CPE 322

Digital Hardware Design Fundamentals

Electrical and Computer Engineering UAH

Review of Basic Number Representation



Unsigned Number

Positional Notation

$$\begin{array}{c|c} \dots K_2K_1K_0 \bullet K_{-1}K_{-2}\dots & \text{where } K_i = \text{symbols} \\ \text{Integer Part} & & Fractional \ Part \\ & & \\$$

Number = ... +
$$K_2R^2 + K_1R^1 + K_0R^0 + K_{-1}R^{-1} + K_{-2}R^{-2} + ...$$

Example: Unsigned Decimal Number

Notation

Number =
$$123.45$$
 =

$$1 \times 10^2 + 2 \times 10^1 + 3 \times 10^0 + 4 \times 10^{-1} + 5 \times 10^{-2}$$

Example: Unsigned Binary Number

Positional Notation

$$...K_{2}K_{1}K_{0} \bullet K_{-1}K_{-2}...$$

$$Integer\ Part$$

$$Fractional\ Part$$

$$Binary\ Point$$

$$Where\ K_{i} = symbols\ 0\ \&\ 1$$

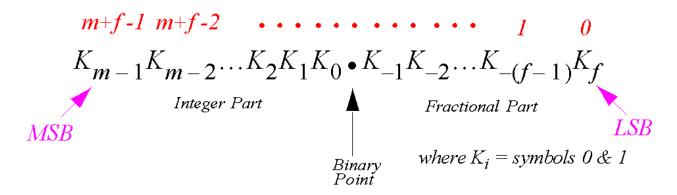
base R=2

Number =
$$101.11_2$$

= $1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 1 \times 2^{-1} + 1 \times 2^{-2}$
= 5.75_{10}

Unsigned Binary Number -- Finite Length (fixed point)

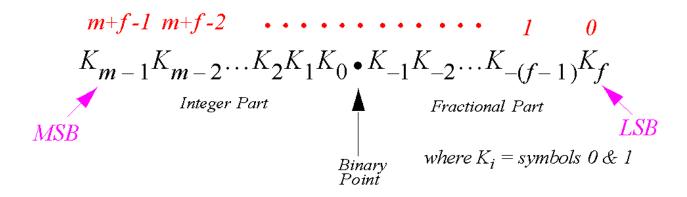
 Digital logic representation of number have a set number of bits.



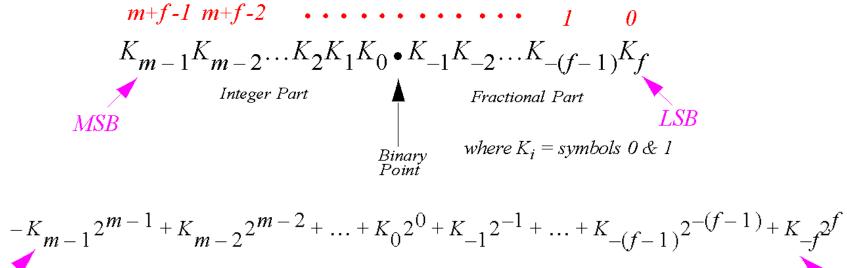
 In general, there are m bits to represent the integer (magnitude) portion of the number, f bits used to represent the fraction portion of the number.

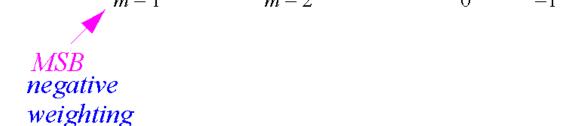
Signed Binary Number -- Finite Length (fixed point)

- Two's Complement is the most common signed binary number format.
- Two's complement uses standard positional notation but with the most significant bit having a negative weighting



Signed Binary Number -- Finite Length (fixed point)





Integers are just the special case where f = 0

Two's Complement Representation of Integers:

• Range: 2^{m-1}-1 positive numbers

2^{m-1} negative numbers

1 representation of zero

MSB => sign bit: 0 = positive (or zero) 1 = negative

Two's Complement Representation of Integers:

 To represent positive or zero numbers, simply enter binary value

i.e. for m=8 then
$$15_{10} = 00001111_2$$

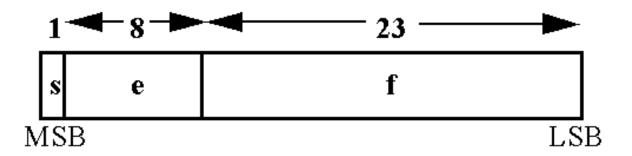
 To represent negative numbers, first enter the binary form of the numbers absolute value, then complement each bit and add 1.

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i.e. for m=8 then -15_{10} is found by comp(00001111) + 1 = 11110000 + 1 = 11110001<sub>2</sub>
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Signed binary number – Finite Length (floating point):

The format for an IEEE 32-bit floating-point number is shown below

Floating Point Number = -1^s X 1.f X 2^{e-b}
where:
s=sign bit (0=positive mantissa, 1=negative mantissa)
e=exponent biased by b (b= 127 for IEEE 32-bit format)
f=fractional mantissa



Signed binary number – Finite Length (floating point):

Special Case Numbers

Туре	Sign	Exp	Exp+Bias	Exponent	Significand	Value
Zero	0	-127	0	0000 0000	000 0000 0000 0000 0000 0000	0.0
One	0	0	127	0111 1111	000 0000 0000 0000 0000 0000	1.0
Minus One	1	0	127	0111 1111	000 0000 0000 0000 0000 0000	-1.0
Smallest denormalized number	*	-127	0	0000 0000	000 0000 0000 0000 0000 0001	$\pm 2^{-23} \times 2^{-126} = \pm 2^{-149} \approx \pm 1.4 \times 10^{-45}$
"Middle" denormalized number	*	-127	0	0000 0000	100 0000 0000 0000 0000 0000	$\pm 2^{-1} \times 2^{-126} = \pm 2^{-127} \approx \pm 5.88 \times 10^{-39}$
Largest denormalized number	*	-127	0	0000 0000	111 1111 1111 1111 1111 1111	±(1-2 ⁻²³) × 2 ⁻¹²⁶ ≈ ±1.18×10 ⁻³⁸
Smallest normalized number	*	-126	1	0000 0001	000 0000 0000 0000 0000 0000	±2 ⁻¹²⁶ ≈ ±1.18×10 ⁻³⁸
Largest normalized number	*	127	254	1111 1110	111 1111 1111 1111 1111 1111	$\pm (2-2^{-23}) \times 2^{127} \approx \pm 3.4 \times 10^{38}$
Positive infinity	0	128	255	1111 1111	000 0000 0000 0000 0000 0000	+∞
Negative infinity	1	128	255	1111 1111	000 0000 0000 0000 0000 0000	
Not a number	*	128	255	1111 1111	non zero	NaN
* Sign bit can be either 0 or 1 .						

^{29/04/2021}

Binary Coded Decimal (BCD) Numbers:

- Encoding where each 'digit' (0-9) is represented by its own 4-bit binary sequence (0000₂—1001₂)
- Advantage: Easy to convert to the decimal digits needed for I/O devices and in some cases faster decimal calculations
 - Disadvantage: Requires more bits than an equivalent binary representation. Also requires more complex circuitry for arithmetic operations.

Binary Coded Decimal (BCD) Numbers:

example:

for m=8 bit encoding:

$$01111000_2 => 0111 1000 => 78_{10}$$

Conversion of Binary to Octal Numbers (and conversely):

Converting binary numbers to Octal Numbers can be done by inspection

Each octal digit corresponds to 3 bits.

Just begin at the binary replace each group of three bits with the corresponding octal digit (assume leading and lagging 0's). example:

 $011010111110.0011_2 =$ $011 \ 010 \ 111 \ 110 \ .001 \ 100 =$ $3 \ 2 \ 7 \ 6 \ .1 \ 4_8$

Conversion of Binary to Hexadecimal Numbers (and conversely):

Converting binary numbers to Hexadecimal Numbers can also be done by inspection

Each hex digit corresponds to 4 bits.

Just begin at the binary point and replace each group of four bits with the corresponding hexadecimal symbol (0-F). example:

```
0110101111110.0011_2 =
0110 \ 1011 \ 1110 \ .0011 =
6 \ B \ E \ .3_{16}
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 Note: Conversion from binary to hexadecimal (or octal) is so easy hexadecimal and octal are often considered to be short-hand notation form binary!

Review of Number/Character Representations

ASCII Table and Description

ASCII stands for American Standard Code for Information Interchange. Computers can only understand numbers, so an ASCII code is the numerical representation of a character such as 'a' or '@' or an action of some sort. ASCII was developed a long time ago and now the non-printing characters are rarely used for their original purpose. Below is the ASCII character table and this includes descriptions of the first 32 non-printing characters. ASCII was actually designed for use with teletypes and so the descriptions are somewhat obscure. If someone says they want your CV however in ASCII format, all this means is they want 'plain' text with no formatting such as tabs, bold or underscoring - the raw format that any computer can understand. This is usually so they can easily import the file into their own applications without issues. Notepad.exe creates ASCII text, or in MS Word you can save a file as 'text only'

0 0 000 NUL (null) 32 20 040 6#32; Space 64 40 100 6#64; 8 96 60 140 6#96; a 1 1 001 S0H (start of heading) 33 21 041 6#33; 4 65 41 101 6#65; A 97 61 141 6#97; a 34 22 002 STX (start of text) 34 22 042 6#344; 66 41 102 6#66; B 98 62 142 6#98; b 34 03 03 ETX (end of text) 35 23 043 6#35; # 67 43 103 6#67; C 99 63 143 6#99; C 100 64 144 6#100; d 100 6#104 6#88; b 100 64 144 6#100; d 100 6#104 6#101; d 100 6#104 6#1	Dec	Нх Ос	Cha	r	Dec	Нх	Oct	Html	Chr	Dec	Нх	Oct	Html	Chr	Dec	: Н <u>х</u>	Oct	Html Cl	nr
2 2 002 STX (start of text) 3 3 4 22 042 & #34;" 3 66 42 102 & #66; B 98 62 142 & #98; b 3 3 03 ETX (end of text) 4 4 004 EOT (end of transmission) 36 24 044 & #36; \$ 68 44 104 & #68; D 100 64 144 & #9100; d 5 5 005 ENQ (enquiry) 37 25 045 & #37; \$ 69 45 105 & #69; E 6 6 006 ACK (acknowledge) 38 26 046 & #38; \$ 70 46 106 & #70; F 102 66 146 & #102; f 7 700 BEL (bell) 39 27 047 & #39; ' 71 47 107 & #71; G 102 66 146 & #102; f 103 67 147 & #103; g 8 8 010 BS (backspace) 40 28 050 & #40; (72 48 110 & #72; H 104 68 150 & #104; h 10 A 012 LF (NL line feed, new line) 11 B 013 VT (vertical tab) 41 29 051 & #41;) 73 49 111 & #73; I 10 A 012 LF (NF form feed, new page) 14 E 016 SO (shift out) 42 20 055 & #44; 45 20 055 & #44; 47 2F 057 & #47; 48 E 116 & #78; N 110 66 154 & #108; n 111 021 DC1 (device control 1) 11 021 DC1 (device control 1) 12 10 10 10 020 DLE (data link escape) 13 10 203 DC3 (device control 2) 15 13 025 NAK (negative acknowledge) 22 16 026 SYN (symchronous idle) 23 17 027 ETB (end of trans. block) 25 19 031 EM (end of medium) 25 73 07 1 & #55; P 26 1A 032 SUB (substitute) 26 1A 032 SUB (substitute) 27 1B 033 ESC (escape) 38 20 046 & #38; # 37 25 045 & #37; * 46 42 102 & #66; B 66 44 104 & #66; D 70 46 106 & #70; F 102 66 146 & #101; e 70 46 116 & #70; F 102 66 146 & #101; e 70 47 11 7 107 & #71; G 70 48 111 & #73; K 107 6B 153 & #105; I 77 40 111 & #73; D 108 6C 154 & #108; I 77 40 111 & #73; D 108 6C 154 & #108; I 108 6C 154 & #108; I 109 6D 155 & #109; m 110 6 155 & #109; m 111 6 1 16 154 & #101; e 100 6 155 & #109; m 110 6 155 & #109; m 111 6 1 16 16 145 & #101; e 112 70 160 & #11; e 113 D 105 CR (arriage return) 14 5 10 05 6 #46; D 15 6 10 05 0	0	0 000	NUL	(null)	32	20	040	a#32;	Space	64	40	100	a#64;	0	96	60	140	a#96;	8
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31 1F 037 <mark>US</mark> (unit separator) 63 3F 077 ? ? 95 5F 137 _ _ 127 7F 177  DEL					I														
	31	1F 037	US	(unit separator)	63	ЗF	077	?	2	95	5F	137	6#95;	_	127	7F	177		DEL

Source: www.LookupTables.com

Review of Number/Character Representations

 Other encodings of characters and numbers are also used. Examples, EBSIDIC, Gray codes, etc.

Gr	ay	Со	de				Binary						
2 ³	2 ²	2 ¹	2°	P	ositio	on	2 ³	2 ²	21	2º			
0	0	0	0		0		0	0	0	0			
0	0	0	1		1		0	0	0	1			
0	0	1	1		2		0	0	1	0			
0	0	1	0		3		0	0	1	1			
0	1	1	0		4		0	1	0	0			
0	1	1	1		5		0	1	0	1			
0	1	0	1		6		0	1	1	0			
0	1	0	0	٨	7	4	0	1	1	1			
1	1	0	0	٨	8	•	1	0	0	0			
1	1	0	1		9		1	0	0	1			
1	1	1	1		10		1	0	1	0			
1	1	1	0		11		1	0	1	1			
1	0	1	0		12		1	1	0	0			
1	0	1	1		13		1	1	0	1			
1	0	0	1		14		1	1	1	0			
1	0	0	0		15		1	1	1	1			

Floating Point Representations

- A floating point binary number consists of three parts:
 - sign (S), exponent (E), and mantissa (M).
 - Each (S, E, M) pattern uniquely identifies a floating point number.
- For each bit pattern, its IEEE floating-point value is derived as:
 - value = $(-1)^S$ * M * {2^E}, where 1.0 ≤ M < 10.0_B
- S=0 results in a positive number and S=1 a negative number.

Floating Point Representations (Mantissa part, M)

- Specifying that 1.0_B ≤ M < 10.0_B makes the mantissa value for each floating point number unique.
 - For example, the only one mantissa value allowed for 0.5_D is M =1.0
 - $0.5_D = 1.0_B * 2^{-1}$
 - Neither 10.0_B * 2 ⁻² nor 0.1_B * 2 ⁰ qualifies
- Because all mantissa values are of the form 1.XX..., one can omit the "1." part in the representation.
 - The mantissa value of 0.5_D in a 2-bit mantissa is 00, which is derived by omitting "1." from 1.00.
 - Mantissa without the implied 1 is called the fraction

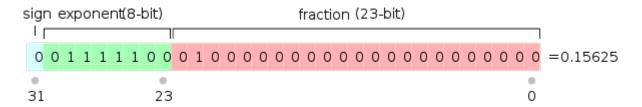
Floating Point Representations (Exponent, E)

- In an n-bits exponent representation, 2^{n-1} -1 is added to its 2's complement representation to form its excess representation.
 - See Table for a 3-bit exponent representation
- A simple unsigned integer comparator can be used to compare the magnitude of two FP numbers
- Symmetric range for +/exponents (case where Exponent is all 1's is reserved)

2's complement	Actual decimal	Excess-3
000	0	011
001	1	100
010	2	101
011	3	110
100	(reserved pattern)	111
101	-3	000
110	-2	001
111	-1	010

Floating Point Representations IEEE 754 Format

- Single Precision
 - 1 bit sign, 8 bit exponent (bias-127), 23 bit fraction



- Double Precision
 - 1 bit sign, 11 bit exponent (1023-bias), 52 bit fraction

