CSE 2021
COMPUTER ORGANIZATION

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CSEB 1012U

W3-W

Example from last time….

Activity 2: Consider the C instruction

A[300] = h + A[300]

A. Write the equivalent MIPS code for the above C instruction assuming $t1 contains the base address of array A (i.e., address of A[0]) and $s2 contains the value of h

B. Write the binary machine language code for the result in part A.

MIPS Code:

```
lw $t2,1200($t1)       # load A[300] from memory
add $t2,$t2,$s2        # A[300]= A[300] + h
sw $t2,1200($t1)       # save result to memory A[300]
```

Example from last time (cont'd)…

Example: **lw $t2,1200($t1)**

I-Format			
op	**rs**	**rt**	**address**
6 bits	**5 bits**	**5 bits**	**16 bits**
opcode	**1st operand**	**2nd operand**	**Memory address (offset)**

op = 0x23 = $(100011)_2$

rs = 9 = $(01001)_2$ ($t1 is register 9)

rt = 10 = $(01010)_2$ ($t2 is register 10)

address = 1200 = 0x4b0 = $(0000\ 0100\ 1011\ 0000)_2$

leads to the binary machine language code: 100011 01001 01010 0000 0100 1011 0000

Completing the Example…

add $t2,$t2,$s2

R-Format					
op	**rs**	**rt**	**rd**	**shamt**	**funct**
6 bits	**5 bits**	**5 bits**	**5 bits**	**5 bits**	**6 bits**
opcode	**1st operand**	**2nd operand**	**destination**	**shift**	**function**

op = 0x0 = $(000000)_2$

funct = 0x20

rs = 10 = $(01010)_2$ ($t2 is register 10)

rt = 18 = $(10010)_2$ ($s2 is register 18)

rd = 10 = (01010)2 ($t2 is register 10)

leads to the binary machine language code: 000000 01010 10010 01010 00000 100000

Completing the Example (cont'd)…

sw $t2,1200($t1)

I-Format			
op	**rs**	**rt**	**address**
6 bits	**5 bits**	**5 bits**	**16 bits**
opcode	**1^{st} operand**	**2^{nd} operand**	**Memory address (offset)**

op = 0x2b = $(101011)_2$

rs = 10 = $(01001)_2$ ($t1 is register 9)

rt = 10 = $(01010)_2$ ($t2 is register 10)

address = 1200 = 0x4b0 = $(0000\ 0100\ 1011\ 0000)_2$

leads to the binary machine language code: 101011 01001 01010 0000 0100 1011 0000

Agenda for Today

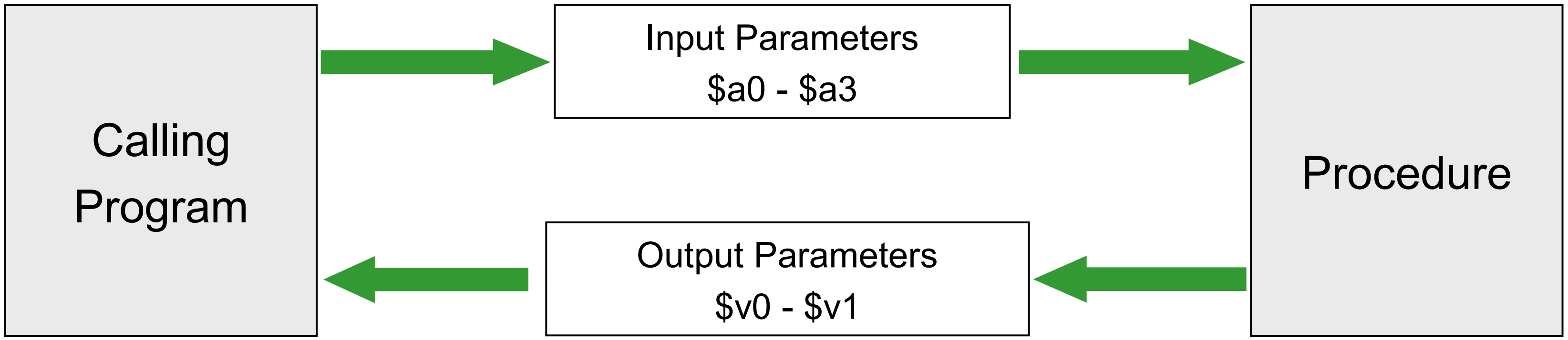
- Procedures
- Characters and Strings
- Immediate Operands
- Decoding Machine Language (read on your own)
- Putting it all together (read on your own)
- SPIM Programming (Lab B, C, D)

- Patterson: Sections 2.8 – 2.13 and Appendix B.9

What we have learned so far …

Category	Instruction	Example	Meaning	Comments
Arithmetic	**add**	`add $s1,$s2,$s3`	$s1 ← $s2+$s3	
	subtract	`sub $s1,$s2,$s3`	$s1 ← $s2-$s3	
Data Transfer	**load word**	`lw $s1,100($s2)`	$s1 ← Mem[$s2+100]	
	store word	`lw $s1,100($s2)`	Mem[$s2+100] ← $s1	
Conditional branch	**branch on equal**	`beq $s1,$s2,L`	if($s1==$s2) go to L	
	branch not equal	`bne $s1,$s2,L`	if($s1!=$s2) go to L	
	set on less than	`slt $s1,$s2,$s3`	if($s2 < $s3) $s1 = 1 else $s1 = 0	
Unconditional jump	**jump**	`j 2500`	go to (4 x 2500)	
	Jump register	`jr $t1`	go to $t1	
Logical Instructions	**Shift left (right)**	`sll $t2,$s0,4`	$t2 ← $s0<<4 bits	
	And, Or, Nor	`nor $t0,$t1,$t2`	$t0=~($t1|$t2)	

Procedures (1)



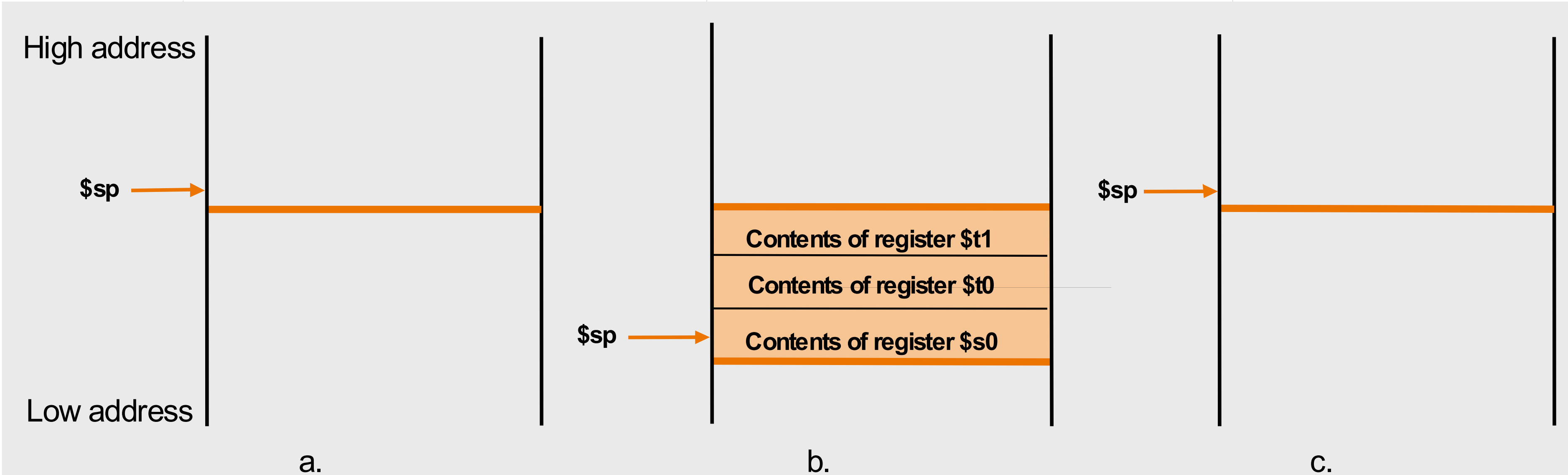
<u>Calling program:</u>

1. Places parameters in registers $a0 - $a3 where the called procedure can access them
2. Transfers control to the procedure
   – Address of the next instruction in the calling program is automatically placed in register $ra

<u>Called Procedure:</u>

3. Acquires additional space needed to perform the task
   – Saves values of required registers in a stack $sp
4. Performs the desired task
5. Restores the values of registers that it used
6. Saves the result in registers $v0 - $v1
7. Returns control to the calling program by returning to instruction whose address is saved in $ra

Procedures (2)



Where are values of the calling function stored:

1. The values of registers that you will use in the called function must be stored
2. It is the responsibility of the called function to store these values and restore them
3. A stack (assigned space) in the memory is used to store the values of the registers
4. Register $sp contains the address of the stack pointer
5. Registers are typically stored in order, from up to down in the stack

Procedures (2)

Example:

```
int leaf_example (int g, int h, int i, int j)
{
        int f;
        f = (g + h) – (i + j);
        return f;
}
```

Assume that variables g, h, i, j are stored in registers $a0 - $a3.

Calling function in MIPS:

```
main:
…
jal leaf_example
…
```

Activity 1:

Why is it perfectly correct not to store and restore registers $t0, $t1?

Procedure in MIPS :

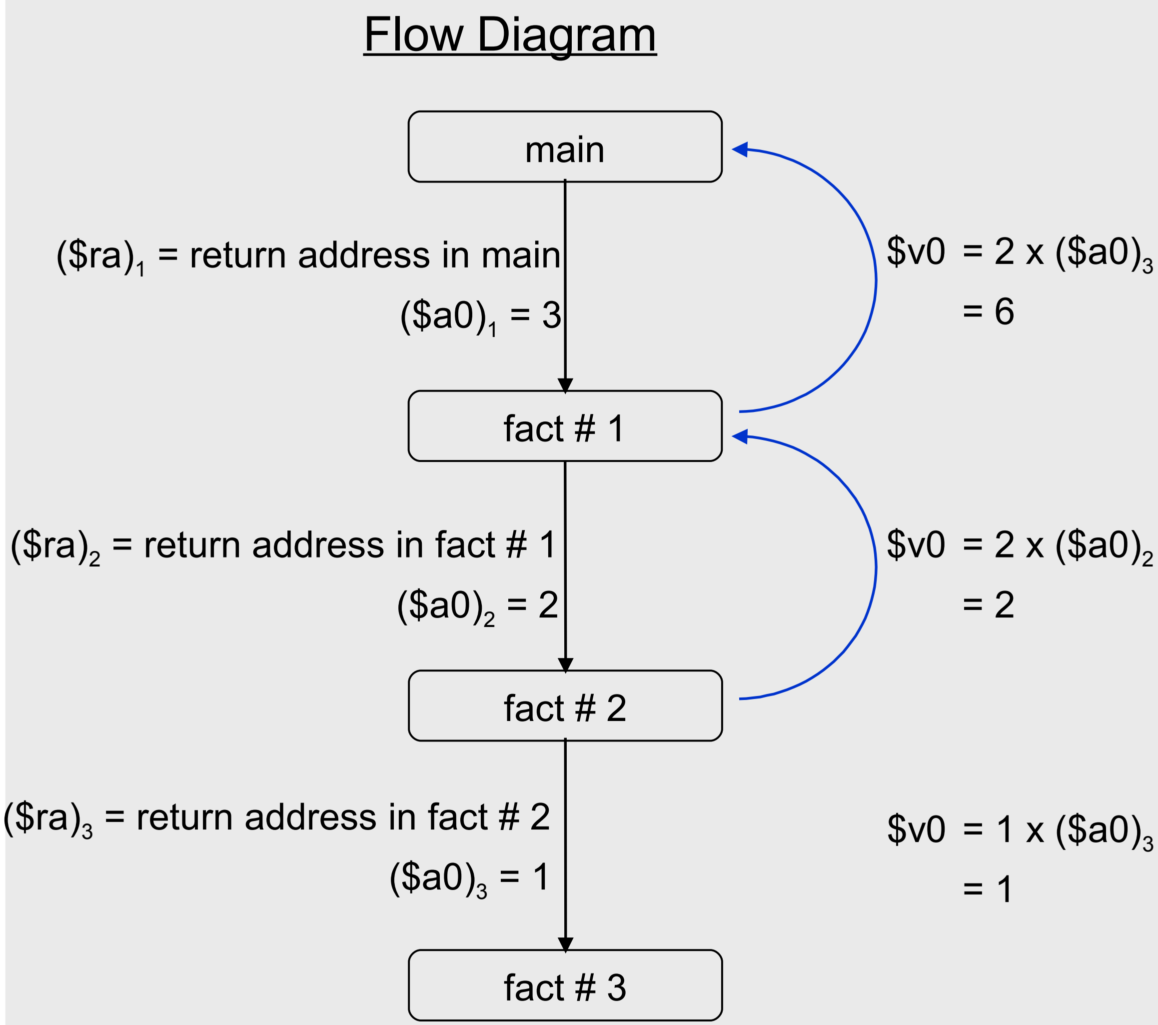
```
leaf_example:
# save registers $t0, $t1, $s1
        sub $sp, $sp, 12
        sw $t1, 8($sp)
        sw $t0, 4($sp)
        sw $s0, 0 ($sp)
# perform the required operation

        add $t0, $a0, $a1
        add $t1, $a2, $a3
        sub $s0, $t0, $t1
        add $v0, $s0,$zero
# restore registers $t0, $t1, $s1
        lw $t1, 8($sp)
        lw $t0, 4($sp)
        lw $s0, 0 ($sp)
        add $sp, $sp, 12
# return control
        jr $ra
```

Procedures: Nested (3)

Nested Procedure Example:

```
int fact (int n)
{
    if (n < 1) return (1)
    else return (n * fact(n-1));
    }
```

Assume variable n is stored in \$a0.



<u>Conclusions:</u>

Before each function call

1) value of \$ra must be saved in the stack

2) value of \$a0 must be saved in the stack

After returning from a function

3) value of \$a0 be recalled for (\$v0 × \$a0)

4) value of \$ra be recalled to return control to the calling function

Procedures: Nested (4)

Nested Procedure Example:

```
int fact (int n)
{
    if (n < 1) return (1)
    else return (n * fact(n-1));
    }
```

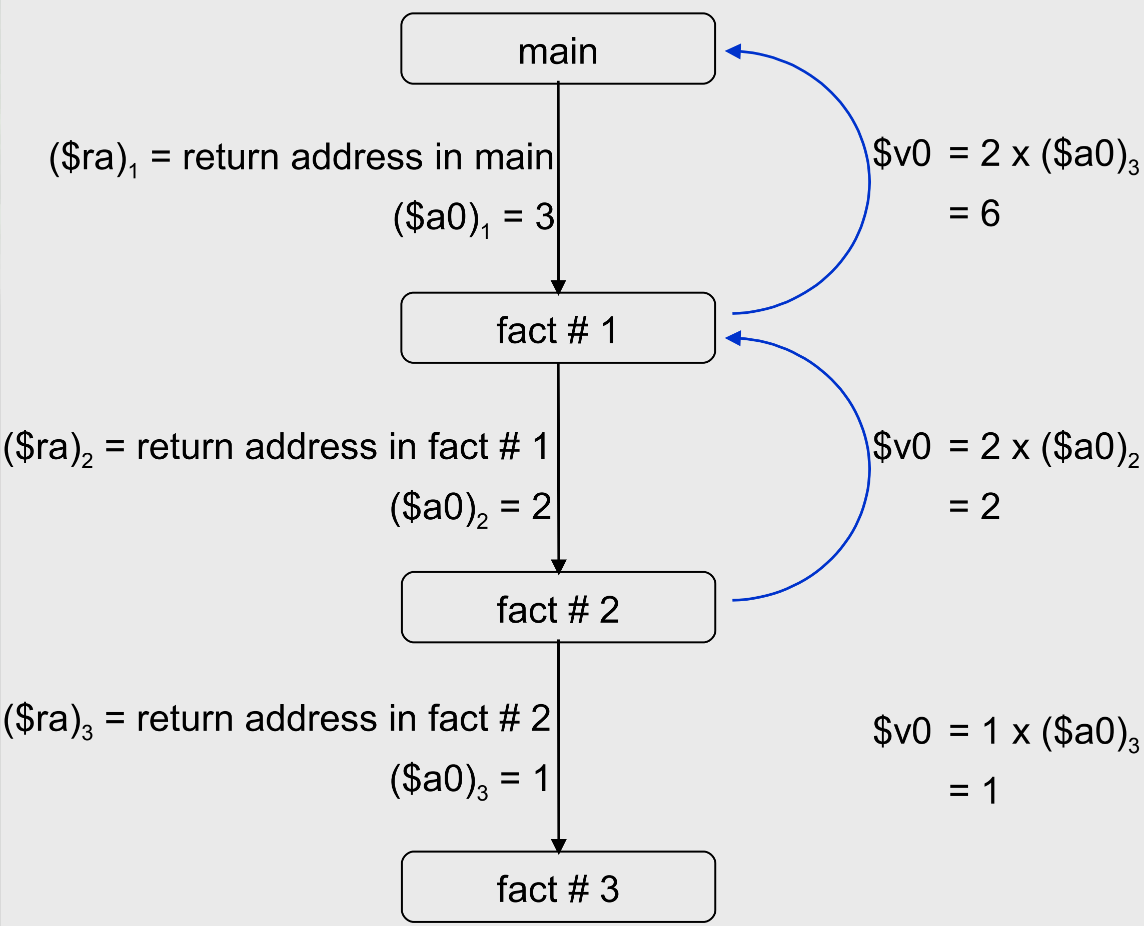
Assume variable n is stored in $a0.

MIPS Code:

```
fact:
# input value is stored in $a0 and output value in $v0
# add commands for saving $ra, $a0

      addi    $t1, $zero, 1      # initialize $t1 = 1
      slt     $t0, $a0, $t1      # if (n < 1), $t0 = 1
      beq     $t0, $zero, L1     # if $t0 == 0, go to L1
# if n < 1
      addi    $v0, $zero,1       # return 1
      jr      $ra
# if n >= 1
L1: addi      $a0, $a0, -1       # $a0 = $a0 -1
      jal fact

# add commands to retrieve $ra, $a0
# return answer in $v0
```

Procedures: Nested (5)

Flow Diagram



MIPS Code:

```
fact:
addi $sp, $sp, -8          # clear stack for 2 items
sw  $ra, 4($sp)            # save return address
sw  $a0, 0($sp)            # save n
addi $t1, $zero, 1         # initialize $t1 = 1
slt $t0, $a0, $t1          # if (n < 1), $t0 = 1
beq $t0, $zero, L1         # if $t0 == 0, go to L1
# if n < 1
add $v0,$zero,1            # return 1
addi $sp, $sp, 8
jr $ra
# if n >= 1
L1: addi $a0, $a0, -1      # $a0 = $a0 -1
jal fact
lw $a0, 0($sp)
lw $ra, 4($sp)
addi $sp, $sp, -8
mul $v0,$a0,$v0            # not exact instruction
jr $ra
```

Registers (review)

Name	Example	Comments
32 Registers	`$s0,$s1,…$s7, $zero` `$t0,$t1,…$t9`	**$s0-$s7 are preserved across procedures, $t0-$t9 are not preserved**
Memory w/ 2^{30} words	**Memory[0], Memory[4], … Memory[4294967292]**	**Memory is accessed one word at a time**

Name	Register number	Usage
`$zero`	0	Constant value of 0
`$v0-$v1`	2 - 3	Values for results and expression evaluation
`$a0-$a3`	4 - 7	Input arguments to a procedure
`$t0-$t7`	8 - 15	Not preserved across procedures (temp)
`$s0-$s7`	16 - 23	Preserved across procedure calls
`$t8-$t9`	24 - 25	More temporary registers
`$gp`	28	Global pointer
`$sp`	29	Stack pointer, points to last location of stack
`$fp`	30	Frame pointer
`$ra`	31	Return address from a procedure call

ASCII Characters (1)

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

ASCII Characters (2)

1. Characters are represented on a computer using American Standard Code for Information Interchange (ASCII). Java uses Unicode.
2. Most computers use 8-bits to represent each character (16-bits for Unicode)
   Example: ASCII code for character C is $(67)_{10}$ or $(01000011)_2$
   ASCII code for character null is $(\backslash 0)_{10}$ or $(00000000)_2$
3. Strings are combination of characters
4. In ANSI C, the end of a string is represented by a null character

	72	101	108	108	111	32	83	105	114	0

5. Other high level languages may use other choices as:
   a. Using the first byte to represent the length of the string
   b. Using an accompaning variable to indicate the length of the string
6. How to load a byte at a time? (Unicode has half-byte instructions lh, lhu, sh)

```
lb $t0,100($s1) # $t0 = Mem[$s1 + 100] except 1 byte is transferred
sb $t0,100($s1) # Mem[$s1 + 100] = $t0 except 1 byte is transferred
```

ASCII Characters (3)

Example:

```
void strcpy (char x[ ], char y [ ])
{
        int j;
        j = 0;
        while ((x[i] = y[i] != 0) /* copy and test */
                        i = i + 1;
}
```

Assume that the addresses of x[0] and y[0] are contained in registers $a0, $a1.

```
strcpy:
    # store value of register $s0
    addi $sp,$sp,-4
    sw $s0,0($sp)

    add $s0,$zero,$zero # set $s0 = 0
L1: add $t1,$a1,$s0  # address of y[i]
    lb $t2,0($t1)    # load y[i] to $t2
    add $t3,$a0,$s0  # address of x[i]
    sb $t2,0($t3)    # save $t2 to x[i]
    beq $t2,$zero,L2 # exit
    addi $s0,$s0,1
    j L1

    # restore value of register $s0
L2: lw $s0,0($sp)
    addi $sp,$sp,4
    jr $ra
```

Immediate Operands (1)

1. Set value of register to a constant

```
addi $s0,$zero,88     # $s0 = 88
```

Machine code for `addi` instruction:

op	rs	rt	Immediate
$8_{10} = 001000_2$	$0_{10} = 00000_2$	$16_{10} = 10000_2$	$88_{10} = 0000\ 0000\ 0101\ 1000_2$
6 bits	**5 bits**	**5 bits**	**16 bits**
opcode	**1st operand**	**2nd operand**	**Immediate operand**

2. What if the value of constant to be loaded is greater than $(2^{16} - 1) = 65535$?
Example: Load the following binary number into $s0?

0000 0000 0011 1101 0000 1001 0000 0000

```
lui $s0,61            # load 61 = 0000 0000 0011 1101 into the most
                      # significant 16 bits

addi $s0,$s0,2304
```

Immediate Operands (2)

1. Branch statements

```
bne $s0,$s1,Exit      # go to Exit if $s0 != $s1
```

Machine code for `bne` instruction:

op	rs	rt	Immediate
$5_{10} = 000101_2$	$s1 = 00000_2	$s0 = 10000_2	address of Exit
6 bits	**5 bits**	**5 bits**	**16 bits**
opcode	**1st operand**	**2nd operand**	**Immediate operand**

2. What if the value of address corresponding to Exit is greater than $(2^{16} - 1) = 65535$?

Use unconditional jump with syntax: `j 10000`

op	Immediate		
$2_{10} = 000010_2$			
6 bits	**26 bits**		
opcode	**1st operand**	**2nd operand**	**Immediate operand**

MIPS Code:

```
beq $s0,$s1,L2
L2:     j L1
```

SPIM Simulator

1. SPIM is a software simulator for running MIPS program
2. SPIM's name is just MIPS spelled backwards
3. There are different versions for different machines:
   - Unix: spim, xspim
   - PC: PCspim (download instructions available on course homepage)
4. SPIM provides additional features not available in MIPS like system calls
   - Systems calls are operating-system like calls for inputting variables, displaying results, etc.
   - Format for system calls is:

```
place value of input argument in $a0
place value of system-call-code in $v0
syscall
```

System Calls

Example # 1: Print a string

```
.data
    str:    .asciiz "the answer is"
.text
    addi $v0,$zero,4
    la $a0,str    # pseudoinstruction
    syscall
```

Example # 2: Input an integer

```
    addi $v0,$zero,5
    syscall
```

Example # 3: Print an integer

```
    addi $v0,$zero,1
    addi $a0,$s0,$zero
    syscall
```

Example # 4: Read String

```
    addi $v0,$zero,8
    la $a0,Buff  #$a0=address of Buff
    addi $a1,$zero,60 #$a1=max. len.
    syscall
```

Service	System Call Code ($v0)	Arguments	Result
print_int	1	$a0 = int	
print_float	2	$f12 = float	
print_double	3	$f12 = double	
print_string	4	$a0 = string address	
read_int	5		int (in $v0)
read_float	6		float (in $f0)
read_double	7		double (in $f0)
read_string	8	$a0 = buffer $a1 = length	
sbrk	9	$a0 = amount	address (in $v0)
exit	10		terminate prog

Putting it all together (2)

Activity: Write a MIPS program which does the following:

1. Accepts an integer N using the following prompt

   Please input a value for N =

2. Computes the sum of integers from 1 to N, i.e., (1 + 2 + … + N) if N > 0
3. Displays the result (X) as

   The sum of the integers from 1 to N is X

2. Waits for the next number N.
3. If N <= 0, the program exits with the following farewell

   Chao - Have a good day

Run the program in the spim simulator to verify the results