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UCB CS61C : Machine Structures

Lecture 6 – Introduction to MIPS Data Transfer & Decisions I

2013-02-04

ROBOTS THAT LEARN FROM US!

Prof Pieter Abbeel's recent research is in having robots learn from the way humans do tasks as apprentices. His robots have learned to perform flying acrobatics, tie surgical sutures and neatly sort socks…

www.technologyreview.com/tr35/profile.aspx?trid=1082

Review

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

  `add, addi, sub`
- **New Registers:**

  C Variables: `$s0 - $s7`

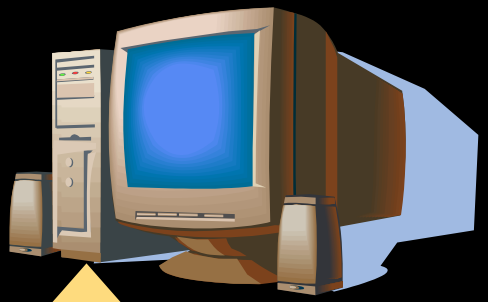
  Temporary Variables: `$t0 - $t7`

  Zero: `$zero`

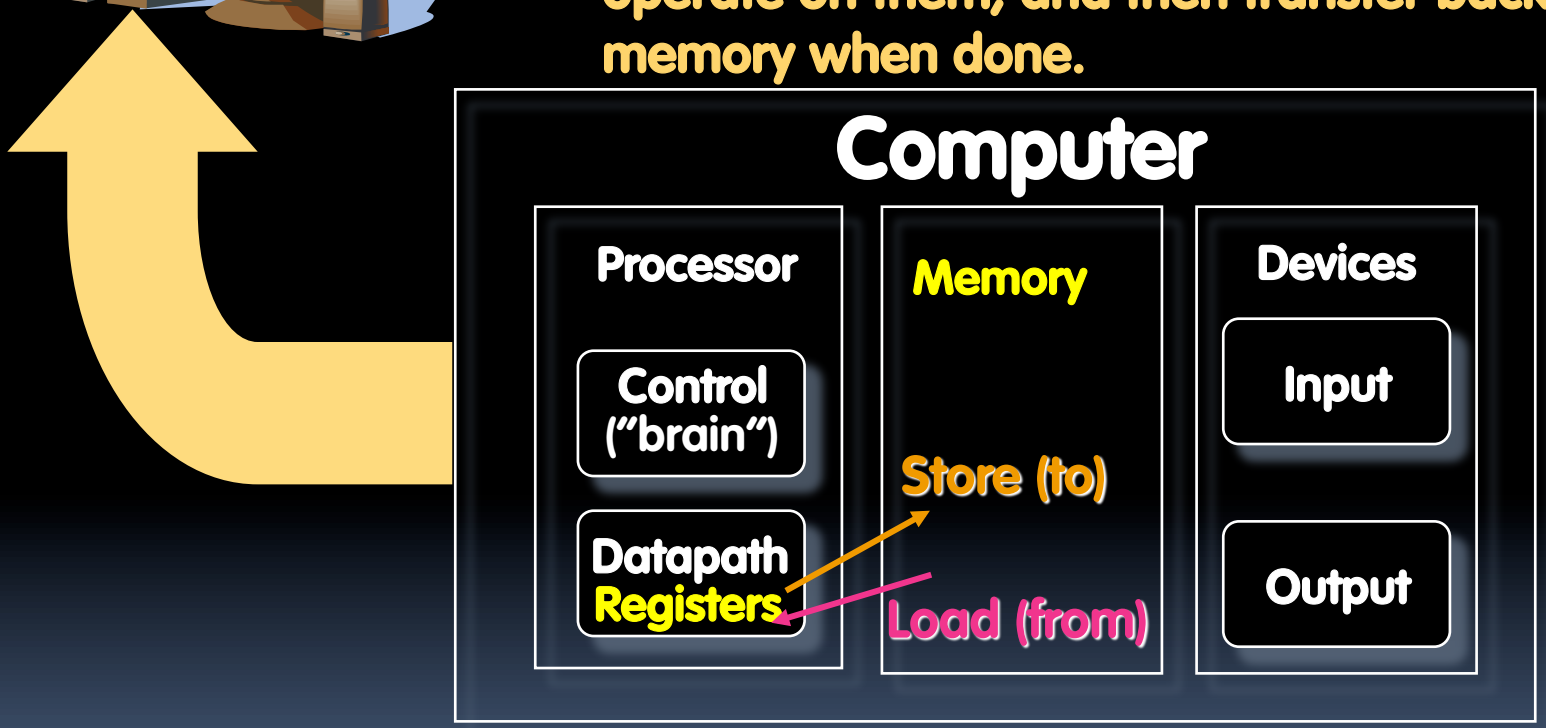
Assembly Operands: Memory

- 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 number `($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)

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 (note offset must be a constant known at assembly time)

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 is stored at a time)

- **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 addr), and so on**
  - E.g., If you write: `add $t2,$t1,$t0`
    then `$t0` and `$t1` better contain values that can be added
  - E.g., 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.
  - Also, 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

Last hex digit of address is:

0, 4, 8, or C_{hex}

1, 5, 9, or D_{hex}

2, 6, A, or E_{hex}

3, 7, B, or F_{hex}

- Called Alignment: objects 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 variables 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

Administrivia

- **Midterm scheduled 2013-03-04 @ 7-9pm**
  - Rooms TBA

So Far...

- All instructions so far only manipulate data...we've built a calculator of sorts.
- In order to build a computer, we need ability to make decisions...
- C (and MIPS) provide labels to support "`goto`" jumps to places in code.
  - C: Horrible style; MIPS: Necessary!

- Heads up: pull out some papers and pens, you'll do an in-class exercise!

C Decisions: if Statements

- 2 kinds of if statements in C

```
if (condition) clause
if (condition) clause1 else clause2
```

- Rearrange 2nd if into following:

```
if   (condition) goto L1;
   clause2;
      goto L2;
L1: clause1;
L2:
```

- Not as elegant as if-else, but same meaning

MIPS Decision Instructions

- **Decision instruction in MIPS:**

```
beq   register1, register2, L1
```

beq is "Branch if (registers are) equal"

Same meaning as (using C):

if (register1==register2) goto L1

- **Complementary MIPS decision instruction**

```
bne   register1, register2, L1
```

bne is "Branch if (registers are) not equal"

Same meaning as (using C):

```
if  (register1!=register2) goto L1
```

- **Called conditional branches**

MIPS Goto Instruction

- In addition to conditional branches, MIPS has an unconditional branch:

```
j label
```

- Called a Jump Instruction: jump (or branch) directly to the given label without needing to satisfy any condition
- Same meaning as (using C): `goto label`
- Technically, it's the same effect as:

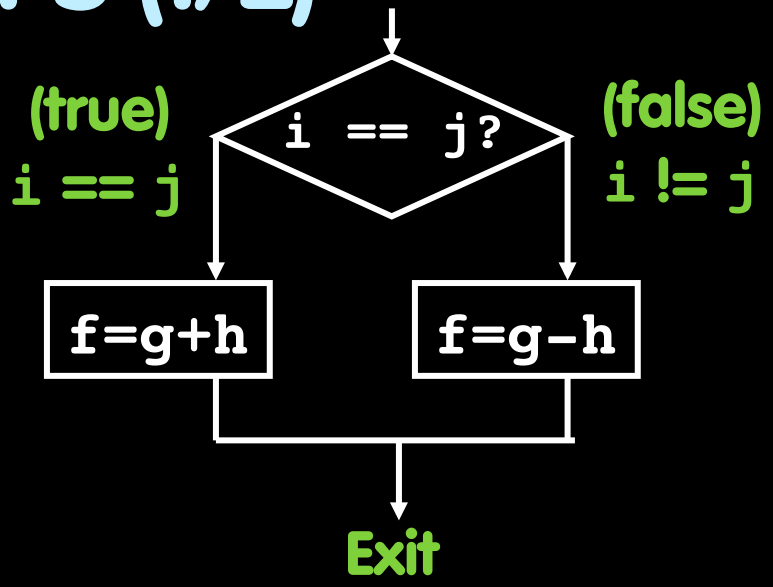
```
beq $0,$0,label
```

since it always satisfies the condition.

Compiling C if into MIPS (1/2)

- Compile by hand

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



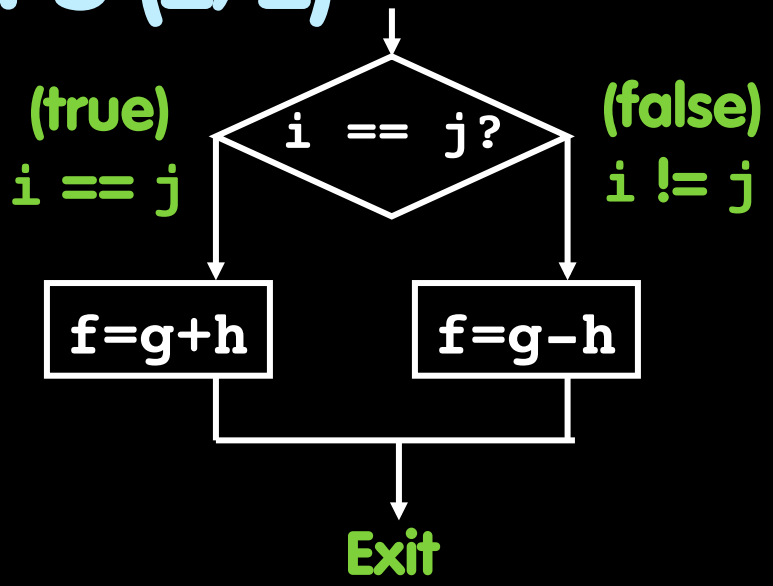
- Use this mapping:

```
f: $s0
g: $s1
h: $s2
i: $s3
j: $s4
```

Compiling C if into MIPS (2/2)

- Compile by hand

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



- Final compiled MIPS code:

```
      beq $s3,$s4,True   # branch i==j
      sub $s0,$s1,$s2    # f=g-h(false)
      j   Fin            # goto Fin
True: add $s0,$s1,$s2    # f=g+h (true)
Fin:
```

Note: Compiler automatically creates labels to handle decisions (branches). Generally not found in HLL code.

Peer Instruction

We want to translate `*x = *y` into MIPS
(x, y ptrs stored in: `$s0 $s1`)

```
1: add $s0,    $s1, zero
2: add $s1,    $s0, zero
3: lw  $s0, 0($s1)
4: lw  $s1, 0($s0)
5: lw  $t0, 0($s1)
6: sw  $t0, 0($s0)
7: lw  $s0, 0($t0)
8: sw  $s1, 0($t0)
```

a) 1 or 2
b) 3 or 4
c) 5→6
d) 6→5
e) 7→8

"And in Conclusion…"

- 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, we can add to it or subtract from it (using offset).
- A Decision allows us to decide what to execute at run-time rather than compile-time.
- C Decisions are made using conditional statements within `if`, `while`, `do while`, `for`.
- MIPS Decision making instructions are the conditional branches: `beq` and `bne`.
- New Instructions:

```
lw, sw, beq, bne, j
```