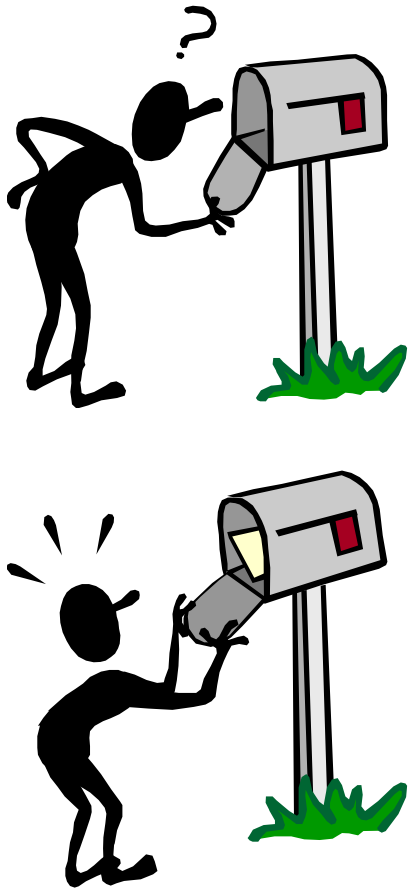
Operands and Addressing Modes



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

Just enough C

For our purposes C is almost identical to JAVA except:

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

function ≡ method without "class".

A global method.

C has "pointers" explicitly. JAVA has them but hides them under the covers.

C pointers

```
int i;       // simple integer variable
int a[10];   // array of integers
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)

Legal uses of C Pointers

```
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

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;
}

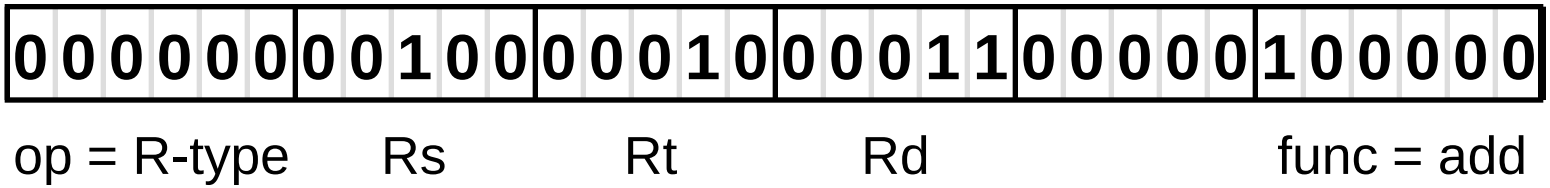
void clear3(int *array, int size) {
  int *arrayend = array + size;
  while(array < arrayend) *array++ = 0;
}
```

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)

Last Time - "Machine" Language

32-bit (4-byte) ADD instruction:



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        # 2nd 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"

- **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)

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

Common "Addressing Modes"

MIPS can do these with appropriate choices for Ra and const

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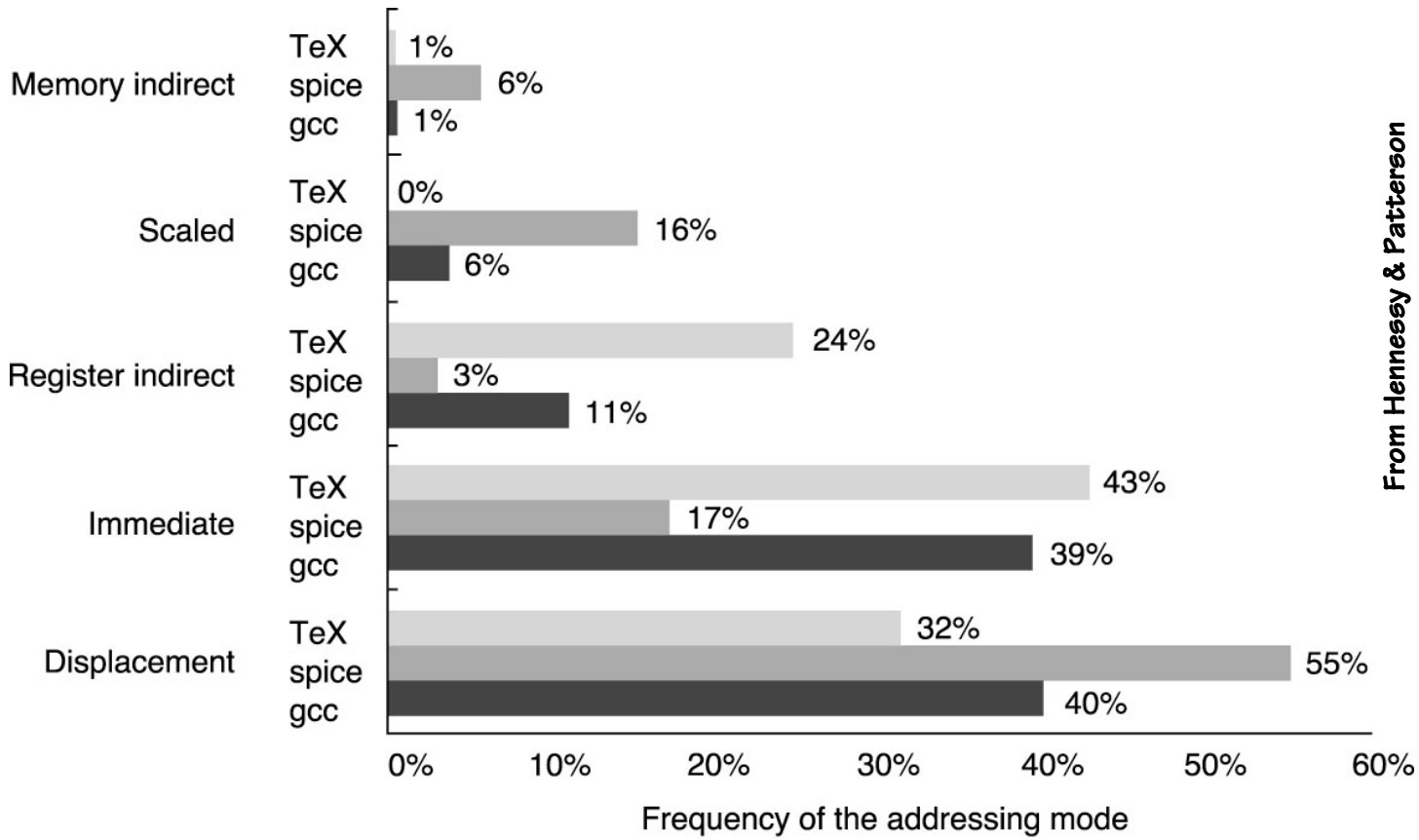
Memory Operands: Usage



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"

```
.data
.global x
x: .word 10

.text
.global main
main:
        lw   $2,x($0)
        addi $2,$2,1
        sw   $2,x($0)
```

- Caveats
  - In practice $gp is used instead of $0
  - Can only address the first and last 32K of memory this way
  - Sometimes generates a two instruction sequence:

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- Caveats
  - In practice $gp is used instead of $0
  - 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)
```

Absolute (Direct) Addressing

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

"C"

```
int x = 10;

main() {
    x = x + 1;
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```
.data
.global x
x: .word 10

.text
.global main
main:
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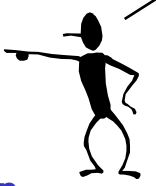
        addi $2,$2,1
        sw   $2,x($0)
```

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



- Caveats
  - In practice $gp is used instead of $0
  - 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)
```

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"

```
.data
.global x
x: .word   10

.text
.global main
main:
        la   $2,x
        addi $3,$0,2
        sw   $3,0($2)
```

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

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"

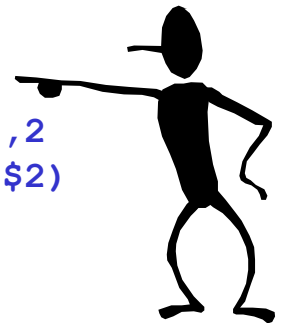
```
.data
.global x
x: .word   10

.text
.global main
main:
        la   $2,x
        addi $3,$0,2
        sw   $3,0($2)
```

"la" is not a real instruction, it's a convenient pseudoinstruction that constructs a constant via either a 1 instruction or 2 instruction sequence

```
ori  $2,$0,x

lui  $2,xhighbits
ori  $2,$2,xlowbits
```



- 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"

```
.data
.global a
a: .space   20

.text
.global main
main:
    addi $2,$0,3
    addi $3,$0,2
    sll  $1,$2,2
    sw   $3,a($1)
```

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

Displacement Addressing

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

"C"

```
int a[5];

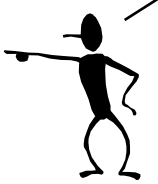
main() {
    int i = 3;
    a[i] = 2;
}
```

"MIPS Assembly"

```
.data
.global a
a: .space   20

.text
.global main
main:
    addi $2,$0,3
    addi $3,$0,2
    sll  $1,$2,2
    sw   $3,a($1)
```

Allocates space for a 5 uninitialized 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"

```
.data
.global p
p: .space   8

.text
.global main
main:
    la   $1,p
    addi $2,$0,3
    sw   $2,0($1)
    addi $2,$0,2
    sw   $2,4($1)
```

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

Displacement Addressing: Once More

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

"C"

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

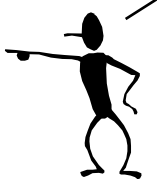
main() {
    p.x = 3;
    p.y = 2;
}
```

"MIPS Assembly"

```
.data
.global p
p: .space   8

.text
.global main
main:
    la   $1,p
    addi $2,$0,3
    sw   $2,0($1)
    addi $2,$0,2
    sw   $2,4($1)
```

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

Conditionals

C code:

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

C code:

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

MIPS assembly:

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

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:
```

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"

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

- We'll write some real assembly code
- Play with a simulator