This simplified tutorial contains the basics of different bases.

You are responsible for the **[Required]** sections. That is, conversions from binary, octal and hex to decimal, and from binary to octal and hex.

1. Number Systems

There are infinite ways to represent a number. The four commonly associated with modern computers and digital electronics are: Decimal, Binary, Octal, and Hexadecimal.

Decimal (base 10) is the way most human beings represent numbers.

Decimal counting goes:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21 and so on.

Binary (base 2) is the natural way most digital circuits represent and manipulate numbers.

Binary counting goes:
0, 1, 10, 11, 100, 101, 110, 111, 1000, 1001, 1010, 1011, 1100, 1101, 1110, 1111, 10000, 10001, and so on.

Octal (base 8) was previously a popular choice for representing digital circuit numbers in a form that is more compact than binary. Octal is sometimes abbreviated as **oct**.

Octal counting goes:
0, 1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 14, 15, 16, 17, 20, 21, and so on.

Hexadecimal (base 16) is currently the most popular choice for representing digital circuit numbers in a form that is more compact than binary. Hexadecimal numbers are sometimes represented by preceding the value with '0x', or '0X', as in 0x1B84. Hexadecimal is sometimes abbreviated as **hex**.

Hexadecimal counting goes:
0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F, 10, 11, 12,13,14,15,16,17,18,19,1A,1B,1C,1D,1E,1F, 20, 21 and so on.

All four number systems are equally capable of representing any number. Furthermore, a number can be perfectly converted between the various number systems without loss of numeric value.

Two observations: For a number system of base *x*, where *x* is 10 (decimal), 2 (binary), 8 (oct) or 16 (hex),

- Starting from the right most position, the 1st position has base value x^0, the 2nd position has base value x^1, the 3rd position has base value x^2 and so on, i.e., … $x^3\ x^2\ x^1\ x^0$. Thus a decimal literal 134 represents one 10^2 and three 10^1 and four 10^0. That is, $1\times10^2 + 3\times10^1 + 4\times10^0 = 100+ 30+ 4 = 134$.
- For each position, there are *x* possible values, ranging from 0 to *x*-1. So each position of decimal has 10 possible values (0-9), binary has 2 values (0-1), oct has 8 values (0-7), and hex has 16 values (0-9 and then A-F -- we cannot use 10-15 as each position can has only one letter).

2. Conversion from Bin, Oct, Hex to Decimal

2.1 Binary to Decimal

They say there are only 10 people in this world: those that understand binary and those that don't. Ha ha.

If you don't get that joke, you'll need a method to convert from binary to decimal.

[Required] The conversion can be performed in the conventional mathematical way, by showing each digit place as an increasing power of 2.

$11100001 = (1 \times 2^7) + (1 \times 2^6) + (1 \times 2^5) + (0 \times 2^4) + (0 \times 2^3) + (0 \times 2^2) + (0 \times 2^1) + (1 \times 2^0)$

$= 225$ decimal

[Optional] One another method involves addition and multiplication.

1. Start the decimal result at 0.
2. Remove the most significant binary digit (leftmost) and add it to the result.
3. If all binary digits have been removed, you're done. Stop.
4. Otherwise, **multiply the result by 2.**
5. Go to step 2.

Here is an example of converting 11100001 binary to decimal:

Binary Digits	Operation	Decimal Result	Operation	Decimal Result
11100001	+1	1	× 2	2
1100001	+1	3	× 2	6
100001	+1	7	× 2	14
00001	+0	14	× 2	28
0001	+0	28	× 2	56
001	+0	56	× 2	112
01	+0	112	× 2	224
1	+1	225	done	

2.2 Octal to Decimal

[Required] The conversion can be performed in the conventional mathematical way, by showing each digit place as an increasing power of 8.

345 octal = $(3 \times 8^2) + (4 \times 8^1) + (5 \times 8^0)$

$= (3 \times 64) + (4 \times 8) + (5 \times 1) = 229$ decimal

[Optional] Converting octal to decimal can be done with addition and multiplication.

1. Start the decimal result at 0.
2. Remove the most significant octal digit (leftmost) and add it to the result.
3. If all octal digits have been removed, you're done. Stop.
4. Otherwise, **multiply the result by 8.**
5. Go to step 2.

Octal Digits	**Operation**	**Decimal Result**	**Operation**	**Decimal Result**
345	+3	3	× 8	24
45	+4	28	× 8	224
5	+5	229	done.	

2.3 Hexadecimal to Decimal

[Required] Converting hexadecimal to decimal can be performed in the conventional mathematical way, by showing each digit place as an increasing power of 16. Of course, hexadecimal letter values need to be converted to decimal values before performing the math.

Hexadecimal:	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
Decimal:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

34F hexadecimal:
$= (3 \times 16^2) + (4 \times 16^1) + ((F) \times 16^0)$

$= (3 \times 256) + (4 \times 16) + (15 \times 1) = 847$ decimal

[Optional] Converting hex to decimal can also be done with addition and multiplication.

1. Start the decimal result at 0.
2. Remove the most significant hex digit (leftmost) and add it to the result.
3. If all hex digits have been removed, you're done. Stop.
4. Otherwise, **multiply the result by 16.**
5. Go to step 2.

Of course, hexadecimal letter values (i.e., A - F) need to be converted to decimal values before performing the math.

Hex Digits	Operation	Decimal Result	Operation	Decimal Result
34F	+3	3	× 16	48
4F	+4	52	× 16	832
F	+15	847	done.	

3. Conversion from Binary to Oct and Hex

3.1 Binary to Octal

[Required] An easy way to convert from binary to octal is to group binary digits into sets of **three**, starting with the least significant (rightmost) digits.

Binary: 11100101 = 11 100 101

011 100 101 Pad the most significant digits with zeros if necessary to complete a group of three.

Then, look up the decimal value of each group, as shown in the table:

Binary:	**000**	**001**	**010**	**011**	**100**	**101**	**110**	**111**
Octal:	0	1	2	3	4	5	6	7

Binary = 011 100 101

Octal = 3 4 5 = 345

3.2 Binary to Hexadecimal

[Required] An equally easy way to convert from binary to hexadecimal is to group binary digits into sets of **four**, starting with the least significant (rightmost) digits.

Binary: 11100101 = 1110 0101

Then, look up the decimal value of each group, as shown in the table:

Binary:	**0000**	**0001**	**0010**	**0011**	**0100**	**0101**	**0110**	**0111**
Hexadecimal:	0	1	2	3	4	5	6	7
Binary:	**1000**	**1001**	**1010**	**1011**	**1100**	**1101**	**1110**	**1111**
Hexadecimal:	8	9	A	B	C	D	E	F

Binary = 1110 0101

Hexadecimal = E 5 = E5