COMP 303
Computer Architecture
Lecture 2

Hardware Operations

- Every computer must be able to perform arithmetic

```
add a, b, c
```

- In order to do a = b+c+d+e

```
add a, b, c     # Sum of b+c to a
add a, a, d     # Sum of b+c+d to a
add a, a, e     # Sum of b+c+d+e to a
```

Hardware operations

- # is used for comments (until the end of line)
- The natural number of operands for an operation like addition is three.

Design Principle 1: Simplicity favors regularity

Compiling a complex C assignment into MIPS

f=(g+h)-(i+j)

```
add t0, g, h # temporary variable t0 contains g+h
add t1, i, j # temporary variable t1 contains i+j
sub f, t0, t1# f gets t0-t1
```

MIPS Assembly Language

- Arithmetic operations
  - add. Usage: `add a,b,c` Meaning: a=b+c
  - sub. Usage: `sub a,b,c` Meaning: a=b-c

Operands of the hardware

- Operands of the instructions are from a limited number of special locations called registers
- The size of registers in MIPS is 32 bit.
- The word size in MIPS is 32 bit.
- MIPS has 32 registers. The reason of 32 registers in MIPS is

Design Principle 2: Smaller is faster

Compiling a C assignment using registers

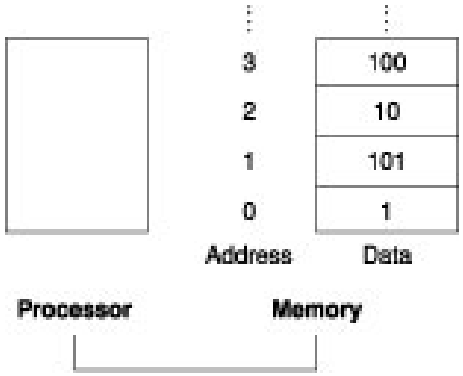
f=(g+h)-(i+j)

- The variables f, g, h, i and j are assigned to the registers $s0, $s1, $s2, $s3 and $s4, respectively

```
add $t0, $s1, $s2 # temporary variable t0 contains g+h
add $t1, $s3, $s4 # temporary variable t1 contains i+j
sub $s0, $t0, $t1 # f gets t0-t1
```

Memory operands

- MIPS must include instructions that transfer data between memory and registers:
  - Data transfer instructions



Compiling an assignment when an operand is in memory

- g = h + A[8]
- We can add two numbers when they are in registers. So transfer the memory data (A[8])into a register.
- Assume the base address of the array is stored in $s3

```
lw $t0,8($s3) # temp reg $t0 gets A[8]
```

- A[8] is in $t0

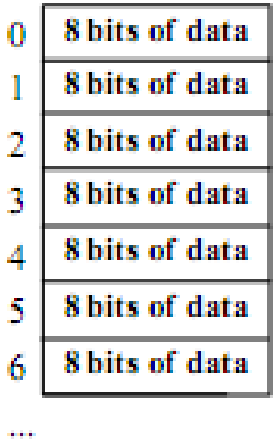
```
add $s1, $s2, $t0 # g = h + A[8]
```

Offset

Base register

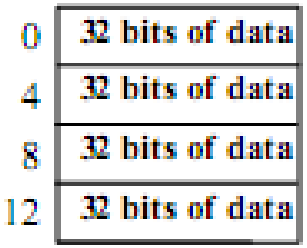
Memory organization

- 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.



Memory organization

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

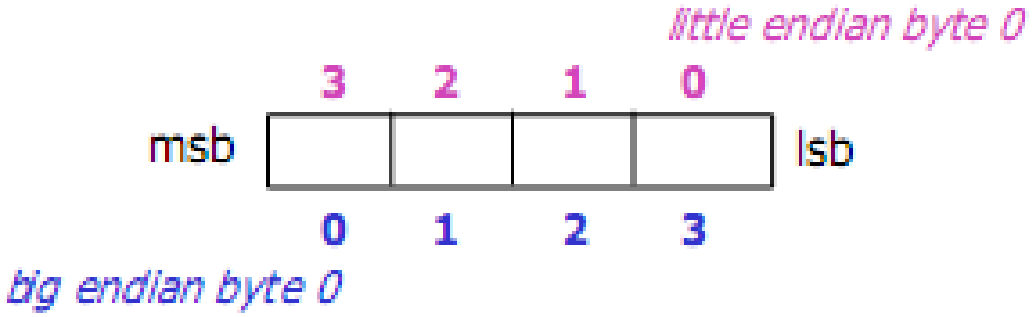


- 2^{32} bytes with byte addresses from 0 to 2^{32-1}
- 2^{30} words with byte addresses 0, 4, 8, ... 2^{32-4}

Hardware/Software Interface

- In MIPS, words must start at addresses that are multiple of 4
  - *Alignment restriction*
- Computers divide into those that use the address of the leftmost (or "big end") byte as the word address versus that use the rightmost (or "little end") byte.
- MIPS is big-endian. In order to get A[8] we should load 32nd byte (which is the 8.th word)

Alignment



Alignment: require that objects fall on address that is multiple of their size.

Load and Store

- Assume h is in $s2. The base address of the array A is in $s3.

A[12] = h + A[8]

```
lw $t0,32($s3)    # Temporary reg $t0 gets A[8]
add $t0, $s2, $t0 # Temporary reg $t0 gets h+A[8]
sw $t0, 48($s3)   # Stores h+A[8] back into A[12]
```

Constant or immediate operands

- Adding constants to registers.
- Two way:
  - Load the constant from the memory location
  - Add immediate

```
addi $s3, $s3, 4  # $s3 = $s3 + 4
```

  - Constant operands occur frequently

Design Principle 3: Make the common case fast

- There is no subtract immediate! Why?

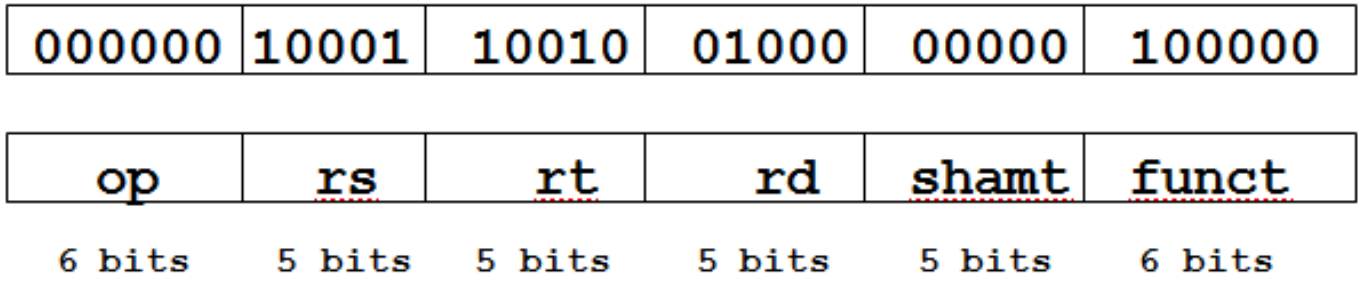
Representing insturctions in the computer

- Since all kind of information is stored in computer as binary digits (*bits*) there should be binary representations of instructions.
- Mapping of register names into numbers.
- In MIPS assembly language
  - registers $s0 to $s7 map onto register numbers 16 to 23
  - registers $t0 to $t7 map onto register numbers 8 to 15

Translating a MIPS Assembly instruction into a machine instruction

- `add $t0, $s1, $s2`
- registers have numbers, `$t0=8, $s1=17, $s2=18`

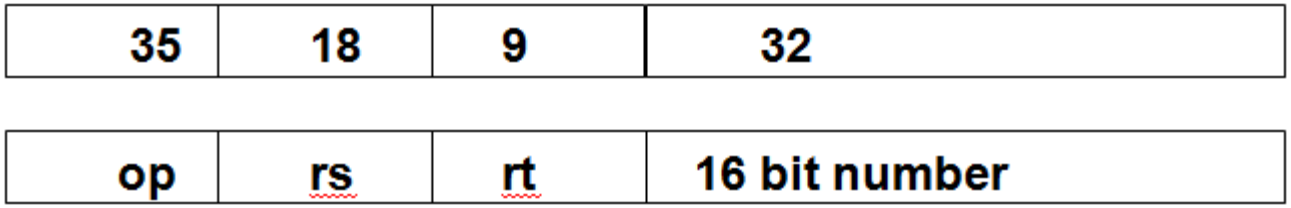
- Instruction Format:



- op: operation code (opcode)
- rs: the first register source operand
- rt: the second register source operand
- rd: the register destination operand
- shamt: shift amount. Used in shift operations
- funct: function. Specific variant of the opcode (function code)

Instruction formats

- R-type (for register) or R-format
- I-type (for immediate) or I-format
  - Example: `lw $t0, 32($s2)`



- The formats are distinguished by the values in the first field

Logical operations

Instruction	Example	Meaning
And	and $s1,$s2,$s3	$s1 = $s2 & $s3
Or	or $s1,$s2,$s3	$s1 = $s2 | $s3
Nor	nor $s1,$s2,$s3	$s1 = ~($s2 | $s3)
And immediate	andi $s1,$s2,100	$s1 = $s2 & 100
Or immediate	ori $s1,$s2,100	$s1 = $s2 | 100
Shift left logical	sll $s1,$s2,10	$s1 = $s2<<10
Shift right logical	srl $s1,$s2,10	$s1 = $s2>>10

Branch instructions

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

- goes to L1 if register1 == register2

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

- goes to L1 if register1 != register2

if-then-else

- Replace the C code for

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

by equivalent MIPS instructions.

- Assume variables f through j correspond to registers $s0 through $s4.

```
   Instruction                  Comment
        bne $s3, $s4, Else      if (i != j) goto Else
        add $s0, $s1, $s2       f = g + h
        j Exit                  go to Exit
Else:   sub $s0, $s1, $s2       f = g - h
Exit:
```

Jump to Exit

For loop

- Branch instructions end up the way we implement C-style loops

```
for ( j = 0; j < 10; j++) {
   a = a + j;
}
```

- assume s0 == j; s1 == a; t0 == temp;

```
Instruction                    Comment
       addi $s0, $zero, 0      j = 0 + 0
       addi $t0, $zero, 10     temp = 0 + 10
Loop:  beq $s0, $t0, Exit      if (j == temp) goto Exit
       add  $s1, $s1, $s0      a = a + j
       addi $s0, $s0, 1        j = j + 1
       j    Loop               goto Loop
Exit:  …                       exit from loop and continue
```

Set on less than

```
slt $t0, $s3, $s4
```

- Register $t0 is set to 1 if the value in register $s3 is less than the value in register $s4

```
slti $t0, $s3, 10
```

- Register $t0 is set to 1 if the value in register $s3 is less than the immediate value 10