CSE378 - Lecture 3

- Announcements

- Today:
  - — Finish up memory
  - — Control-flow (branches) in MIPS
    - if/then
    - loops
    - case/switch
  - — (maybe) Start: Array Indexing vs. Pointers
    - In particular pointer arithmetic
    - String representation

Quick Review

- Registers x Memory

lw $t0, 4($a0)

$a0 is simply another name for register 4
$t0 is another name for register ____ (green sheet)

What does $a0 contain?

What will $t0 contain after the instruction is executed? (address)

An array of words

- Remember to be careful with memory addresses when accessing words.
- For instance, assume an array of words begins at address 2000.
  - The first array element is at address 2000.
  - The second word is at address *2004*, not 2001.
- Example, if $a0 contains 2000, then

```
lw $t0, 0($a0)
```

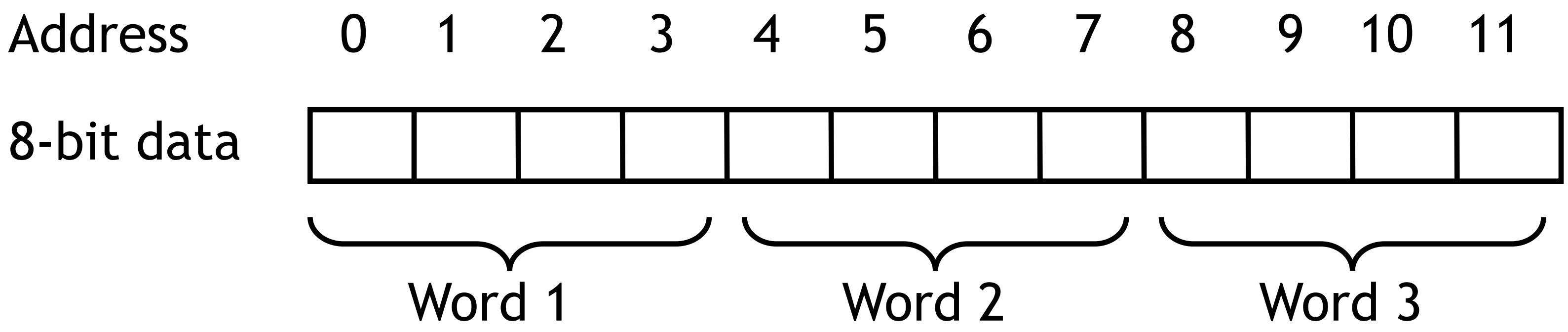
accesses the first word of the array, but

```
lw $t0, 8($a0)
```

would access the *third* word of the array, at address 2008.

Memory alignment

- Keep in mind that memory is byte-addressable, so a 32-bit word actually occupies four contiguous locations (bytes) of main memory.



- The MIPS architecture requires words to be aligned in memory; 32-bit words must start at an address that is divisible by 4.
  - 0, 4, 8 and 12 are valid word addresses.
  - 1, 2, 3, 5, 6, 7, 9, 10 and 11 are *not* valid word addresses.
  - Unaligned memory accesses result in a bus error, which you may have unfortunately seen before.
- This restriction has relatively little effect on high-level languages and compilers, but it makes things easier and faster for the processor.

Pseudo-instructions

- MIPS assemblers support pseudo-instructions that give the illusion of a more expressive instruction set, but are actually translated into one or more simpler, "real" instructions.
- For example, you can use the li and move pseudo-instructions:

```
li    $a0, 2000          # Load immediate 2000 into $a0
move $a1, $t0            # Copy $t0 into $a1
```

- They are probably clearer than their corresponding MIPS instructions:

```
addi $a0, $0, 2000       # Initialize $a0 to 2000
add   $a1, $t0, $0       # Copy $t0 into $a1
```

- We'll see lots more pseudo-instructions this semester.
  - A complete list of instructions is given in Appendix A of the text.
  - Unless otherwise stated, you can always use pseudo-instructions in your assignments and on exams.

Control flow in high-level languages

- The instructions in a program usually execute one after another, but it's often necessary to alter the normal control flow.
- Conditional statements execute only if some test expression is true.

```
// Find the absolute value of a0
v0 = a0;
if (v0 < 0)
    v0 = -v0;              // This might not be executed
v1 = v0 + v0;
```

- Loops cause some statements to be executed many times.

```
// Sum the elements of a five-element array a0
v0 = 0;
t0 = 0;
while (t0 < 5) {
    v0 = v0 + a0[t0];   // These statements will
    t0++;               // be executed five times
}
```

Control-flow graphs

```
// Find the absolute value of a0
v0 = a0;
if (v0 < 0)
    v0 = -v0;
v1 = v0 + v0;
```

```
// Sum the elements of
v0 = 0;
t0 = 0;
while (t0 < 5) {
    v0 = v0 + a0[t0];
    t0++;
}
```

MIPS control instructions

- MIPS's control-flow instructions

j	// for unconditional jumps
bne and beq	// for conditional branches
slt and slti	// set if less than (w/o and w an immediate)

- Now we'll talk about
  - MIPS's pseudo branches
  - if/else
  - case/switch

Pseudo-branches

- The MIPS processor only supports two branch instructions, beq and bne, but to simplify your life the assembler provides the following other branches:

```
blt  $t0, $t1, L1        // Branch if $t0 < $t1
ble  $t0, $t1, L2        // Branch if $t0 <= $t1
bgt  $t0, $t1, L3        // Branch if $t0 > $t1
bge  $t0, $t1, L4        // Branch if $t0 >= $t1
```

- There are also immediate versions of these branches, where the second source is a constant instead of a register.

- Later this quarter we'll see how supporting just beq and bne simplifies the processor design.

Implementing pseudo-branches

- Most pseudo-branches are implemented using slt. For example, a branch-if-less-than instruction `blt $a0, $a1, Label` is translated into the following.

```
slt  $at, $a0, $a1      // $at = 1 if $a0 < $a1
bne  $at, $0, Label     // Branch if $at != 0
```

- This supports immediate branches, which are also pseudo-instructions. For example, `blti $a0, 5, Label` is translated into two instructions.

```
slti $at, $a0, 5        // $at = 1if $a0 < 5
bne  $at, $0, Label     // Branch if $a0 < 5
```

- All of the pseudo-branches need a register to save the result of slt, even though it's not needed afterwards.
  - MIPS assemblers use register $1, or $at, for temporary storage.
  - You should be careful in using $at in your own programs, as it may be overwritten by assembler-generated code.

Translating an if-then statement

- We can use branch instructions to translate if-then statements into MIPS assembly code.

```
v0 = a0;
if (v0 < 0)
    v0 = -v0;
v1 = v0 + v0;
```

```
move $v0 $a0
bge $v0, $0   Label
sub $v0, 0, $v0
Label: add $v1, $v0, $v0
```

- Sometimes it's easier to *invert* the original condition.
  - In this case, we changed "continue if v0 < 0" to "skip if v0 >= 0".
  - This saves a few instructions in the resulting assembly code.

What does this code do?

```
label:  sub     $a0, $a0, 1
        bne     $a0, $zero, label
```

Loops

```
Loop:    j    Loop              # goto Loop
```

```
for (i = 0; i < 4; i++) {
    // stuff
}
```

```
        add     $t0, $zero, $zero   # i is initialized to 0, $t0 = 0
Loop:   // stuff
        addi    $t0, $t0, 1         # i ++
        slti    $t1, $t0, 4         # $t1 = 1 if i < 4
        bne     $t1, $zero, Loop    # go to Loop if i < 4
```

Control-flow Example

- Let's write a program to count how many bits are set in a 32-bit word.

```
int count = 0;
for (int i = 0 ; i < 32 ; i ++) {
   int bit = input & 1;
   if (bit != 0) {
     count ++;
   }
   input = input >> 1;
}
```

```
.text
main:

        li      $a0, 0x1234          ## input = 0x1234
        li      $t0, 0               ## int count = 0;
        li      $t1, 0               ## for (int i = 0

main_loop:
        bge     $t1, 32, main_exit   ## exit loop if i >= 32

        andi    $t2, $a0, 1          ## bit = input & 1
        beq     $t2, $0, main_skip   ## skip if bit == 0

        addi    $t0, $t0, 1          ## count ++

main_skip:
        srl     $a0, $a0, 1          ## input = input >> 1
        add     $t1, $t1, 1          ## i ++

        j       main_loop

main_exit:
        jr      $ra
```

Translating an if-then-else statements

- If there is an else clause, it is the target of the conditional branch
  - And the then clause needs a jump over the else clause

```
// increase the magnitude of v0 by one
if (v0 < 0)
    v0 --;

else
    v0 ++;
v1 = v0;
```

```
        bge  $v0, $0, E
        sub  $v0, $v0, 1
        j    L

E:      add  $v0, $v0, 1
L:      move $v1, $v0
```

  - Drawing the control-flow graph can help you out.

Case/Switch Statement

- Many high-level languages support multi-way branches, e.g.

```
switch (two_bits) {
  case 0:    break;
  case 1:    /* fall through */
  case 2:    count ++;     break;
  case 3:    count += 2;   break;
}
```

- We could just translate the code to if, thens, and elses:

```
if ((two_bits == 1) || (two_bits == 2)) {
  count ++;
} else if (two_bits == 3) {
  count += 2;
}
```

- This isn't very efficient if there are many, many cases.

Case/Switch Statement

```
switch (two_bits) {
  case 0:    break;
  case 1:    /* fall through */
  case 2:    count ++;     break;
  case 3:    count += 2;   break;
}
```

- Alternatively, we can:
  1. Create an array of jump targets
  2. Load the entry indexed by the variable two_bits
  3. Jump to that address using the jump register, or jr, instruction

Representing strings

- A C-style string is represented by an array of bytes.
  - Elements are one-byte ASCII codes for each character.
  - A 0 value marks the end of the array.

32	space	48	0	64	@	80	P	96	`	112	p
33	!	49	1	65	A	81	Q	97	a	113	q
34	”	50	2	66	B	82	R	98	b	114	r
35	#	51	3	67	C	83	S	99	c	115	s
36	$	52	4	68	D	84	T	100	d	116	t
37	%	53	5	69	E	85	U	101	e	117	u
38	&	54	6	70	F	86	V	102	f	118	v
39	’	55	7	71	G	87	W	103	g	119	w
40	(	56	8	72	H	88	X	104	h	120	x
41	)	57	9	73	I	89	Y	105	I	121	y
42	*	58	:	74	J	90	Z	106	j	122	z
43	+	59	;	75	K	91	[	107	k	123	{
44	,	60	<	76	L	92	\	108	l	124	|
45	-	61	=	77	M	93	]	109	m	125	}
46	.	62	>	78	N	94	^	110	n	126	~
47	/	63	?	79	O	95	_	111	o	127	del

Null-terminated Strings

- For example, “Harry Potter” can be stored as a 13-byte array.

72	97	114	114	121	32	80	111	116	116	101	114	0
H	a	r	r	y		P	o	t	t	e	r	\0

- Since strings can vary in length, we put a 0, or null, at the end of the string.
  - This is called a null-terminated string

- Computing string length
  - We’ll look at two ways.

What does this C code do?

```
int foo(char *s) {
int L = 0;
while (*s++) {
      ++L;
}
return L;
}
```

Array Indexing Implementation of strlen

```
int strlen(char *string) {
    int len = 0;
    while (string[len] != 0) {
        len ++;
    }
    return len;
}
```

Pointers & Pointer Arithmetic

- Many programmers have a vague understanding of pointers
  — Looking at assembly code is useful for their comprehension.

```
int strlen(char *string) {
    int len = 0;
    while (string[len] != 0) {
        len ++;
    }
    return len;
}
```

```
int strlen(char *string) {
    int len = 0;
    while (*string != 0) {
        string ++;
        len ++;
    }
    return len;
}
```

What is a Pointer?

- A pointer is an address.
- Two pointers that point to the same thing hold the same address
- Dereferencing a pointer means loading from the pointer's address
- A pointer has a type; the type tells us what kind of load to do
  - — Use load byte (lb) for char *
  - — Use load half (lh) for short *
  - — Use load word (lw) for int *
  - — Use load single precision floating point (l.s) for float *
- Pointer arithmetic is often used with pointers to arrays
  - — Incrementing a pointer (i.e., ++) makes it point to the next element
  - — The amount added to the point depends on the type of pointer
    - pointer = pointer + sizeof(*pointer's type)*
      - 1 for char *, 4 for int *, 4 for float *, 8 for double *

What is really going on here…

```
int strlen(char *string) {
    int len = 0;

    while (*string != 0) {
        string ++;
        len ++;
    }


    return len;
}
```

Pointers Summary

- Pointers are just addresses!!
  - "Pointees" are locations in memory
- Pointer arithmetic updates the address held by the pointer
  - "string ++" points to the next element in an array
  - Pointers are typed so address is incremented by sizeof(pointee)