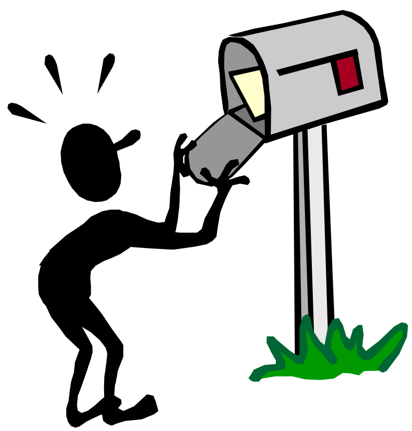
Operands and Addressing Modes



- Where is the data?
- Addresses as data
- Names and Values
- Indirection

Last Time - "Machine" Language

32-bit (4-byte) ADD instruction:

op = R-type	Rs	Rt	Rd		func = add
0 0 0 0 0 0	0 0 1 0 0	0 0 0 1 0	0 0 0 1 1	0 0 0 0 0	1 0 0 0 0 0

Means, to MIPS, Reg[3] = Reg[4] + Reg[2]

But, most of us would prefer to write

```
add $3, $4, $2
```

(ASSEMBLER)

or, better yet,

```
a = b + c;
```

(C)

Revisiting Operands

- Operands – the variables needed to perform an instruction's operation
- Three types in the MIPS ISA:
  - Register:

    add $2, $3, $4   # operands are the "Contents" of a register
  - Immediate:

    addi $2,$2,1   # 2^{nd} source operand is part of the instruction
  - Register-Indirect:

    lw $2, 12($28)   # source operand is in memory

    sw $2, 12($28)   # destination operand is memory
- Simple enough, but is it enough?

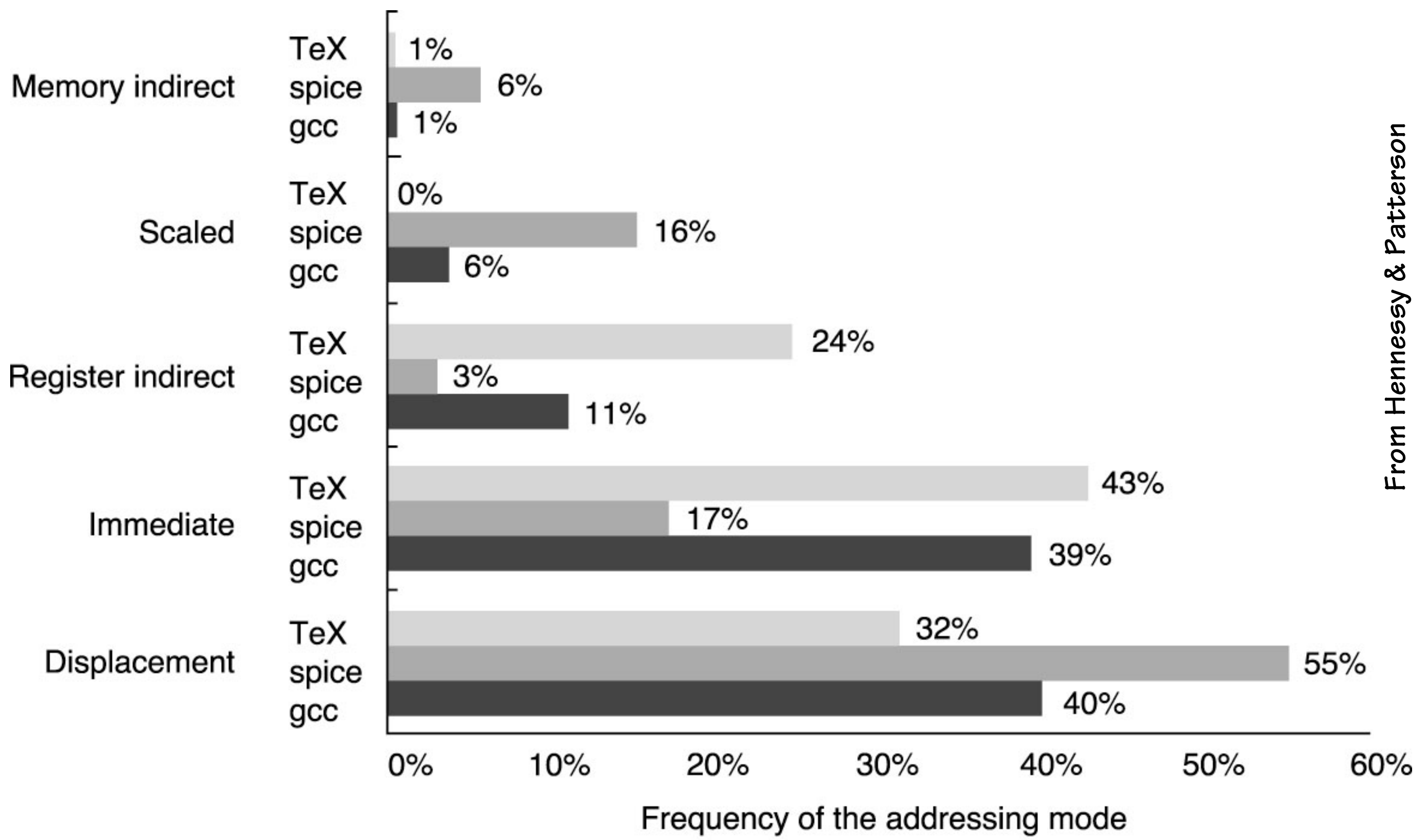
Common "Addressing Modes"

MIPS can do these with appropriate choices for Ra and const

- Absolute (Direct): `lw $8, 0x1000($0)`
  - Value = Mem[constant]
  - Use: accessing static data
- Indirect: `lw $8, 0($9)`
  - Value = Mem[Reg[x]]
  - Use: pointer accesses
- Displacement: `lw $8, 16($9)`
  - Value = Mem[Reg[x] + constant]
  - Use: access to local variables
- Indexed:
  - Value = Mem[Reg[x] + Reg[y]]
  - Use: array accesses (base+index)
- Memory indirect:
  - Value = Mem[Mem[Reg[x]]]
  - Use: access thru pointer in mem
- Autoincrement:
  - Value = Mem[Reg[x]]; Reg[x]++
  - Use: sequential pointer accesses
- Autodecrement:
  - Value = Reg[X]--; Mem[Reg[x]]
  - Use: stack operations
- Scaled:
  - Value = Mem[Reg[x] + c + d*Reg[y]]
  - Use: array accesses (base+index)

Argh! Is the complexity worth the cost?
Need a cost/benefit analysis!

Memory Operands: Usage



From Hennessy & Patterson

Usage of different memory operand modes

Absolute (Direct) Addressing

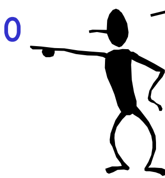
- What we want:
  - The contents of a specific memory location
- Examples:

"C"

```
int x = 10;

main() {
    x = x + 1;
}
```

"MIPS Assembly"

```
main:   lw   $2,x
        addi $2,$2,1
        sw   $2,x
        jr   $31

x: .word 10
```



Allocates space for a single integer (4-bytes) and initializes its value to 10

- Caveats
  - In practice $gp is often used as a base address for variables
  - Can only address the first and last 32K of memory this way
  - Sometimes generates a two instruction sequence:

```
lui  $1,xhighbits
lw   $2,xlowbits($1)
```

An Aside: Let's C

C is an ancestor to many languages commonly used today.
  {Algol, Fortran, Pascal} → C → C++ → Java

C was developed to write the operating system UNIX.

C is still widely used for "systems" programming

C's developers were frustrated that the high-level languages available at the time, lacked the expressiveness and capabilities of assembly code necessary to write an OS.

The advantage of high-level languages is that they are portable (i.e. not ISA specific).

C, thus, was an attempt to create a portable blend of a high -level language and an assembler

C begat Java

C++ was envisioned to add Object-Oriented (OO) concepts on top of C

Java was envisioned to be more purely OO, and hide the details of Class/Method/Member implementation

For our purposes C is almost identical to JAVA except:

C has "functions", whereas JAVA has "methods".

C has explicit variables that contain the addresses of other variables or data structures in memory.

JAVA hides them under the covers.

C pointers

```
int i;       // simple integer variable
int a[10];   // array of integers (a is a pointer)
int *p;      // pointer to integer(s)
```

***(expression)** *is content of address computed by expression.*

a[k] ≡ *(a+k)

a *is a constant of type* "**int ***"

a[k] = a[k+1] ≡ *(a+k) = *(a+k+1)

Other Pointer Related Syntax

```
int i;       // simple integer variable
int a[10];   // array of integers
int *p;      // pointer to integer(s)

p = &i;      // & means address of
p = a;       // no need for & on a
p = &a[5];   // address of 6th element of a
*p           // value of location pointed by p
*p = 1;      // change value of that location
*(p+1) = 1;  // change value of next location
p[1] = 1;    // exactly the same as above
p++;         // step pointer to the next element
```

Legal uses of Pointers

```
int i;          // simple integer variable
int a[10];      // array of integers
int *p;         // pointer to integer(s)
```

So what happens when

```
p = &i;
```

What is value of p[0]?

What is value of p[1]?

C Pointers vs. object size

```
int i;          // simple integer variable
int a[10];      // array of integers
int *p;         // pointer to integer(s)
```

Does "p++" really add 1 to the pointer?
NO! It adds 4. Why 4?

```
char *q;
...
q++; // really does add 1
```

Clear123

```
void clear1(int array[], int size) {
  for(int i=0; i<size; i++)
    array[i] = 0;
}

void clear2(int array[], int size) {
  for(int *p = &array[0]; p < &array[size]; p++)
    *p = 0;
}

void clear3(int *array, int size) {
  while(array < array + size)
    *array++ = 0;
}
```

Pointer summary

- In the "C" world and in the "machine" world:
  - a pointer is just the address of an object in memory
  - size of pointer is fixed regardless of size of object
  - to get to the next object increment by the object's size in bytes
  - to get the the i^{th} object add i*sizeof(object)
- More details:
  - int R[5] ≡ R is int* constant address of 20 bytes storage
  - R[i] ≡ *(R+i)
  - int *p = &R[3] ≡ p = (R+3) (p points 12 bytes after R)

Indirect Addressing

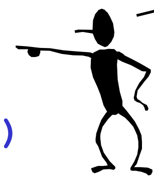
- What we want:
  - The contents of a memory location held in a register
- Examples:

"C"

```
int x = 10;

main() {
    int *y = &x;
    *y = 2;
}
```

"MIPS Assembly"

```
main:    ori   $2,$0,x
         addi  $3,$0,2
         sw    $3,0($2)
         jr    $31

x: .word   10
```



Loads the "address" of x into $2, not its contents

- Caveats
  - You must make sure that the register contains a valid address (double, word, or short aligned as required)

Displacement Addressing

- What we want:
  - The contents of a memory location relative to a register
- Examples:

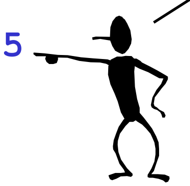
"C"

```
int a[5];

main() {
    int i = 3;
    a[i] = 2;
}
```

"MIPS Assembly"

```
main:   addi $2,$0,3
        addi $3,$0,2
        sll  $1,$2,2
        sw   $3,a($1)
        jr   $31

a:      .space   5
```

Space for a 5 integers (20-bytes)



- Caveats
  - Must multiply (shift) the "index" to be properly aligned

Displacement Addressing: Once More

- What we want:
  – The contents of a memory location relative to a register
- Examples:

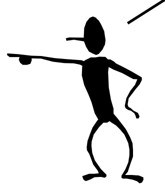
"C"

```
struct p {
   int x, y;
}

main() {
    p.x = 3;
    p.y = 2;
}
```

"MIPS Assembly"

```
main:    ori   $1,$0,p
         addi  $2,$0,3
         sw    $2,0($1)
         addi  $2,$0,2
         sw    $2,4($1)
         jr    $31

p:       .space   8
```

Allocates space for 2 uninitialized integers (8-bytes)



- Caveats
  – Constants offset to the various fields of the structure
  – Structures larger than 32K use a different approach

C/Assembly Translation: Conditionals

C code:

```
if (expr) {
      STUFF
}
```

MIPS assembly:

```
      (compute expr in $rx)
      beq $rx, $0, Lendif
      (compile STUFF)
Lendif:
```

C code:

```
if (expr) {
      STUFF1
} else {
      STUFF2
}
```

MIPS assembly:

```
      (compute expr in $rx)
      beq $rx, $0, Lelse
      (compile STUFF1)
      beq $0, $0, Lendif
Lelse:
      (compile STUFF2)
Lendif:
```

There are little tricks that come into play when compiling conditional code blocks. For instance, the statement:

```
if (y > 32) {
    x = x + 1;
}
```

compiles to:

```
  lw   $24, y
  ori  $15, $0, 32
  slt  $1, $15, $24
  beq  $1, $0, Lendif
  lw   $24, x
  addi $24, $24, 1
  sw   $24, x
Lendif:
```

C/Assembly Translation: Loops

C code:

```
while (expr) {
     STUFF
}
```

MIPS assembly:

```
Lwhile:
      (compute expr in $rx)
      beq $rX,$0,Lendw
      (compile STUFF)
      beq $0,$0,Lwhile
Lendw:
```

Alternate MIPS assembly:

```
      beq $0,$0,Ltest
Lwhile:
      (compile STUFF)
Ltest:
      (compute expr in $rx)
      bne $rX,$0,Lwhile
Lendw:
```

Compilers spend a lot of time optimizing in and around loops.

- moving all possible computations outside of loops
- unrolling loops to reduce branching overhead
- simplifying expressions that depend on “loop variables”

C/Assembly Translation: For Loops

- Most high-level languages provide loop constructs that establish and update an iteration variable, which is used to control the loop's behavior

C code:

```
int sum = 0;

int data[10] =
    {1,2,3,4,5,6,7,8,9,10};


int i;

for (i=0; i<10; i++) {
    sum += data[i]
}
```

MIPS assembly:

```
sum:
    .word 0x0
data:
    .word 0x1, 0x2, 0x3, 0x4, 0x5
    .word 0x6, 0x7, 0x8, 0x9, 0xa

    add $30,$0,$0
Lfor:
    lw $24,sum($0)
    sll $15,$30,2
    lw $15,data($15)
    addu $24,$24,$15
    sw $24,sum
    add $30,$30,1
    slt $24,$30,10
    bne $24,$0,Lfor
Lendfor:
```

Next Time

- Pseudo instructions
- More C idioms
- Calling procedures
- Recursion