

UNIT 7A

Data Representation: Numbers and Text

15110 Principles of Computing,
Carnegie Mellon University - CORTINA

1

Digital Data

10010101011110101010110101001110

- What does this binary sequence represent?
- It could be:
 - an integer
 - a floating point number
 - text encoded with ASCII or another standard
 - a pixel of an image
 - several digital samples of a music recording
 - an instruction that the computer is executing
 - ...

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2

Integer Representation

- An integer can be represented using binary.
- An integer can be:
 - unsigned (always considered non-negative)
 - signed (positive or negative)
- An integer can be represented using varying numbers of bits
 - 8 bits (byte)
 - 16 bits (word)
 - 32 bits
 - 64 bits

Unsigned Integers

- Every bit represents a power of 2.
- Example (8 bits):

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	
128	64	32	16	8	4	2	1	
1	0	1	1	0	1	0	1	
2^7		2^5	2^4		2^2		2^0	
128	+	32	+	16	+	4	+	1 = 181

Unsigned Integers: Range

<u>bits</u>	<u>minimum</u>	<u>maximum</u>
8	0	$2^8 - 1$ (255)
16	0	$2^{16} - 1$ (65,535)
32	0	$2^{32} - 1$ (4,294,967,295)

Signed Integers

- Every bit represents a power of 2 except the “left-most” bit, which represents the sign of the number (0 = positive, 1 = negative)
- Example for positive integer (8 bits):

$$\begin{array}{r}
 \underline{\underline{0}} \\
 + \quad \overline{2^6} \quad \overline{2^5} \quad \overline{2^4} \quad \overline{2^3} \quad \overline{2^2} \quad \overline{2^1} \quad \overline{2^0} \\
 \\
 \underline{\underline{0}} \quad 0 \quad 1 \quad 1 \quad 0 \quad 1 \quad 0 \quad 0 \\
 + \quad \quad \quad \underline{2^5} \quad \underline{2^4} \quad \quad \underline{2^2} \\
 \\
 \quad \quad \quad 32 + 16 + \quad 4 \quad \quad \quad = +52
 \end{array}$$

Signed Integers: 2's complement

- When the leftmost bit is a 1, the integer is negative.
- To find its magnitude, we take the 2's complement of this number.
 - The 2's complement is obtained by flipping each bit of the number (from 0 to 1, or 1 to 0) and then adding 1 to that number.

Signed Integers: Negative

- What value is this signed integer?

1 1 0 0 1 1 0 0
– (leftmost bit 1 -> negative)

Flip each bit:

0 0 1 1 0 0 1 1

and add 00000001 to get magnitude:

0 0 1 1 0 1 0 0

2^5 2^4 2^2

32 + 16 + 4 = 52

So, 11001100 = -52

Signed Integers: Negative

- Example: How do you store -52 in 8 bits?

Start with +52:

$$\begin{array}{cccccccc}
 0 & 0 & 1 & 1 & 0 & 1 & 0 & 0 \\
 & & 2^5 & 2^4 & & 2^2 & & \\
 & & 32 & + & 16 & + & 4 & = & 52
 \end{array}$$

Flip each bit:

$$\begin{array}{cccccccc}
 1 & 1 & 0 & 0 & 1 & 0 & 1 & 1 \\
 \text{and add } 00000001 \text{ (in base 2):} \\
 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & = & -52
 \end{array}$$

2's complement property

- When you add a number to its 2's complement (in binary), you always get 0.
 - Remember, you're using base 2 arithmetic.
- Example (using 8 bits):

$$\begin{array}{r}
 00110100 \quad +52 \\
 + \quad 11001100 \quad -52 \\
 \hline
 00000000 \quad 0
 \end{array}$$

Signed Integers: Range

<u>bits</u>	<u>minimum</u>	<u>maximum</u>
8	-2^7 (-128) 10000000 (binary)	$2^7 - 1$ (+127) 01111111 (binary)
16	-2^{15} (-32,768)	$2^{15} - 1$ (+32,767)
32	-2^{31} (-2,147,483,648)	$2^{31} - 1$ (+2,147,483,647)

Text: ASCII standard

- ASCII (American Standard Code for Information Interchange)
 - 7-bit code to represent standard U.S. characters on a keyboard
 - Typically stored using 8 bits.
 - The 8th bit is sometimes used for parity (more on this shortly).

ASCII table

ASCII Code Chart

	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0	NUL	SOH	STX	ETX	EOT	ENQ	ACK	BEL	BS	HT	LF	VT	FF	CR	SO	SI
1	DLE	DC1	DC2	DC3	DC4	NAK	SYN	ETB	CAN	EH	SUB	ESC	FS	GS	RS	US
2		!	"	#	\$	%	&	'	()	*	+	,	-	.	/
3	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
4	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
5	P	Q	R	S	T	U	V	W	X	Y	Z	[\]	^	_
6	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
7	p	q	r	s	t	u	v	w	x	y	z	{		}	~	DEL

- Values above are represented in hexadecimal (base 16).
- ASCII code for "M" is 4D (hex).

ASCII Example

- The ASCII code for "M" is 4D hexadecimal.
- Conversion from base 16 to base 2:

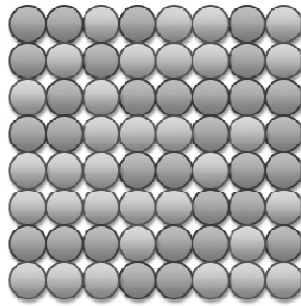
hex	binary	hex	binary	hex	binary	hex	binary
0	0000	4	0100	8	1000	C	1100
1	0001	5	0101	9	1001	D	1101
2	0010	6	0110	A	1010	E	1110
3	0011	7	0111	B	1011	F	1111
- 4D (hex) = 0100 1101 (binary) = 77 (decimal)
(leftmost bit can be used for parity)

Parity

- To detect transmission errors, the 8th (leftmost) bit could be used as an error-detection bit.
- Even parity: Set the leftmost bit so that the number of 1's in the byte is even.
- Odd parity: Set the leftmost bit so that the number of 1's in the byte is odd.

Example

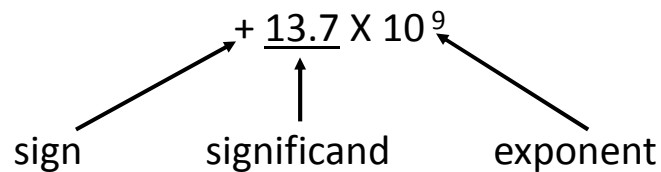
- The character "M" is transmitted using odd parity.
- "M" in ASCII (7-bits) is 1001101.
- Using odd parity, we transmit 11001101 since this makes the number of 1's odd.
- If the receiver receives a character with an even number of 1's, the receiver knows something went wrong and requests a retransmission.
 - If two bits are flipped during transmission, we can't detect this with this simple parity scheme, however the probability of 2 or more bits in error is extremely low.



- Seven characters are transmitted here as bytes using even parity along with a special 8th byte.
- The two colors represent 1's and 0's.
- One bit is in error. Can you find it?

Floating Point Numbers

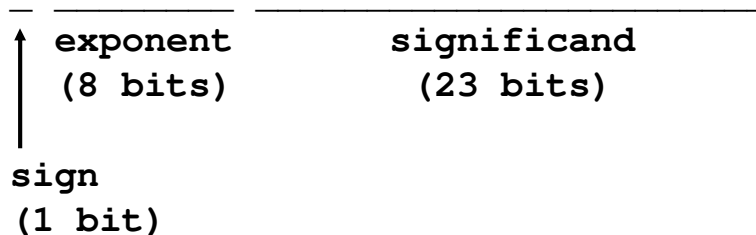
Age of the Universe in years:



- Floating point numbers are commonly represented as a binary number with these three components.

IEEE-754 standard

- Most common encoding of floating point numbers on computers today.
- 32-bit (“single-precision”) floating point:



IEEE-754 standard

- Binary Significand
 - Always assumes the form 1.XXXXXXXXXX in binary. Does not store the leading 1.
 - Stores the fractional part using 23 bits.
- Exponent
 - Stores exponent offset by 127.
 - Example: An exponent of -6 would be stored as 121.
 - Stores exponent as unsigned 8-bit integer.
 - Exponent range: min -126, max +127

