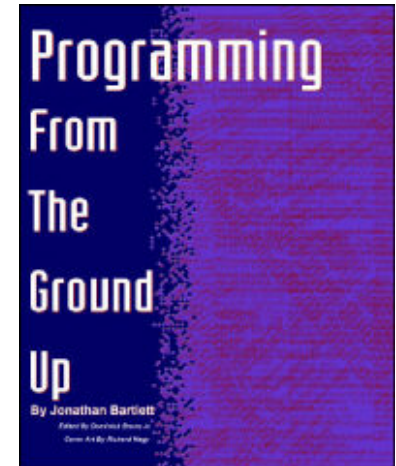
Instruction Set Architectures

- **Early trend was to add more and more instructions to new CPUs to do elaborate operations**

  - **VAX architecture had an instruction to multiply polynomials!**

- **RISC philosophy (Cocke IBM, Patterson, Hennessy, 1980s) – Reduced Instruction Set Computing**

  - **Keep the instruction set small and simple, makes it easier to build fast hardware.**

  - **Let software do complicated operations by composing simpler ones.**

MIPS Architecture

- **MIPS – semiconductor company that built one of the first commercial RISC architectures**

- **We will study the MIPS architecture in some detail in this class (also used in upper division courses CS 152, 162, 164)**

- **Why MIPS instead of Intel 80x86?**
  - **MIPS is simple, elegant. Don't want to get bogged down in gritty details.**
  - **MIPS widely used in embedded apps, x86 little used in embedded, and more embedded computers than PCs**

Most HP LaserJet workgroup printers are driven by MIPS-based™ 64-bit processors.

Assembly Variables: Registers (1/4)

- **Unlike HLL like C or Java, 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 (faster than 1 billionth of a second)**

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 <u>word</u> 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 - $23➡ $s0 - $s7

  (correspond to C variables)

  $8 - $15➡ $t0 - $t7

  (correspond to temporary variables)

  Later will explain other 16 register names

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

C, Java variables vs. registers

- 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).

- In Assembly Language, the registers have no type; operation determines how register contents are treated

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**
  - **This is just like the C99 //**

- **Note: Different from C.**
  - **C comments have format /* comment */ so they can span many lines**

HW1?

a) Done!

b) Almost done.

c) Started. I'm in the mix.

d) Just basically read it.

e) Haven't even started.

How many hours h on Homework 1?

a) $0 \leq h < 5$

b) $5 \leq h < 10$

c) $10 \leq h < 15$

d) $15 \leq h < 20$

e) $20 \leq h$

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 to 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

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

2) **If p (stored in $s0) were a pointer to an array of ints, then p++; would be addi $s0 $s0 1**

```
      12
a)  FF
b)  FT
c)  TF
d)  TT
e) dunno
```

"And in Conclusion..."

- **In MIPS Assembly Language:**
  - **Registers replace C variables**
  - **One Instruction (simple operation) per line**
  - **Simpler is Better**
  - **Smaller is Faster**

- **New Instructions:**
  add, addi, sub

- **New Registers:**
  C Variables: $s0 - $s7
  Temporary Variables: $t0 - $t9
  Zero: $zero

Administrivia

- **Exams will be returned via Pandagrader!**
  - Grades should be returned quickly
  - You will have one week to ask for regrade via the pandagrader system
  - After that one week, the grade will be frozen

- **Regrading projects: possible to go up or down; we'll regrade whole thing**
  - Beware: no complaints if grade goes down