

CSE378 - Lecture 3

- Announcements
 - HW1 out today or Monday, due April 14.

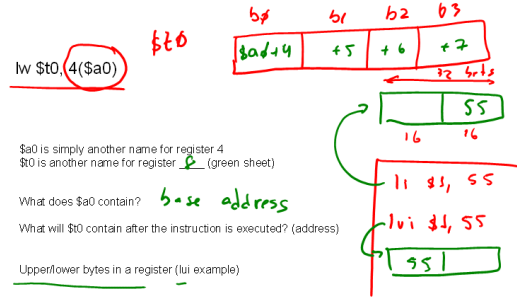
TGIF! ☺

- 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

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Quick Review

- Registers x Memory



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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;
}
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
}
```

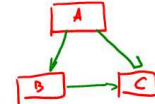
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CFG

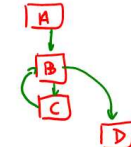
Control-flow graphs

Basic block

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



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



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MIPS control instructions

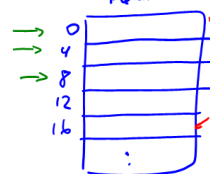
- MIPS's control-flow instructions
 - j* 16 // for unconditional jumps
 - bne and beq* // for conditional branches
 - slt and slti* // set if less than (w/o and w an immediate)

relative → *bne and beq*
→ *absolute*

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

```
slt $s, $2, $3
if ($2 < $3)
    $1 = 1
else
    $1 = 0
```

PC
Program Counter



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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.

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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 = 1 if $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.

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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.

```

move $v0, $a0
bit $v0, $0, L1
j L2
L1: sub $v0, $0, $v0
L2: add $v1, $v0, $v0
    
```

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What does this code do?

```

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

loops forever
max(1, \$a0)

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Loops

```

Loop: j Loop # goto Loop
    
```

loops forever

```

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++
      sli $t1, $t0, 4 # $t1 = 1 if i < 4
      bne $t1, $zero, Loop # goto Loop if i < 4
    
```

add \$t0, \$zero, \$zero
sli
// stuff
addi
bne

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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:
    sri $a0, $a0, 1 # input = input >> 1
    add $t1, $t1, 1 # i++
    j main_loop

main_exit:
    jr $ra
    
```

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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.

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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, then, and else:

```
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**.

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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:
 - Create an array of jump targets
 - Load the entry indexed by the variable `two_bits`
 - Jump to that address using the jump register, or `jr`, instruction

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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

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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.

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What does this C code do?

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

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Array Indexing Implementation of strlen

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

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Pointers & Pointer Arithmetic

- Many programmers have a vague understanding of pointers
 - Looking at assembly code is useful for their comprehension.
 - (But if you have an aggressive optimizing compiler, you may see the same assembly code for both versions!)

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

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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
- In C, 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 *

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What is really going on here...

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

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

    return len;
}
```

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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)

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