CSE 2021 COMPUTER ORGANIZATION

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W3-M

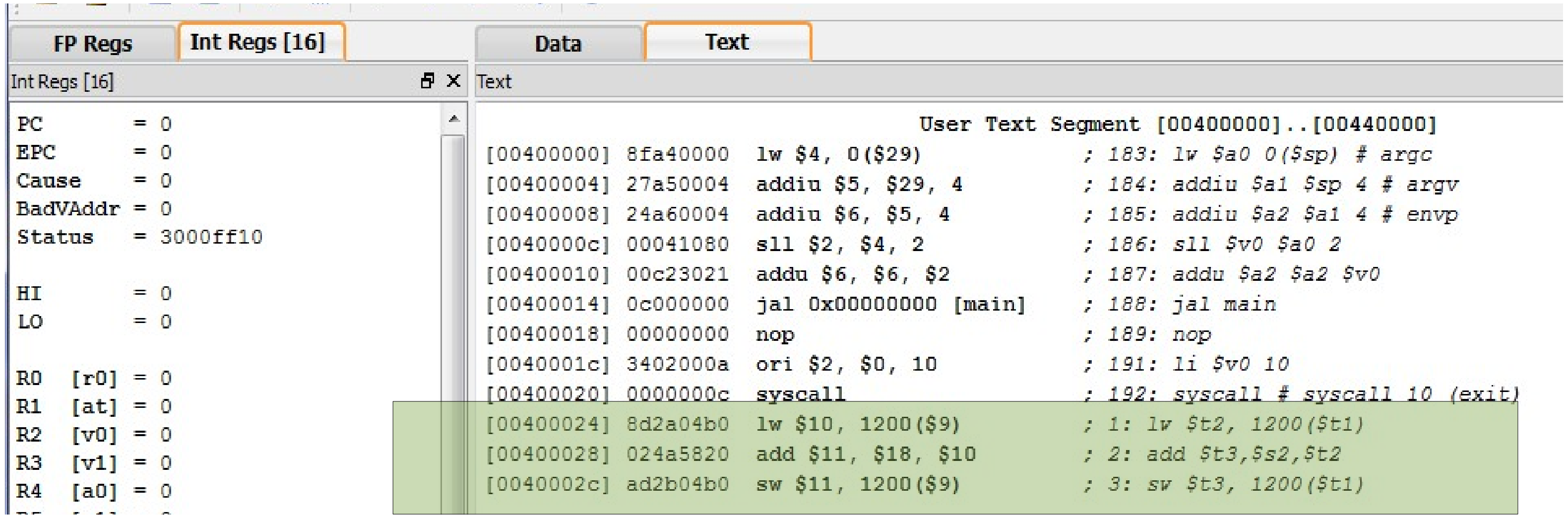
Example from last time….

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.



```
Int Regs [16]

PC       = 0
EPC      = 0
Cause    = 0
BadVAddr = 0
Status   = 3000ff10

HI       = 0
LO       = 0

R0  [r0] = 0
R1  [at] = 0
R2  [v0] = 0
R3  [v1] = 0
R4  [a0] = 0
```

```
Text
                         User Text Segment [00400000]..[00440000]
[00400000] 8fa40000  lw $4, 0($29)          ; 183: lw $a0 0($sp) # argc
[00400004] 27a50004  addiu $5, $29, 4       ; 184: addiu $a1 $sp 4 # argv
[00400008] 24a60004  addiu $6, $5, 4        ; 185: addiu $a2 $a1 4 # envp
[0040000c] 00041080  sll $2, $4, 2          ; 186: sll $v0 $a0 2
[00400010] 00c23021  addu $6, $6, $2        ; 187: addu $a2 $a2 $v0
[00400014] 0c000000  jal 0x00000000 [main]  ; 188: jal main
[00400018] 00000000  nop                    ; 189: nop
[0040001c] 3402000a  ori $2, $0, 10         ; 191: li $v0 10
[00400020] 0000000c  syscall                ; 192: syscall # syscall 10 (exit)
[00400024] 8d2a04b0  lw $10, 1200($9)       ; 1: lw $t2, 1200($t1)
[00400028] 024a5820  add $11, $18, $10      ; 2: add $t3,$s2,$t2
[0040002c] ad2b04b0  sw $11, 1200($9)       ; 3: sw $t3, 1200($t1)
```

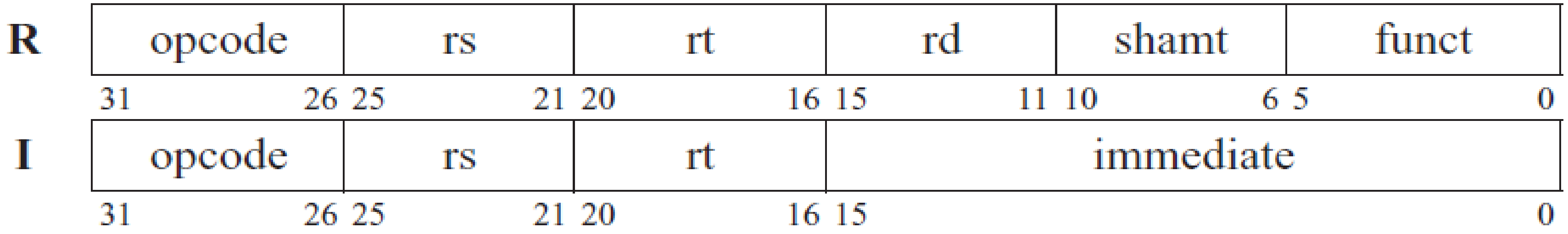
Assembler

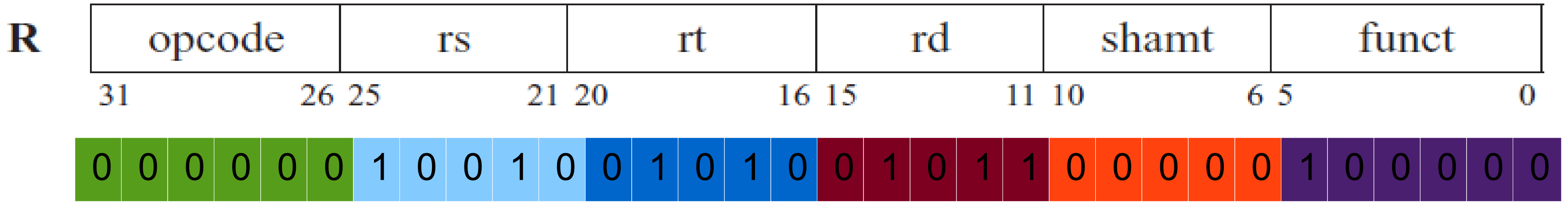
NAME	NUMBER
$zero	0
$at	1
$v0-$v1	2-3
$a0-$a3	4-7
$t0-$t7	8-15
$s0-$s7	16-23
$t8-$t9	24-25

CORE INSTRUCTION SET

NAME, MNEMONIC		FOR-MAT	OPERATION (in Verilog)		OPCODE / FUNCT (Hex)
Add	add	R	R[rd] = R[rs] + R[rt]	(1)	0 / 20_{hex}
Load Word	lw	I	R[rt] = M[R[rs]+SignExtImm]	(2)	23_{hex}
Store Word	sw	I	M[R[rs]+SignExtImm] = R[rt]	(2)	$2b_{hex}$

BASIC INSTRUCTION FORMATS





Agenda for Today

Number representations

MIPS Logical Instructions

- Patterson: Sections 2.4, 2.6

Decimal to Binary Conversion

Any integer, N can be represented as follows:

$$N = \sum_{i=0}^{n} b_i 2^n \quad \text{where } n = floor(\log_2 N) = floor\left(\frac{\log N}{\log 2}\right)$$

If N is odd, then b_0 = 1, otherwise is b_0 = 0

$$N_e = \begin{cases} N - 1\times 2^0 = \sum_{i=1}^{n} b_i 2^i \text{ for N odd, } b_0 = 1 \\ N = \sum_{i=1}^{n} b_i 2^i \text{ for N even, } b_0 = 0 \end{cases}$$

Divide even integer by 2

$$N_e/2 = M = \sum_{i=1}^{n} b_i 2^{i-1}$$

Repeat until left with integer of 0

$$M_e = \begin{cases} M - 1\times 2^{1-1} = \sum_{i=1}^{n} b_{i-1} 2^{i-1} \text{ for M odd, } b_1 = 1 \\ M = \sum_{i=1}^{n} b_i 2^{i-1} \text{ for M even, } b_1 = 0 \end{cases}$$

Example Decimal to Binary

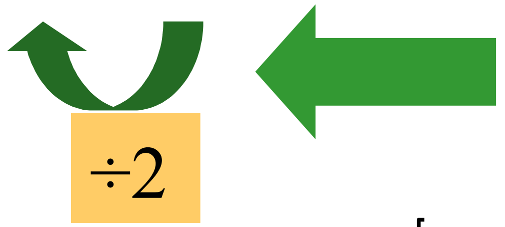
Case 1: Convert 445_{ten} to binary representation.

Answer:

$$n = floor\left(\frac{\log 445}{\log 2}\right) = 8$$

8	7	6	5	4	3	2	1	0	
1	1	0	1	1	1	1	0	1	=445
0	2	6	12	26	54	110	222	444	

Numbers in this row MUST be even



Binary to Decimal Conversion

Case 2: Convert the following binary number to decimal representation: 110011001_{two}

$$\underbrace{(1\times2^8)}_{256}+\underbrace{(1\times2^7)}_{128}+\underbrace{(0\times2^6)}_{0}+\underbrace{(0\times2^5)}_{0}+\underbrace{(1\times2^4)}_{16}+\underbrace{(1\times2^3)}_{8}+\underbrace{(0\times2^2)}_{0}+\underbrace{(0\times2^1)}_{0}+\underbrace{(1\times2^0)}_{1}$$
$$=409_{ten}$$

Decimal to Hexadecimal Conversion

Any integer, N can be represented as follows

$$N = \sum_{i=0}^{n} h_i 16^i$$

$$\text{where } n = floor\left(\log_{16} N\right) = floor\left(\frac{\log N}{\log 16}\right)$$

Divide integer by 16

$$N/16 = I + \frac{h_0}{16}$$

$$I = floor\left(N/16\right)$$

$$h_0 = 16\left(N/16 - floor\left(N/16\right)\right)$$

Repeat until left with integer less than 16

$$I = \sum_{i=1}^{n} h_i 16^{i-1} = J + \frac{h}{16} \ldots$$

Hexa	Decimal
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
a	10
b	11
c	12
d	13
e	14
f	15

Hexadecimal Representation (1)

Case 3: <u>Decimal to Hexadecimal Conversion</u>

Example: Convert 445_{ten} into hexadecimal

$$n = floor\left(\frac{\log 445}{\log 16}\right) = 2$$

2	*1*	*0*	
1	*b (11)*	*d (13)*	*=445*
0	*1*	*27*	

$445_{ten} = 000001bd_{hex}$ in 1 word

Case 4: <u>Hexadecimal to Decimal Conversion</u>

Example: Convert $000001db_{hex}$ to decimal

$$\underbrace{\left(1\times16^{2}\right)}_{256}+\underbrace{\left(d\times16^{1}\right)}_{208}+\underbrace{\left(b\times16^{0}\right)}_{11}$$

$$= \ 475_{ten}$$

Hexa	Decimal
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
a	10
b	11
c	12
d	13
e	14
f	15

Binary to Hexadecimal Conversion

Any integer, N can be represented as follows

$$N = \sum_{i=0}^{n} b_i 2^i = \sum_{k=0}^{\left[\frac{n}{4}\right]} \left(b_{4k+3} 2^3 + b_{4k+2} 2^2 + b_{4k+1} 2^1 + b_{4k}\right) 2^{4k}$$

$$= \sum_{k=0}^{m} h_k 16^k$$

$$h_k = b_{4k+3} 2^3 + b_{4k+2} 2^2 + b_{4k+1} 2^1 + b_{4k}$$

Each group of 4 binary digits (starting from LSB) can be converted to a hexadecimal digit – represents a shortcut to working out the binary representation

Hexadecimal Representation (2)

Case 5: Hexadecimal to Binary Conversion

Example: Convert $000001bd_{hex}$ into binary

$$\underbrace{(0)}_{0000_{two}} + \underbrace{(0)}_{0000_{two}} + \underbrace{(0)}_{0000_{two}} + \underbrace{(0)}_{0000_{two}} + \underbrace{(0)}_{0000_{two}} + \underbrace{(0)}_{0000_{two}} + \underbrace{(1)}_{0001_{two}} + \underbrace{(b)}_{1011_{two}} + \underbrace{(d)}_{1101_{two}}$$

Case 6: Binary to Hexadecimal Conversion

Example: Convert $0000\ 0000\ 0000\ 0000\ 0000\ 0001\ 1011\ 1101_{two}$ to hexadecimal

$$\underbrace{(0000)}_{0_{hex}} + \underbrace{(0000)}_{0_{hex}} + \underbrace{(0000)}_{0_{hex}} + \underbrace{(0000)}_{0_{hex}} + \underbrace{(0000)}_{0_{hex}} + \underbrace{(0000)}_{0_{hex}} + \underbrace{(0001)}_{1_{hex}} + \underbrace{(1011)}_{b_{hex}} + \underbrace{(1101)}_{d_{hex}}$$

Activity 1: Convert 1998_{ten} into binary using the hexadecimal shortcut.

2’s Complement (1)

1. MIPS uses 2’s complement to represent signed numbers
2. In 2’s complement, a positive number is represented using a 31-bit binary number
   - Example: $+2_{ten}$ is represented as $0000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0010_{two}$ or 00000002_{hex}
3. In 2’s complement, a negative number $–X_{two}$ is represented by taking the complement of its magnitude X_{two} plus 1.
   - Example: $–2_{ten}$

     Represent the magnitude in binary format

     2_{ten} is represented as $0000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0010_{two}$

     Take the complement of each digit

     The results is $1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1101_{two}$

     Add 1

     $–2_{ten}$ is represented as $1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1110_{two}$ or $\mathrm{fffffffe}_{hex}$

2’s Complement (2)

4. The MSB (32nd bit) is the sign bit.
5. To convert a 32-bit number in 2’s complement to decimal

$$b_{31} \times -2^{31} + \sum_{i=0}^{30} b_i 2^i$$

— Example:

0000 0000 0000 0000 0000 0000 0000 0010_{two} is represented by 2

1111 1111 1111 1111 1111 1111 1111 1110_{two} is represented by

$$\left(1 \times -2^{31}\right) + \left(1 \times 2^{30}\right) + \ldots + \left(1 \times 2^{1}\right) + \left(1 \times 2^{0}\right) = -2$$

Unsigned and Signed Arithmetic

MIPS has a separate format for unsigned and signed integers

1. Unsigned integers
   - are saved as 32-bit words
   - Example: Smallest unsigned integer is $00000000_{hex} = 0_{ten}$

     Largest unsigned integer is $ffffffff_{hex} = 4,294,967,295_{ten}$
2. Signed integers
   - are saved as 32-bit words in 2's complement with the MSB reserved for sign
   - If MSB = 1, then the number is negative
   - If MSB = 0, then the number is positive
   - Example:

     Smallest signed integer: $1000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0000\ 0000_{two}$ $= -(2^{31})_{10} = -2,147,483,648_{10}$

     Largest signed integer: $0111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111\ 1111_{two}$ $= (2^{31} - 1)_{10} = 2,147,483,647_{10}$

MIPS Logical Instructions

1. Shift logical left (shift right logical – srl):

```
sll $t2,$s0,4            # reg $s0 = reg $s0 << 4 bits
```

2. AND:

```
and $t0,$t1,$t2          # reg $t0 = reg $t1 & reg $t2
```

3. OR (NOR, XOR):

```
or  $t0,$t1,$t2          # reg $t0 = reg $t1 | reg $t2
nor $t1,$t1,$t3          # reg $t0 = ~ (reg $t1 | reg $t3)
```

MIPS Branch Instructions for *if* (1)

1. Branch if equal to:

```
        beq $s1,$s2,L1          # if $s1 == $s2, go to L1
```

2. Branch if not equal to:

```
        bne $s1,$s2,L2          # if $s1 != $s2, go to L2
```

3. Unconditional jump:

```
        j L3                    # go to L3
```

Example:

```
        if (i == j) go to L1;
        f = g + h;
L1:     f = f – i
```

Assume that the five variables f, g, h, i, and j are stored in the registers: $s0 to $s4

MIPS Code:

```
        beq $s3,$s4,L1          # go to L1 if i == j
        add $s0,$s1,$s2         # f = g + h
L1:     sub $s0,$s0,$s3         # f = f - i
```

MIPS Branch Instructions for *if* (2)

Example: C instructions

```
if (i == j)
   f = g + h;
else
   f = g - h;
```

Assume that the five variables f, g, h, i, and j are stored in the registers: $s0 to $s4

MIPS Code:

```
        bne $s3,$s4,L1          # go to L1 if i == j
        add $s0,$s1,$s2         # f = g + h
        j L2                    #
L1:     sub $s0,$s0,$s2         # f = f – I
L2:
```

Activity 3: Write the above code using “branch if equal to” statement?