

**Lecture 9 – Introduction to MIPS
Data Transfer & Decisions I**



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There is **one** handout today at the front and back of the room!

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Human-assisted searching ⇒

A new search engine company is betting that a FREE human-assistant will be worth the ad-revenue they get from the Google ads on the right. I tried it, was sent to 3 "guides" (each didn't have access to the previous chat transcript...grr!) but all ended well!



Guide Session

Cheryl L: Welcome to Chacha! Please wait a moment while I search for your results.

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www.chacha.com
technologyreview.com/Infotech/18132/

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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



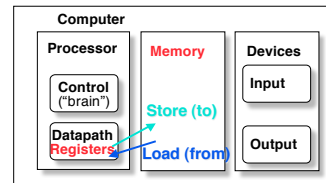
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Anatomy: 5 components of any Computer



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"

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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



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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)



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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)).



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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”



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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!



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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 `lw` 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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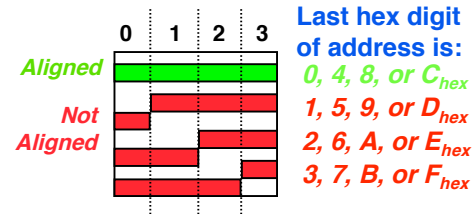
Notes about Memory

- **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



- 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

- Project 1 due this Sun @ 11:59pm
- Other administrivia?



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
```

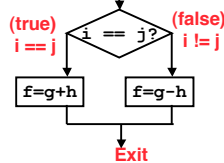


since it always satisfies the condition.

Compiling C if into MIPS (1/2)

- Compile by hand

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



- Use this mapping:

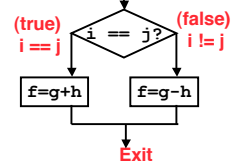
```
f: $s0
g: $s1
h: $s2
i: $s3
j: $s4
```



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)

```
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)
```

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