

CS61C – Machine Structures

Lecture 9 - MIPS Load/Store & Branch Instructions

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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

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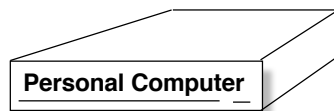
Assembly Operands: Memory

- 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

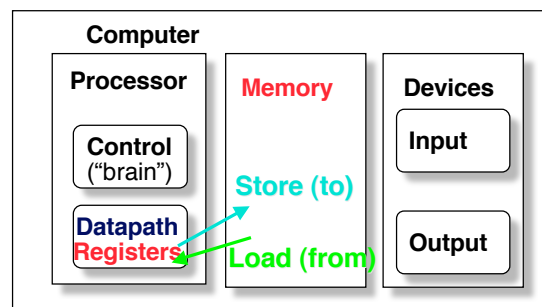
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Anatomy: 5 components of any Computer



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...

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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 (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)

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], ...`

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Compilation with Memory

- What offset in $1w$ to select `A[5]` in C?
- $4 \times 5 = 20$ 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]`

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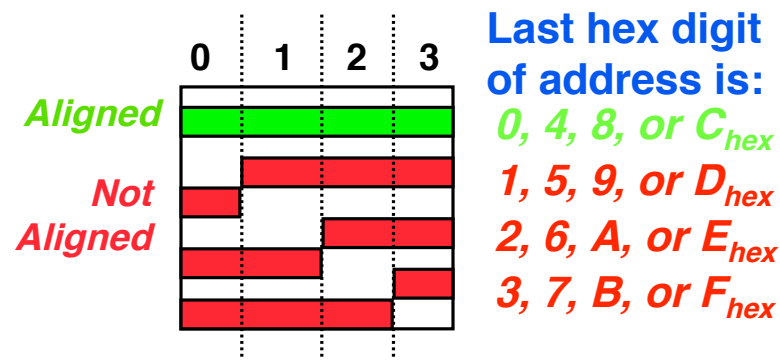
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Notes about Memory

- **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 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

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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!**

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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.

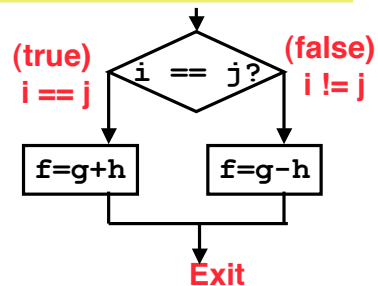
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Compiling C if into MIPS (1/2)

- 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
```

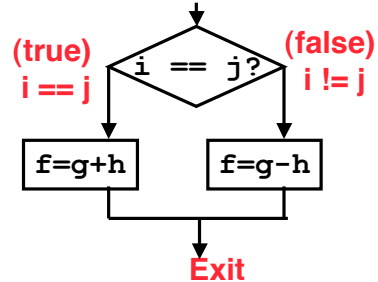
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Compiling C if into MIPS (2/2)

- 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.

“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`