https://youtu.be/OAU28NfySsQ

Memory Addresses and Hexadecimal Numbers

Understanding the number system used by computers to store and process data is essential for effective memory management, which is why we will start with an introduction into the binary and hexadecimal number systems and the structure of memory addresses.

Early attempts to invent an electronic computing device met with disappointing results as long as engineers and computer scientists tried to use the decimal system. One of the biggest problems was the low distinctiveness of the individual symbols in the presence of noise. A 'symbol' in our alphabet might be a letter in the range A-Z while in our decimal system it might be a number in the range 0-9. The more symbols there are, the harder it can be to differentiate between them, especially when there is electrical interference. After many years of research, an early pioneer in computing, John Atanasoff, proposed to use a coding system that expressed numbers as sequences of only two digits: one by the presence of a charge and one by the absence of a charge. This numbering system is called Base 2 or binary and it is represented by the digits 0 and 1 (called 'bit') instead of 0-9 as with the decimal system. Differentiating between only two symbols, especially at high frequencies, was much easier and more robust than with 10 digits. In a way, the ones and zeroes of the binary system can be compared to Morse Code, which is also a very robust way to transmit information in the presence of much interference. This was one of the primary reasons why the binary system quickly became the standard for computing.

Inside each computer, all numbers, characters, commands and every imaginable type of information are represented in binary form. Over the years, many coding schemes and techniques were invented to manipulate these 0s and 1s effectively. One of the most widely used schemes is called ASCII (*American Standard Code for Information Interchange*), which lists the binary code for a set of 127 characters. The idea was to represent each letter with a sequence of binary numbers so that storing texts on in computer memory and on hard (or floppy) disks would be possible.

The film enthusiasts among you might know the scene in the hit movie "The Martian" with Mat Daemon, in which an ASCII table plays an important role in the rescue from Mars.

The following figure shows an ASCII table, where each character (rightmost column) is associated with an 8-digit binary number:

Dec	Bin	Hex	Char	Dec	Bin	Hex	Char	Dec	Bin	Hex	Char	Dec	Bin	Hex	Char
0	0000 0000	00	[NUL]	32	0010 0000	20	space	64	0100 0000	40	@	96	0110 0000	60	`
1	0000 0001	01	[SOH]	33	0010 0001	21	!	65	0100 0001	41	A	97	0110 0001	61	a
2	0000 0010	02	[STX]	34	0010 0010	22	"	66	0100 0010	42	B	98	0110 0010	62	b
3	0000 0011	03	[ETX]	35	0010 0011	23	#	67	0100 0011	43	C	99	0110 0011	63	c
4	0000 0100	04	[EOT]	36	0010 0100	24	$	68	0100 0100	44	D	100	0110 0100	64	d
5	0000 0101	05	[ENQ]	37	0010 0101	25	%	69	0100 0101	45	E	101	0110 0101	65	e
6	0000 0110	06	[ACK]	38	0010 0110	26	&	70	0100 0110	46	F	102	0110 0110	66	f
7	0000 0111	07	[BEL]	39	0010 0111	27	'	71	0100 0111	47	G	103	0110 0111	67	g
8	0000 1000	08	[BS]	40	0010 1000	28	(	72	0100 1000	48	H	104	0110 1000	68	h
9	0000 1001	09	[TAB]	41	0010 1001	29	)	73	0100 1001	49	I	105	0110 1001	69	i
10	0000 1010	0A	[LF]	42	0010 1010	2A	*	74	0100 1010	4A	J	106	0110 1010	6A	j
11	0000 1011	0B	[VT]	43	0010 1011	2B	+	75	0100 1011	4B	K	107	0110 1011	6B	k
12	0000 1100	0C	[FF]	44	0010 1100	2C	,	76	0100 1100	4C	L	108	0110 1100	6C	l
13	0000 1101	0D	[CR]	45	0010 1101	2D	-	77	0100 1101	4D	M	109	0110 1101	6D	m
14	0000 1110	0E	[SO]	46	0010 1110	2E	.	78	0100 1110	4E	N	110	0110 1110	6E	n
15	0000 1111	0F	[SI]	47	0010 1111	2F	/	79	0100 1111	4F	O	111	0110 1111	6F	o
16	0001 0000	10	[DLE]	48	0011 0000	30	0	80	0101 0000	50	P	112	0111 0000	70	p
17	0001 0001	11	[DC1]	49	0011 0001	31	1	81	0101 0001	51	Q	113	0111 0001	71	q
18	0001 0010	12	[DC2]	50	0011 0010	32	2	82	0101 0010	52	R	114	0111 0010	72	r
19	0001 0011	13	[DC3]	51	0011 0011	33	3	83	0101 0011	53	S	115	0111 0011	73	s
20	0001 0100	14	[DC4]	52	0011 0100	34	4	84	0101 0100	54	T	116	0111 0100	74	t
21	0001 0101	15	[NAK]	53	0011 0101	35	5	85	0101 0101	55	U	117	0111 0101	75	u
22	0001 0110	16	[SYN]	54	0011 0110	36	6	86	0101 0110	56	V	118	0111 0110	76	v
23	0001 0111	17	[ETB]	55	0011 0111	37	7	87	0101 0111	57	W	119	0111 0111	77	w
24	0001 1000	18	[CAN]	56	0011 1000	38	8	88	0101 1000	58	X	120	0111 1000	78	x
25	0001 1001	19	[EM]	57	0011 1001	39	9	89	0101 1001	59	Y	121	0111 1001	79	y
26	0001 1010	1A	[SUB]	58	0011 1010	3A	:	90	0101 1010	5A	Z	122	0111 1010	7A	z
27	0001 1011	1B	[ESC]	59	0011 1011	3B	;	91	0101 1011	5B	[	123	0111 1011	7B	{
28	0001 1100	1C	[FS]	60	0011 1100	3C	<	92	0101 1100	5C	\	124	0111 1100	7C	|
29	0001 1101	1D	[GS]	61	0011 1101	3D	=	93	0101 1101	5D	]	125	0111 1101	7D	}
30	0001 1110	1E	[RS]	62	0011 1110	3E	>	94	0101 1110	5E	^	126	0111 1110	7E	~
31	0001 1111	1F	[US]	63	0011 1111	3F	?	95	0101 1111	5F	_	127	0111 1111	7F	[DEL]

The letter `U` for example can be represented by the following sequence of bits: `0101 0101`

QUESTION 1 OF 2

Can you figure out the binary sequence for the word "UDACITY"?

- ○ 01001000 01100101 01101100 01101100 01101111 0100000 01010111 01101111 01110010 01101100 01100100
- ○ 01110100 01110010 01111001 01000001 01100111 01100001 01101001 01101110
- ✓ 01010101 01000100 01000001 01000011 01001001 01010100 01011001
- ○ 01010101 01000100 01001111 01001110 01001101 01001101 01001101

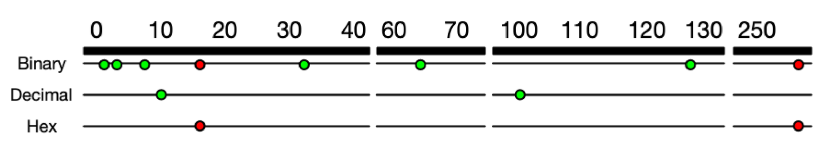
SUBMIT

In addition to the decimal number (column "Dec") and the binary number, the ASCII table provides a third number for each character (column "Hex"). According to the table above, the letter `z` is referenced by the decimal number `122`, by the binary number `0111 1010` and by `7A`. You have probably seen this type of notation before, which is called "*hexadecimal*". Hexadecimal (hex) numbers are used often in computer systems, e.g for displaying memory readouts - which is why we will look into this topic a little bit deeper. Instead of having a base of 2 (such as binary numbers) or a base of 10 (such as our conventional decimal numbers), hex numbers have a base of 16. The conversion between the different numbering systems is a straightforward operation and can be easily performed with any scientific calculator. More details on how to do this can e.g. be found here.

There are several reasons why it is preferable to use hex numbers instead of binary numbers (which computers store at the lowest level), three of which are given below:

1. **Readability**: It is significantly easier for a human to understand hex numbers as they resemble the decimal numbers we are used to. It is simply not intuitive to look at binary numbers and decide how big they are and how they relate to another binary number.
2. **Information density**: A hex number with two digits can express any number from 0 to 255 (because 16^2 is 256). To do the same in the binary system, we would require 8 digits. This difference is even more pronounced as numbers get larger and thus harder to deal with.
3. **Conversion into bytes**: Bytes are units of information consisting of 8 bits. Almost all computers are byte-addressed, meaning all memory is referenced by byte, instead of by bit. Therefore, using a counting system that can easily convert into bytes is an important requirement. We will shortly see why grouping bits into a byte plays a central role in understanding how computer memory works.

The reason why early computer scientists have decided to not use decimal numbers can also be seen in the figure below. In these days (before pocket calculators were widely available), programers had to interpret computer output in their head on a regular basis. For them, it was much easier and quicker to look at and interpret `7E` instead of `0111 1110`. Ideally, they would have used the decimal system, but the conversion between base 2 and base 10 is much harder than between base 2 and base 16. Note in the figure that the decimal system's digit transitions never match those of the binary system. With the hexadecimal system, which is based on a multiple of 2, digit transitions match up each time, thus making it much easier to convert quickly between these numbering systems.



Each dot represents an increase in the number of digits required to express a number in different number systems. For base 2, this happens at 2, 4, 8, 32, 64, 128 and 256. The red dots indicate positions where several numbering systems align. Note that there are breaks in the number line to conserve space.

QUESTION 2 OF 2

Convert the following numbers from binary into hex and vice-versa:

Submit to check your answer choices!

NUMBER	CONVERSION
FF	1111 1111
1D	11101
1101 1001	D9
1001 0110	96

SUBMIT

Outro

https://youtu.be/q1C7lBXNGn0