IC220
SlideSet #2: Instructions
(Chapter 2)

Credits: Much course material in some way derived from…
Official textbook (Copyright Morgan Kaufmann)
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Chapter Goals

- Teach a subset of MIPS assembly language
- Introduce the stored program concept
- Explain how MIPS instructions are represented in machine language
- Illustrate basic instruction set design principles

Instructions:

- Language of the Machine
- More primitive than higher level languages
- Very restrictive
  e.g., MIPS Arithmetic Instructions
- We'll be working with the MIPS instruction set architecture
  - similar to other architectures developed since the 1980's
  - used by Tivo, Cisco routers, Nintendo 64, Sony PlayStation…

Design principles: to be found…
Design goals:

MIPS arithmetic

- All instructions have 3 operands
- Operand order is fixed

Example:

C code: `A = B + C`

MIPS code: `add $s0, $s1, $s2`

MIPS arithmetic

- **Design Principle #1: simplicity favors regularity. Why?**
- **Of course this complicates some things...**

C code:

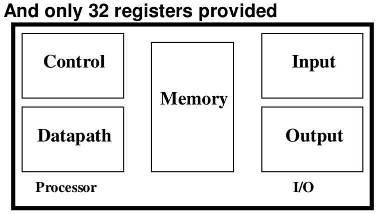
```
A = B + C + D;
E = F - A;
```

MIPS code:

```
add $t0, $s1, $s2
add $s0, $t0, $s3
sub $s4, $s5, $s0
```


Registers vs. Memory

- **Design Principle #2: smaller is faster. Why?**
- **Therefore, arithmetic instruction operands must be "registers"**
  - **And only 32 registers provided**



- **Compiler associates variables with registers**
- **What about programs with lots of variables?**

Memory Organization

- **Viewed as a large, single-dimension array, with an address.**
- **A memory address is an index into the array**
- **"Byte addressing" means that the index points to a byte of memory.**

0	8 bits of data
1	8 bits of data
2	8 bits of data
3	8 bits of data
4	8 bits of data
5	8 bits of data
6	8 bits of data
...	

Memory Organization

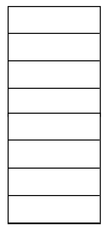
- **Bytes are nice, but most data items use larger "words"**
- **For MIPS, a word is 32 bits or 4 bytes.**

0	32 bits of data
4	32 bits of data
8	32 bits of data
12	32 bits of data
...	

Registers hold 32 bits of data

- **2^{32} bytes with byte addresses from 0 to $2^{32}-1$**
- **2^{30} words with byte addresses 0, 4, 8, ... $2^{32}-4$**
- **Words are aligned**
  i.e., what are the least 2 significant bits of a word address?

Array layout in memory



Memory Instructions

- **Load and store instructions**
- **Example:**

C code: `A[8] = h + A[8];`

MIPS code:

```
lw  $t0, 32($s3)
add $t0, $s2, $t0
sw  $t0, 32($s3)
```

- **For lw/sw, address always = register value + offset**
- **How about this?**

```
add $t0, 32($s3), $t0
```


So far we've learned:

- **MIPS**
  - **— loading words but addressing bytes**
  - **— arithmetic on registers only**

- **<u>Instruction</u>** **<u>Meaning</u>**

Instruction	Meaning
`add $s1, $s2, $s3`	`$s1 = $s2 + $s3`
`sub $s1, $s2, $s3`	`$s1 = $s2 – $s3`
`lw $s1, 100($s2)`	`$s1 = Memory[$s2+100]`
`sw $s1, 100($s2)`	`Memory[$s2+100] = $s1`

Machine Language

- **Instructions, like registers and words of data, are also 32 bits long**
  - **Example:** `add $t0, $s1, $s2`
  - **registers have numbers,** `$t0=8, $s1=17, $s2=18`

- **Instruction Format (r-type):**

000000	10001	10010	01000	00000	100000

op	rs	rt	rd	shamt	funct

Machine Language

- Consider the load-word and store-word instructions,
  - What would the regularity principle have us do?
  - Principle #3: Make the common case fast

  - Principle #4: Good design demands a compromise
- Introduce a new type of instruction format
  - I-type for data transfer instructions
- Example: `lw $t0, 44($s2)`

35	18	8	44

op	rs	rt	16 bit number

- Where's the compromise?

Example Part 1

- What is the machine code for the following:

A[300] = h + A[300];

Variable h is assigned register $s2
Array A base address is assigned register $t1

- Do the assembly code first, then machine language instructions, and then machine code

Example Part 2

- What is the machine code for the following: A[300] = h + A[300];
  - Variable h is assigned register $s2 & Array A base address is assigned register $t1
- First part of answer:
  lw $t0, 1200($t1) # Temporary reg $t0 gets A[300]
  add $t0, $s2, $t0 # Temporary reg $t0 gets h + A[300]
  sw $t0, 1200($t1) # Stores h + A[300] back into A[300]
- Second part of answer (DECIMAL):

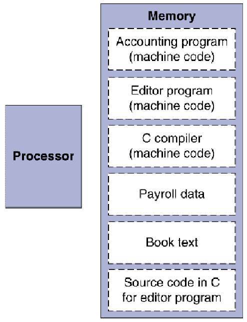
op	rs	rt	rd	shamt	funct
35	9	8	1200		
0	18	8	8	0	32
43	9	8	1200		

Example Part 3

- What is the machine code for the following: A[300] = h + A[300];
  - Variable h is assigned register $s2 & Array A base address is assigned register $t1
- First part of answer:
  lw $t0, 1200($t1) # Temporary reg $t0 gets A[300]
  add $t0, $s2, $t0 # Temporary reg $t0 gets h + A[300]
  sw $t0, 1200($t1) # Stores h + A[300] back into A[300]
- Second part of answer (BINARY):

op	rs	rt	rd	shamt	funct
100011	01001	01000	0000 0100 1011 0000		
000000	10010	01000	01000	00000	100000
101011	01001	01000	0000 0100 1011 0000		

Stored Program Computers



- Instructions represented in binary, just like data
- Instructions and data stored in memory
- Programs can operate on programs
  - e.g., compilers, linkers, …
- Binary compatibility allows compiled programs to work on different computers
  - Standardized ISAs

- Fetch & Execute Cycle
  - Instructions are fetched and put into a special register
  - Bits in the register "control" the subsequent actions
  - Fetch the “next” instruction and continue

QUICK REVIEW

- Design Principles
  - 4 of them
- Arithmetic
  - Operands
  - Order
  - Location of data
- Register
  - MIPS provides
- Memory
  - Organization
  - Bits / Bytes / Words
  - Alignment