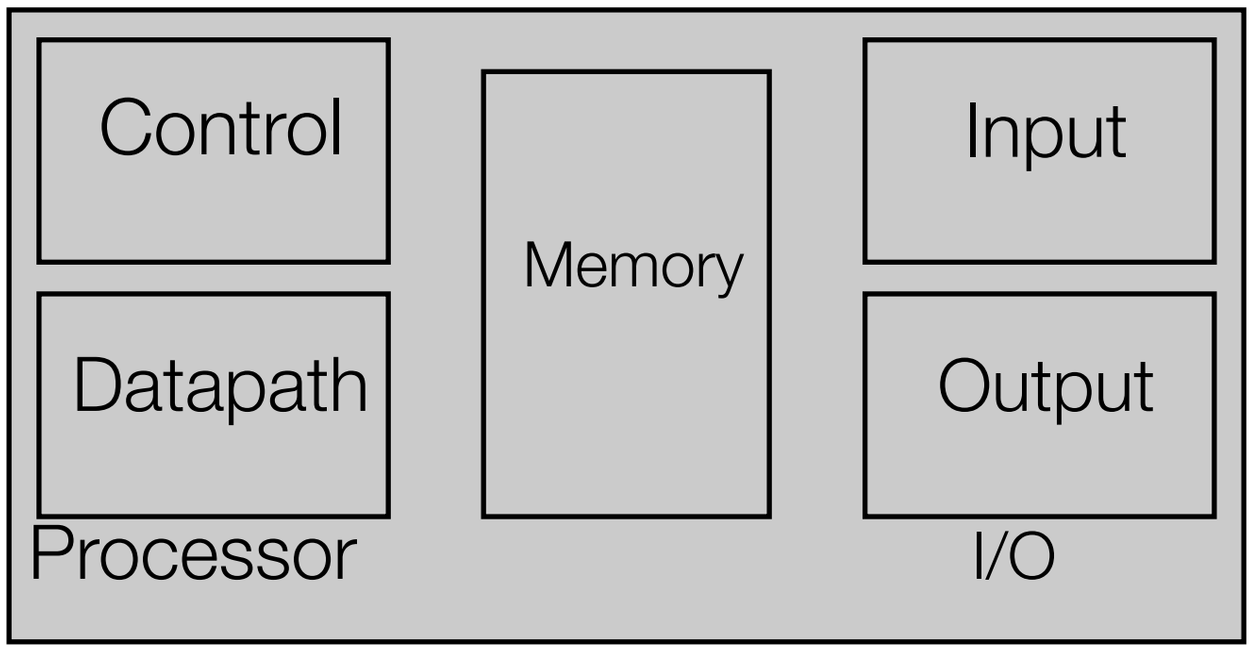
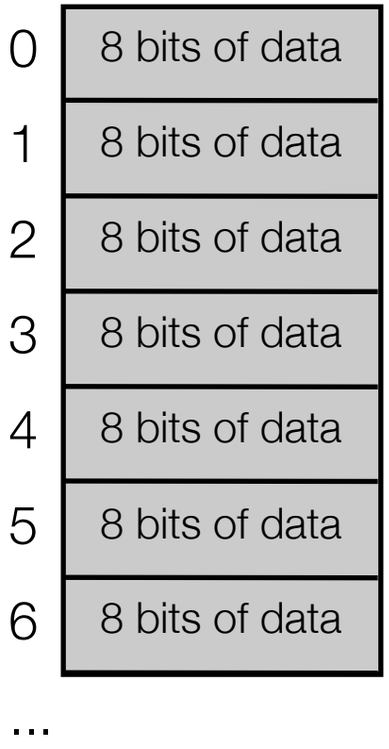
# Registers vs. Memory

- Arithmetic instructions operands must be registers,
  — only 32 registers provided
- Each register: 32 bits = 4 bytes = 1 **word**
- 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.

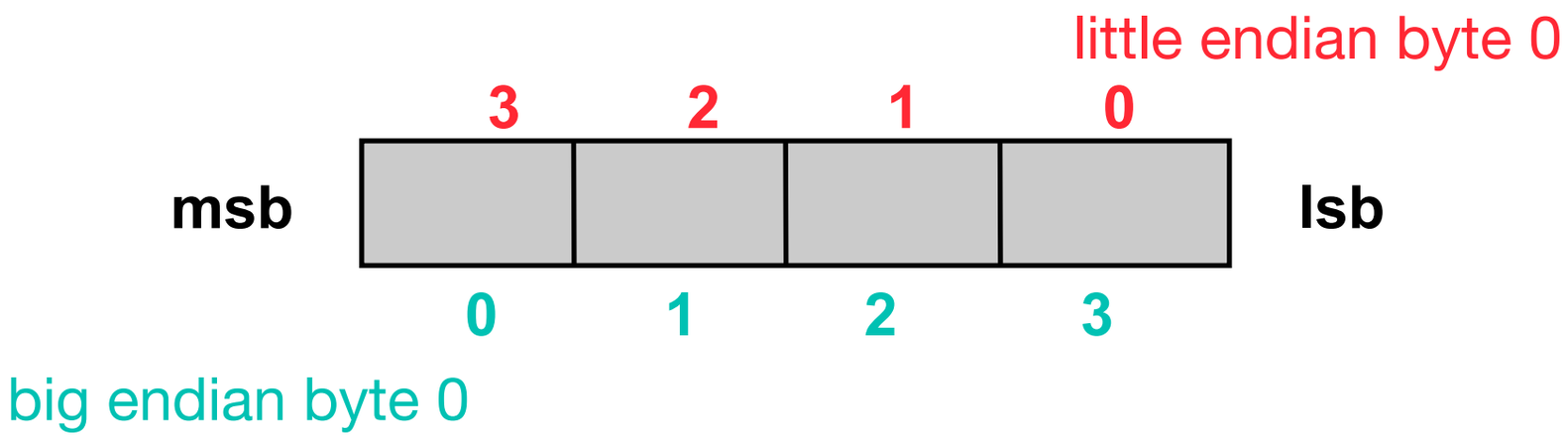


# Byte Addresses

- Since 8-bit bytes are so useful, most architectures address individual bytes in memory
  - MIPS: memory address of a word must be multiple of 4 (alignment restriction)
- Big Endian: leftmost byte is word address

  IBM 360/370, Motorola 68k, MIPS, Sparc, HP PA
- Little Endian: rightmost byte is word address

  Intel 80x86, DEC Vax, DEC Alpha (Windows NT)



# Instructions: a simple example

- A C statement

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

- `f, g, h, i, j` are assigned to `$s0, $s1, $s2, $s3, $s4`

```
add $t0, $s1, $s2
add $t1, $s3, $s4
sub $s0, $t0, $t1
```

# Load and store instructions

- Load and store instructions

- **`lw $tn, c_off($S_base)`**
- **`sw $tn, c_off($S_base)`**

$tn : destination register
$S_base : register with base address
c_off : offset from base

- Example:

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

MIPS code:
```
lw $t0, 32($s3)
add $s1, $s2, $t0
```

g : $s1
h : $s2
base address of A : $s3

- Spilling registers
  - *doubly* slow

# Load and store instructions

- Example:

C code: `A[12] = h + A[8];`

MIPS code:

```
lw $t0, 32($s3)
add $t0, $s2, $t0
sw $t0, 48($s3)
```

- Store word has **destination last**
- Remember: arithmetic operands are **registers**, not memory!

Can’t write: `add 48($s3), $s2, 32($s3)`

# So far we've learned:

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

- 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
```

# Constants

- To use a constant, have to use memory, just like for variables
- Example: add **`4`** to register **`$s3`**

```
lw $t0, AddrConstant4($s1)   # t0 is the constant 4

add $s3, $s3, $t0
```

- Quick add instruction: **`addi`**

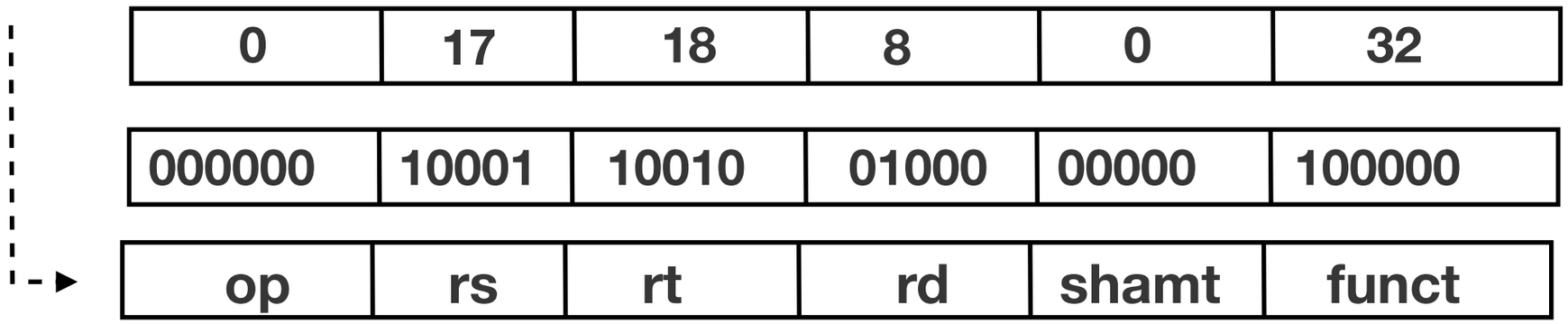
```
addi  $s3, $s3, 4
```

- Design principle: make the common case fast

# Representing Instructions in the Computer
# **Machine Language**

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

- **Instruction Format**:



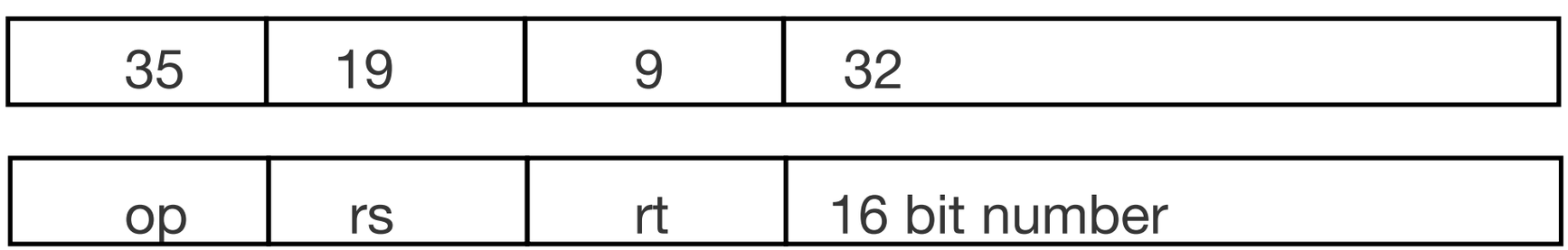

| | | |
|---|---|---|
| op | 6-bits | opcode that specifies the operation |
| rs | 5-bits | register file address of the first source operand |
| rt | 5-bits | register file address of the second source operand |
| rd | 5-bits | register file address of the result's destination |
| shamt | 5-bits | shift amount (for shift instructions) |
| funct | 6-bits | function code augmenting the opcode |

# Aside:  MIPS Register Convention

| Name | Register Number | Usage | Preserve on call? |
|---|---|---|---|
| $zero | 0 | constant 0 (hardware) | n.a. |
| $at | 1 | reserved for assembler | n.a. |
| $v0 - $v1 | 2-3 | returned values | no |
| $a0 - $a3 | 4-7 | arguments | yes |
| $t0 - $t7 | 8-15 | temporaries | no |
| $s0 - $s7 | 16-23 | saved values | yes |
| $t8 - $t9 | 24-25 | temporaries | no |
| $gp | 28 | global pointer | yes |
| $sp | 29 | stack pointer | yes |
| $fp | 30 | frame pointer | yes |
| $ra | 31 | return addr (hardware) | yes |

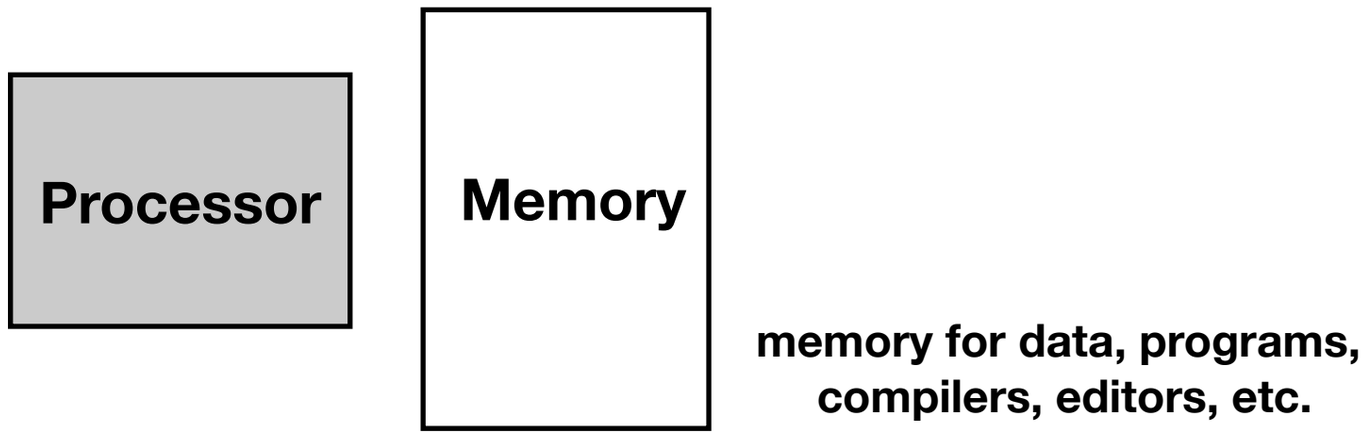
# Machine Language

- What if an instruction needs longer fields
  - e.g.: in **`lw`**, address of constant may be more than 32 ($2^5$)
  - conflict: keep instruction length same vs. have a single instruction format
  - New principle: *Good design demands a compromise*
  - Here: different formats for different instructions (keep length same)
- Introduce a new type of instruction format
  - I-format for data transfer instructions and immediate instructions
  - other format was R-format for register
- Example: **`lw $t0, 32($s3)`**



# Stored Program Concept

- Instructions are bits
- Programs are stored in memory
  — to be read or written just like data




- 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