CS61C : Machine Structures

Lecture 9 – Introduction to MIPS Data Transfer & Decisions I

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Future HVD 1 TB disks! ⇒

The future of digital storage (<u>past</u> the DVD, Blu-Ray and HD DVD) may be the Holographic Versatile Disc. A massive 1 TB on each (200 DVDs)!

www.zdnet.com.au/news/hardware/0,2000061702,39180148,00.htm

Review

- 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: `$t0` - `$t7`

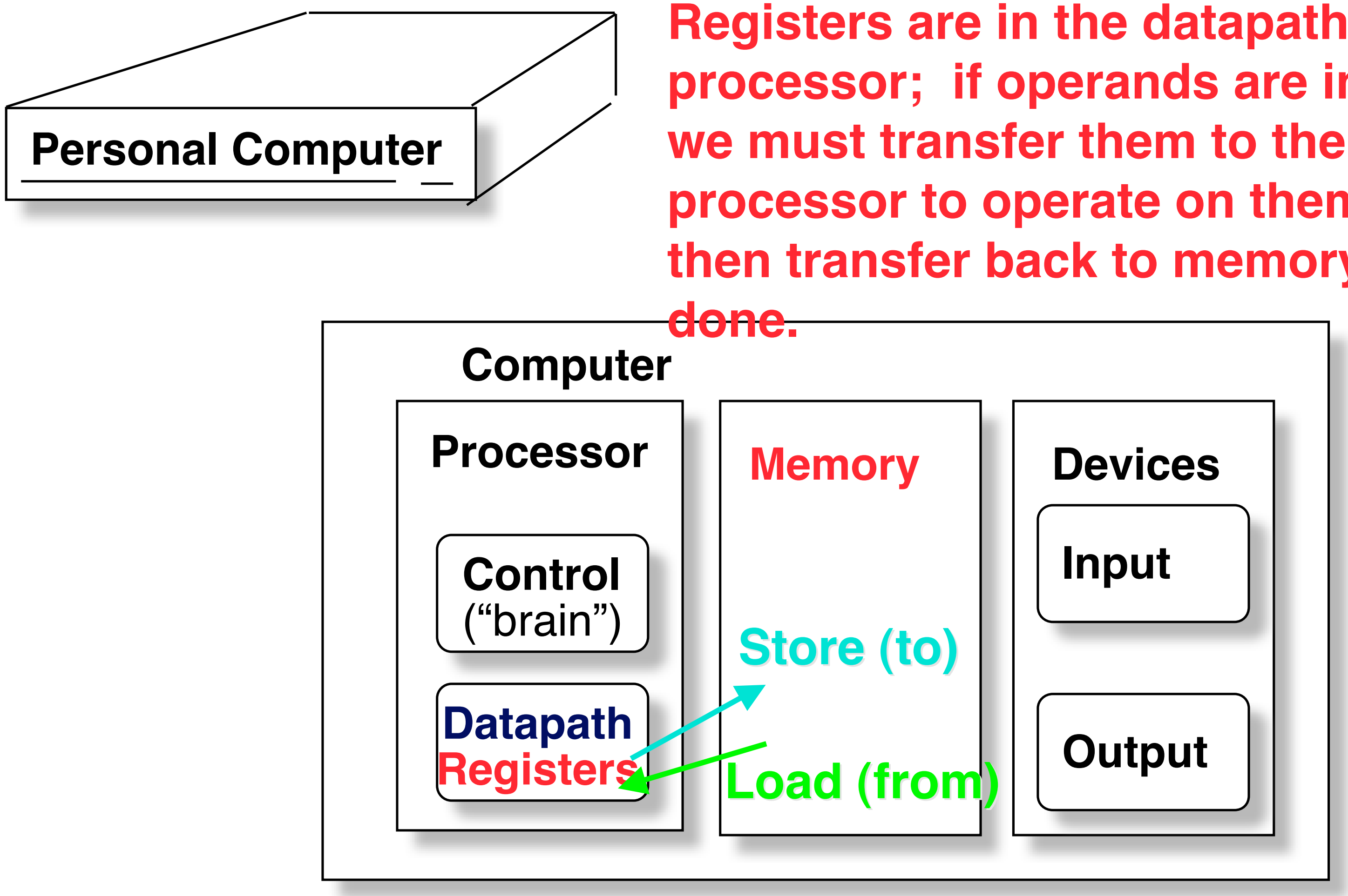
  Zero: `$zero`

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 # ($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

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)

- 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`

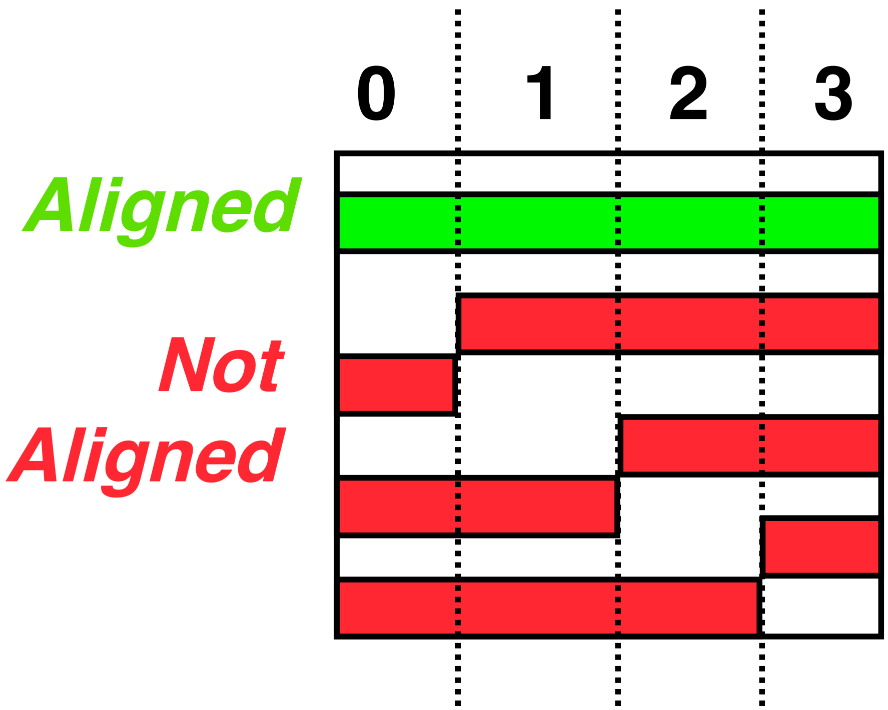
```
add $s1,$s2,$t0   # $s1 = h+A[5]
```

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



Last hex digit of address is:

$0, 4, 8, \text{ or } C_{hex}$

$1, 5, 9, \text{ or } D_{hex}$

$2, 6, A, \text{ or } E_{hex}$

$3, 7, B, \text{ or } F_{hex}$

- Called <u>Alignment</u>: 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**

Administrivia

- **HW3 due Wed @ 23:59**
- **Project 1 up soon, due in 10 days**
  - **Hope you remember your Scheme!**
- `gcc -o foo foo.c`
  - **We shouldn't see any `a.out` files anymore now that you've learned this!**

So Far...

- All instructions so far only manipulate data...we've built a calculator.
- 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:

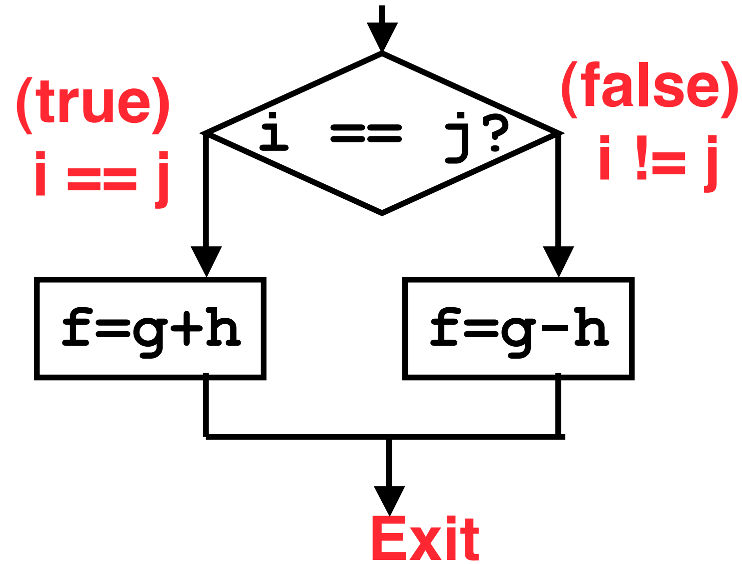
```
j    label
```

- 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 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;
```



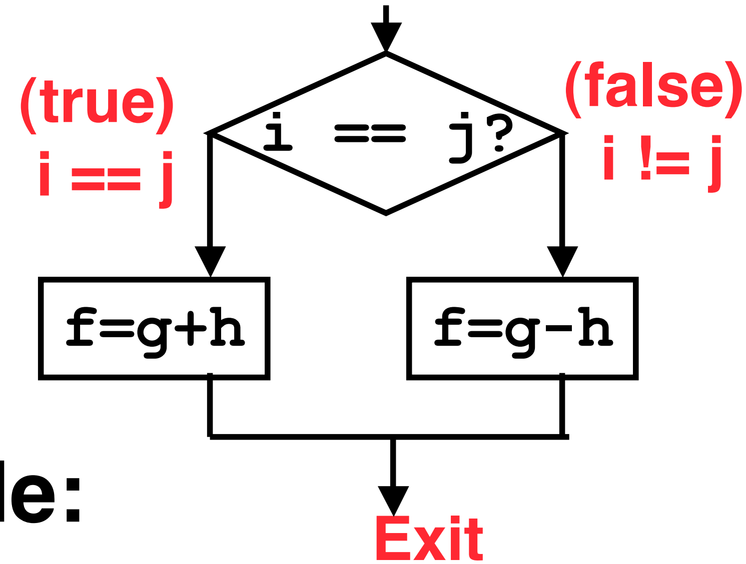
- **Use this mapping:**

```
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`)

```
A: add $s0,   $s1, zero
B: add $s1,   $s0, zero
C: lw  $s0, 0($s1)
D: lw  $s1, 0($s0)
E: lw  $t0, 0($s1)
F: sw  $t0, 0($s0)
G: lw  $s0, 0($t0)
H: sw  $s1, 0($t0)
```

```
1: A
2: B
3: C
4: D
5: E→F
6: E→G
7: F→E
8: F→H
9: H→G
0: G→H
```

"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, so 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
```