

### Signed arithmetic explanation:

Negative numbers are stored as 2s complement form and we can identify negative numbers by checking the MSB of the binary representation of the number. 16 in 16-bit signed binary form has 0 at the MSB, hence this is a positive number. -32767 in 16-bit signed binary form has 1 at the MSB and hence this is a negative number.

#### 1) Arithmetic instruction:

**Case a:** Add Immediate instruction with positive immediate value

ADDI R17, R18, 16     => R17 = R18 + 16

Since ADDI is an I - type instruction in MIPS, this instruction will be encoded as 06510010 in the memory image

**Binary representation:** 000001\_10010\_10001\_0000000000010000

I-type instruction



Since the MSB of the 16-bit Immediate value is 0, this is a positive number.

Integer Value = 16

**Case b:** Add Immediate instruction with negative immediate value

ADDI R17, R18, -32767     => R17 = R18 - 32767

Since ADDI is an I - type instruction in MIPS, this instruction will be encoded as 06518001 in the memory image

**Binary representation:** 000001\_10010\_10001\_1000000000000001

I-type instruction



Since the MSB of the 16-bit Immediate value is 1, this is a negative number and we must perform 2s complement arithmetic.

Note that -32767 is encoded as 1000000000000001 because -32767 is a negative number and negative numbers are stored in 2s complement form.

Conversion of negative number in binary form to an integer value:

Integer value = Unsigned value of 16-bit number -  $2^{16}$

Unsigned value of 1000000000000001 is 32769

Integer value =  $32769 - 65536 = -32767$

(Notes: 32767 in decimal = 0111 1111 1111 1111 in binary => invert each bit: 1000 0000 0000 0000

=> add 1: 1000 0000 0000 0001, therefore -32767 in 2's complement format is 1000 0000 0000 0001).

## 2) Memory access instruction:

**Case a:** Load word instruction with positive immediate value

LDW R17, (R18) 16     =>  $R17 = \text{Mem}[R18 + 16]$

Since LDW is an I - type instruction in MIPS, this instruction will be encoded as 32510010 in the memory image

**Binary representation:** 001100\_10010\_10001\_0000000000010000

I-type instruction



Since the MSB of the 16-bit Immediate value is 0, this is a positive number.

Integer Value = 16

Assuming  $R18 = 2000$ ,

Since each instruction in the memory image is 4 byte aligned,

$R17 = \text{Memory\_image\_file}[(2000 + 16)/4]$  , since  $(2000+16)/4 = 504$

R17 will contain line 504 of the memory image file

**Case b:** Load word instruction with negative immediate value

LDW R17, R18, -32767     =>  $R17 = \text{Mem}[R18 - 32767]$

Since LDW is an I - type instruction in MIPS, this instruction will be encoded as 32518001 in the memory image

**Binary representation:** 001100\_10010\_10001\_1000000000000001

I-type instruction



Since the MSB of the 16-bit Immediate value is 1, this is a negative number and we must perform 2s complement arithmetic.

Note that -32767 is encoded as 1000000000000001 because -32767 is a negative number and negative numbers are stored in 2s complement form.

Conversion of negative number in binary form to an integer value:

Integer value = Unsigned value of 16-bit number -  $2^{16}$

Unsigned value of 1000000000000001 is 32769

Integer value =  $32769 - 65536 = -32767$

Assume R18 = 39999

Since each instruction in the memory image is 4 byte aligned,

$R17 = \text{Memory\_image\_file}[(39999 - 32767)/4]$

R17 will contain line 1808 of the memory image file

### 3) Branch instruction:

**Case a:** Branch instruction with positive immediate value

BEQ R17, R18, 16  $\Rightarrow PC = PC + 16$

Since BEQ is an I - type instruction in MIPS, this instruction will be encoded as 3E510010 in the memory image

**Binary representation:** 001111\_10010\_10001\_000000000010000

I-type instruction



Since the MSB of the 16-bit Immediate value is 0, this is a positive number.

Integer Value = 16

Assuming R18 = R17,

Since each instruction in the memory image is 4 byte aligned,

$PC = \text{Memory\_image\_file}[PC + 16]$

**Case b:** Branch instruction with negative immediate value

BEQ R17, R18, -2  $\Rightarrow PC = PC - 2$

Since BEQ is an I- type instruction in MIPS, this instruction will be encoded as 3E51FFFE in the memory image

**Binary representation:** 001111\_10010\_10001\_ 1111111111111110

I-type instruction



Since the MSB of the 16-bit Immediate value is 1, this is a negative number and we must perform 2s complement arithmetic.

Note that -2 is encoded as 1111111111111110 because -2 is a negative number and negative numbers are stored in 2s complement form.

Conversion of negative number in binary form to an integer value:

Integer value = Unsigned value of 16-bit number -  $2^{16}$

Unsigned value of 1111111111111110 is 65534

Integer value = 65534 - 65536 = -2

Assume R18 = R17

Since each instruction in the memory image is 4 byte aligned,

PC = Memory\_image\_file[PC - 2]