EECE 2322: Fundamentals of Digital Design and Computer Organization

Lecture 8_1: MIPS ISA

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Conditional Branching (beq)

```
# MIPS assembly               Results per line?
 addi $s0, $0, 4              # $s0 = 0 + 4 = 4
 addi $s1, $0, 1              # $s1 = 0 + 1 = 1
 sll  $s1, $s1, 2             # $s1 = 1 << 2 = 4
 beq  $s0, $s1, target        # branch is taken
 addi $s1, $s1, 1             # not executed
 sub  $s1, $s1, $s0           # not executed
```

Is this "targeted" instruction executed or not? and its results?

```
target:          # label
 add  $s1, $s1, $s0           # $s1 = 4 + 4 = 8
```

Labels indicate instruction location. They can't be reserved words and must be followed by colon (:)

The Branch Not Taken (bne)

 # MIPS assembly

```
addi  $s0, $0, 4          # $s0 = 0 + 4 = 4
addi  $s1, $0, 1          # $s1 = 0 + 1 = 1
sll   $s1, $s1, 2         # $s1 = 1 << 2 = 4
bne   $s0, $s1, target    # branch not taken
addi  $s1, $s1, 1         # $s1 = 4 + 1 = 5
sub   $s1, $s1, $s0       # $s1 = 5 - 4 = 1
```

Is this "targeted" instruction executed or not? and its results?

```
target:
  add   $s1, $s1, $s0
```

While Loops

C Code

```
// determines the power
// of x such that 2^x = 128
int pow = 1;
int x   = 0;

while (pow != 128) {
  pow = pow * 2;
  x = x + 1;
}
```

MIPS assembly code

```
# $s0 = pow, $s1 = x

       addi $s0, $0, 1
       add  $s1, $0, $0
       addi $t0, $0, 128
while: beq  $s0, $t0, done
       sll  $s0, $s0, 1
       addi $s1, $s1, 1
       j    while
done:
```

Assembly tests for the opposite case (`pow == 128`) of the C code (`pow != 128`).

For Loops

C Code

```
// add the numbers from 0 to 9
int sum = 0;
int i;

for (i=0; i!=10; i = i+1) {
  sum = sum + i;
}
```

MIPS assembly code

```
# $s0 = i, $s1 = sum
       addi $s1, $0, 0
       add  $s0, $0, $0
       addi $t0, $0, 10
for:   beq  $s0, $t0, done
       add  $s1, $s1, $s0
       addi $s0, $s0, 1
       j    for
done:
```

while and for side-by-side

MIPS assembly code

```
# $s0 = pow, $s1 = x

       addi $s0, $0, 1
       add  $s1, $0, $0
       addi $t0, $0, 128
while: beq  $s0, $t0, done
       sll  $s0, $s0, 1
       addi $s1, $s1, 1
       j    while
done:
```

MIPS assembly code

```
# $s0 = i, $s1 = sum
       addi $s1, $0, 0
       add  $s0, $0, $0
       addi $t0, $0, 10
for:   beq  $s0, $t0, done
       add  $s1, $s1, $s0
       addi $s0, $s0, 1
       j    for
done:
```

Difference/Similarity between for and while Loop

- From logic, they are doing "exactly" the same thing
- If being used to solve the same problem, the assembly code will be the same

- Difference, more from the programming level
- Using the for loop, you usually know the number of iterations
- Using the while loop, you just need to know when/how to finish the loop

Less Than Comparison: slt / slti

- How to convert the C Code into assembly code using slt?
- slt sets rd to 1 when rs < rt, otherwise, rd is 0
- slti sets rd to 1 when rs < imm, otherwise, rd is 0

set on less than	`slt $1,$2,$3`	if($2<$3)$1=1; else $1=0	Test if less than. If true, set $1 to 1. Otherwise, set $1 to 0.
set on less than immediate	`slti $1,$2,100`	if($2<100)$1=1; else $1=0	Test if less than. If true, set $1 to 1. Otherwise, set $1 to 0.

Less Than Comparison: slt

- How to convert the C Code into assembly code using slt?
- slt sets rd to 1 when rs < rt, otherwise, rd is 0

C Code

```
// add the powers of 2 from 1
// to 100
int sum = 0;
int i;

for (i=1; i < 101; i = i*2) {
  sum = sum + i;
}
```

MIPS assembly code

```
# $s0 = i, $s1 = sum
       addi $s1, $0, 0
       addi $s0, $0, 1
       addi $t0, $0, 101
```

Less Than Comparison

- slt sets rd to 1 when rs < rt, otherwise, rd is 0

C Code

```
// add the powers of 2 from 1
// to 100
int sum = 0;
int i;

for (i=1; i < 101; i = i*2) {
  sum = sum + i;
}
```

MIPS assembly code

```
# $s0 = i, $s1 = sum
        addi $s1, $0, 0
        addi $s0, $0, 1
        addi $t0, $0, 101
loop:   slt  $t1, $s0, $t0
        beq  $t1, $0, done
        add  $s1, $s1, $s0
        sll  $s0, $s0, 1
        j    loop
done:
```

$t1 = 1 if i < 101

Less Than Comparison

- slt sets rd to 1 when rs < rt, otherwise, rd is 0

C Code

```
// add the powers of 2 from 1
// to 100
int sum = 0;
int i;

for (i=1; i < 101; i = i*2) {
  sum = sum + i;
}
```

MIPS assembly code

```
# $s0 = i, $s1 = sum
        addi $s1, $0, 0
        addi $s0, $0, 1
        addi $t0, $0, 101
loop:   slt  $t1, $s0, $t0
        beq  $t1, $0, done
        add  $s1, $s1, $s0
        sll  $s0, $s0, 1
        j    loop
done:
```

\$t1 = 1 if i < 101

Less Than Comparison

- slt sets rd to 1 when rs < rt, otherwise, rd is 0

C Code

```
// add the powers of 2 from 1
// to 100
int sum = 0;
int i;

for (i=1; i < 101; i = i*2) {
  sum = sum + i;
}
```

MIPS assembly code

```
# $s0 = i, $s1 = sum
       addi $s1, $0, 0
       addi $s0, $0, 1
       addi $t0, $0, 101
loop:  slt  $t1, $s0, $t0
       beq  $t1, $0, done
       add  $s1, $s1, $s0
       sll  $s0, $s0, 1
       j    loop
done:
```

```
#if(i<101)$t1=1,else$t1=0
# if $t1 == 0 (i >= 101),
  branch to done
```

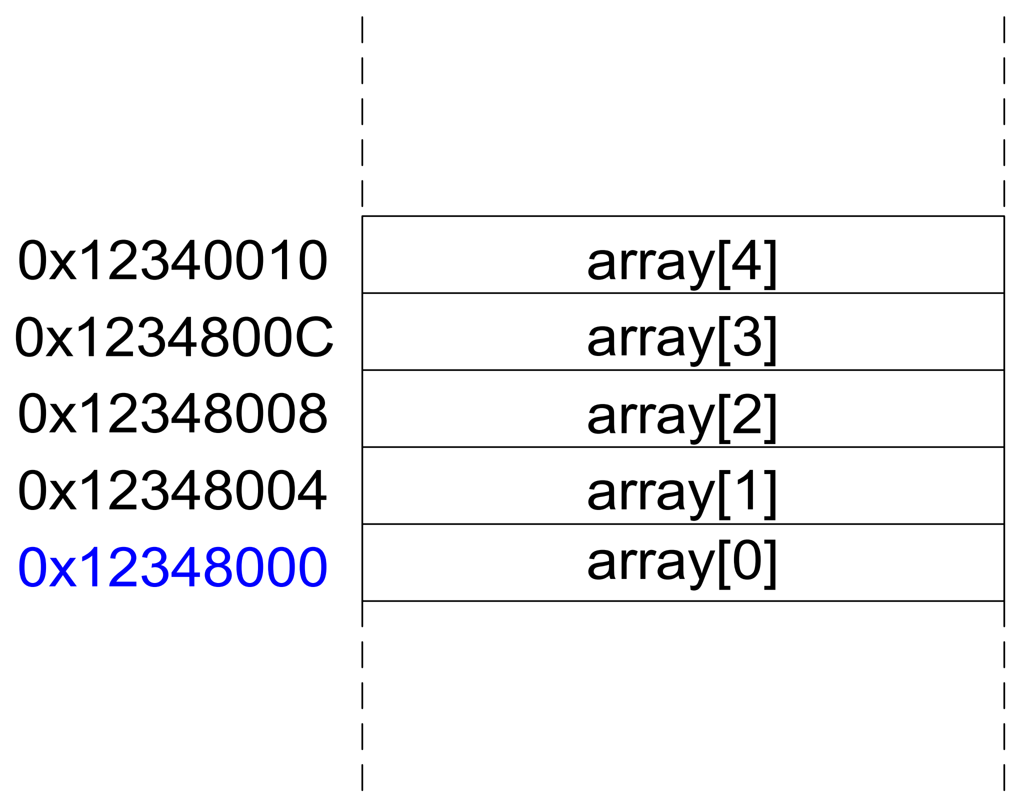
$t1 = 1 if i < 101

Arrays

- Very useful for accessing large amounts of similar data
- **Index**: access each element
- **Size**: number of elements

Arrays

- 5-element array example
- **Base address** = 0x12348000 (address of first element, `array[0]`)
- First step in accessing an array: load base address into a register



Accessing Arrays

```
// C Code
    int array[5];
    array[0] = array[0] * 2;
    array[1] = array[1] * 2;
```

Accessing Arrays

```
// C Code
    int array[5];
    array[0] = array[0] * 2;
    array[1] = array[1] * 2;
```

```
# MIPS assembly code
# array base address = $s0
 lui  $s0, 0x1234          # 0x1234 in upper half of $S0
 ori  $s0, $s0, 0x8000     # 0x8000 in lower half of $s0

 lw   $t1, 0($s0)          # $t1 = array[0]
 sll  $t1, $t1, 1          # $t1 = $t1 * 2
 sw   $t1, 0($s0)          # array[0] = $t1

 lw   $t1, 4($s0)          # $t1 = array[1]
 sll  $t1, $t1, 1          # $t1 = $t1 * 2
 sw   $t1, 4($s0)          # array[1] = $t1
```

Arrays using For Loops

```
// C Code
   int array[1000];
   int i;

   for (i=0; i < 1000; i = i + 1)
    array[i] = array[i] * 8;

# MIPS assembly code
# $s0 = array base address, $s1 = i
```

Arrays Using For Loops

```
# MIPS assembly code
# $s0 = array base address, $s1 = i
# initialization code
  lui  $s0, 0x23B8        # $s0 = 0x23B80000
  ori  $s0, $s0, 0xF000   # $s0 = 0x23B8F000
  addi $s1, $0, 0         # i = 0
  addi $t2, $0, 1000      # $t2 = 1000


loop:
  slt  $t0, $s1, $t2      # i < 1000?
  beq  $t0, $0, done      # if not then done
  sll  $t0, $s1, 2        # $t0 = i * 4 (byte offset)
  add  $t0, $t0, $s0      # address of array[i]
  lw   $t1, 0($t0)        # $t1 = array[i]
  sll  $t1, $t1, 3        # $t1 = array[i] * 8
  sw   $t1, 0($t0)        # array[i] = array[i] * 8
  addi $s1, $s1, 1        # i = i + 1
  j    loop               # repeat
done:
```

ASCII Code

- *American Standard Code for Information Interchange*
- Exchanging text between computers *was* difficult!
- Solution: each text character has unique byte value
  - For example, S = 0x53, a = 0x61, A = 0x41
  - Lower-case and upper-case differ by 0x20 (32)

Cast of Characters

#	Char	#	Char	#	Char	#	Char	#	Char	#	Char
20	space	30	0	40	@	50	P	60	`	70	p
21	!	31	1	41	A	51	Q	61	a	71	q
22	"	32	2	42	B	52	R	62	b	72	r
23	#	33	3	43	C	53	S	63	c	73	s
24	$	34	4	44	D	54	T	64	d	74	t
25	%	35	5	45	E	55	U	65	e	75	u
26	&	36	6	46	F	56	V	66	f	76	v
27	'	37	7	47	G	57	W	67	g	77	w
28	(	38	8	48	H	58	X	68	h	78	x
29	)	39	9	49	I	59	Y	69	i	79	y
2A	*	3A	:	4A	J	5A	Z	6A	j	7A	z
2B	+	3B	;	4B	K	5B	[	6B	k	7B	{
2C	,	3C	<	4C	L	5C	\	6C	l	7C	|
2D	-	3D	=	4D	M	5D	]	6D	m	7D	}
2E	.	3E	>	4E	N	5E	^	6E	n	7E	~
2F	/	3F	?	4F	O	5F	_	6F	o		

Cast of Characters

- What is stored in the memory?

#	Char	#	Char	#	Char	#	Char	#	Char	#	Char
20	space	30	0	40	@	50	P	60	`	70	p
21	!	31	1	41	A	51	Q	61	a	71	q
22	"	32	2	42	B	52	R	62	b	72	r
23	#	33	3	43	C	53	S	63	c	73	s
24	$	34	4	44	D	54	T	64	d	74	t
25	%	35	5	45	E	55	U	65	e	75	u
26	&	36	6	46	F	56	V	66	f	76	v
27	'	37	7	47	G	57	W	67	g	77	w
28	(	38	8	48	H	58	X	68	h	78	x
29	)	39	9	49	I	59	Y	69	i	79	y
2A	*	3A	:	4A	J	5A	Z	6A	j	7A	z
2B	+	3B	;	4B	K	5B	[	6B	k	7B	{
2C	,	3C	<	4C	L	5C	\	6C	l	7C	|
2D	-	3D	=	4D	M	5D	]	6D	m	7D	}
2E	.	3E	>	4E	N	5E	^	6E	n	7E	~
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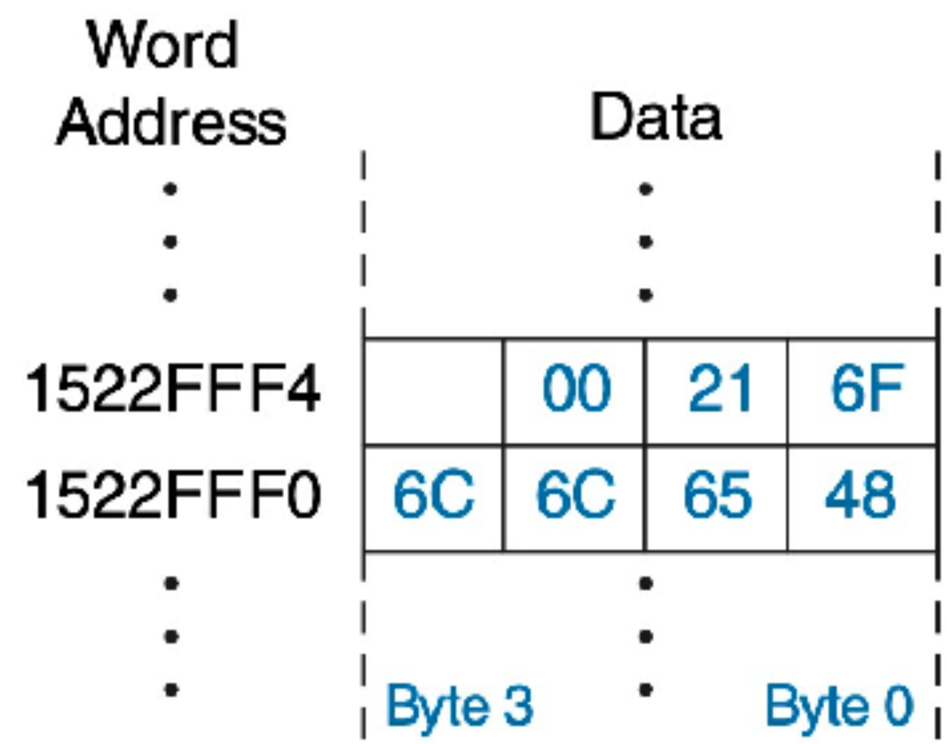

Little-Endian Memory

Function Calls

- **Caller:** calling function (in this case, `main`)
- **Callee:** called function (in this case, `sum`)

C Code

```
void main()
{
  int y;
  y = sum(42, 7);
  ...
}

int sum(int a, int b)
{
  return (a + b);
}
```

Function Conventions

- **Caller:**
  - passes **arguments** to callee
  - jumps to callee
- **Callee:**
  - **performs** the function
  - **returns** result to caller
  - **returns** to point of call
  - **must not overwrite** registers or memory needed by caller

C Code

```
void main()
{
  int y;
  y = sum(42, 7);
  ...
}

int sum(int a, int b)
{
  return (a + b);
}
```

MIPS Function Conventions

- **Call Function:** jump and link (`jal`)
- **Return** from function: jump register (`jr`)

Function Calls

C Code

```
int main() {
  simple();
  a = b + c;
}

void simple() {
  return;
}
```

MIPS assembly code

```
0x00400200 main:   jal  simple
0x00400204         add  $s0, $s1, $s2
...

0x00401020 simple: jr $ra
```

`void` —> `simple` doesn't return a value

Function Calls

C Code

```
int main() {
  simple();
  a = b + c;
}

void simple() {
  return;
}
```

MIPS assembly code

```
0x00400200 main:   jal  simple
0x00400204         add  $s0, $s1, $s2
...

0x00401020 simple: jr $ra
```

`jal`: jumps to `simple`
`$ra` = PC + 4 = 0x00400204

`jr $ra`: jumps to address in `$ra` (0x00400204)

Revisit the MIPS Register Set

Name	Register Number	Usage
$0	0	the constant value 0
$at	1	assembler temporary
$v0-$v1	2-3	Function return values
$a0-$a3	4-7	Function arguments
$t0-$t7	8-15	temporaries
$s0-$s7	16-23	saved variables
$t8-$t9	24-25	more temporaries
$k0-$k1	26-27	OS temporaries
$gp	28	global pointer
$sp	29	stack pointer
$fp	30	frame pointer
$ra	31	Function return address

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$sp	29	stack pointer
$fp	30	frame pointer
$ra	31	Function return address

Input Arguments & Return Value

MIPS conventions:

- Argument values: `$a0 - $a3`
- Return values: `$v0-$v1`

Input Arguments & Return Value

C Code

```
int main()
{
  int y;
  ...
  y = diffofsums(2, 3, 4, 5);  // 4 arguments
  ...
}

int diffofsums(int f, int g, int h, int i)
{
  int result;
  result = (f + g) - (h + i);
  return result;              // return value
}
```

Input Arguments & Return Value

MIPS assembly code

```
# $s0 = y

main:
  ...
  addi $a0, $0, 2     # argument 0 = 2
  addi $a1, $0, 3     # argument 1 = 3
  addi $a2, $0, 4     # argument 2 = 4
  addi $a3, $0, 5     # argument 3 = 5
  jal  diffofsums     # call Function
  add  $s0, $v0, $0   # y = returned value
  ...

# $s0 = result
diffofsums:
  add $t0, $a0, $a1   # $t0 = f + g
  add $t1, $a2, $a3   # $t1 = h + i
  sub $s0, $t0, $t1   # result = (f + g) - (h + i)
  add $v0, $s0, $0    # put return value in $v0
  jr  $ra             # return to caller
```

Input Arguments & Return Value

MIPS assembly code

```
# $s0 = result
diffofsums:
  add $t0, $a0, $a1  # $t0 = f + g
  add $t1, $a2, $a3  # $t1 = h + i
  sub $s0, $t0, $t1  # result = (f + g) - (h + i)
  add $v0, $s0, $0   # put return value in $v0
  jr  $ra            # return to caller
```

- `diffofsums` overwrote 3 registers: `$t0`, `$t1`, `$s0`
- `diffofsums` can use *stack* to temporarily store registers