Digital Data Encoding & Logic

Medical Electrical Equipment (BME590L)

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Digital Data

- Binary states: `HIGH` and `LOW`
- `LOW` is commonly `GND`.
- `HIGH` is commonly either 5, 3.3 or 1.8 V.
- Why binary? Electronics really can only represent "On" and "Off" states at the lowest level in hardware.

Binary (base2) Numbers

- base10 (decimal): 0-9 in summed powers of 10.
- base2 (binary): 0, 1 in summed powers of 2.
- Convert binary to decimal: $a_n 2^n + a_{n-1} 2^{n-1} + \cdots + a_1 2^1 + a_0 2^0$
- Common binary number lengths:

Length	Name	Example
1	Bit	0
4	Nibble	1001
8	Byte	10011011

- **Word**: length dependent on system architecture (16-, 32- or 64-bits)

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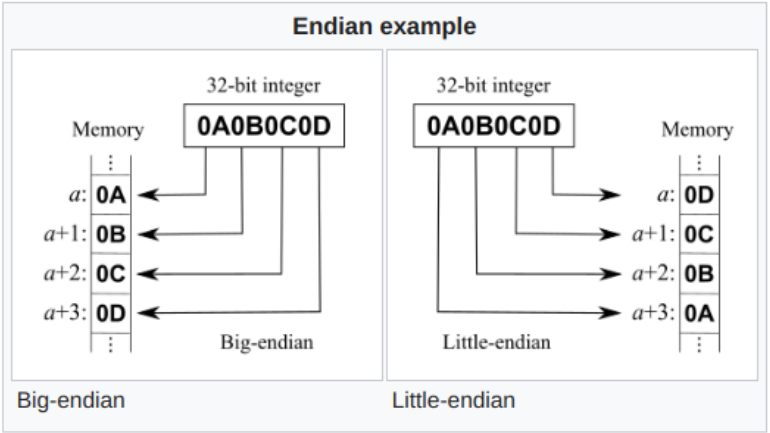
Convert Decimal to Binary: Binary Search

1. Find largest power of 2 not larger than your number.
2. Subtract that number from decimal and then find the next power of 2 not greater than the remainder.
3. Each power of 2 that remains and is subtracted contributes a bit for that power of 2.
4. **Task**: Convert 155 to a binary number.

Convert 155 to binary...

$$155 = 128 \times 1 + 64 \times 0 + 32 \times 0 + 16 \times 1 + 8 \times 1 + 4 \times 0 + 2 \times 1 + 1 \times 1$$
$$155_{10} = 10011011_2$$

Endianess



https://en.wikipedia.org/wiki/Endianness

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Binary Encoding: Hexadecimal ("Hex", `base16`)

- Uses `0-9` and `A-F` to represent values 0-15.
- Hex is indicated by a 16-subscript or the prefix `0x`.
- For example: $22546_{10} == 5812_{16} == \texttt{0x5812} == 101100000010010_2$
- Binary representation quickly becomes too cumbersome. Hex is better, but longer data streams can benefit from even longer word lengths.

`https://en.wikipedia.org/wiki/Hexadecimal`

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Binary Encoding: base64

Index	Binary	Char	Index	Binary	Char	Index	Binary	Char	Index	Binary	Char
0	000000	A	16	010000	Q	32	100000	g	48	110000	w
1	000001	B	17	010001	R	33	100001	h	49	110001	x
2	000010	C	18	010010	S	34	100010	i	50	110010	y
3	000011	D	19	010011	T	35	100011	j	51	110011	z
4	000100	E	20	010100	U	36	100100	k	52	110100	0
5	000101	F	21	010101	V	37	100101	l	53	110101	1
6	000110	G	22	010110	W	38	100110	m	54	110110	2
7	000111	H	23	010111	X	39	100111	n	55	110111	3
8	001000	I	24	011000	Y	40	101000	o	56	111000	4
9	001001	J	25	011001	Z	41	101001	p	57	111001	5
10	001010	K	26	011010	a	42	101010	q	58	111010	6
11	001011	L	27	011011	b	43	101011	r	59	111011	7
12	001100	M	28	011100	c	44	101100	s	60	111100	8
13	001101	N	29	011101	d	45	101101	t	61	111101	9
14	001110	O	30	011110	e	46	101110	u	62	111110	+
15	001111	P	31	011111	f	47	101111	v	63	111111	/
Padding		=									

https://en.wikipedia.org/wiki/Base64

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Text Encoding: ASCII

Bits b_4	b_3	b_2	b_1	Row ↓ / Column →	0 (000)	1 (001)	2 (010)	3 (011)	4 (100)	5 (101)	6 (110)	7 (111)
0	0	0	0	0	NUL	DLE	SP	0	@	P	`	p
0	0	0	1	1	SOH	DC1	!	1	A	Q	a	q
0	0	1	0	2	STX	DC2	"	2	B	R	b	r
0	0	1	1	3	ETX	DC3	#	3	C	S	c	s
0	1	0	0	4	EOT	DC4	$	4	D	T	d	t
0	1	0	1	5	ENQ	NAK	%	5	E	U	e	u
0	1	1	0	6	ACK	SYN	&	6	F	V	f	v
0	1	1	1	7	BEL	ETB	'	7	G	W	g	w
1	0	0	0	8	BS	CAN	(	8	H	X	h	x
1	0	0	1	9	HT	EM	)	9	I	Y	i	y
1	0	1	0	10	LF	SUB	*	:	J	Z	j	z
1	0	1	1	11	VT	ESC	+	;	K	[	k	{
1	1	0	0	12	FF	FS	,	<	L	\	l	¦
1	1	0	1	13	CR	GS	—	=	M	]	m	}
1	1	1	0	14	SO	RS	.	>	N	^	n	~
1	1	1	1	15	SI	US	/	?	O	_	o	DEL

https://en.wikipedia.org/wiki/ASCII

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Text Encoding: UTF-8

- Unicode Transformation Format - 8-bit
- 1,112,064 "code points"
  - Characters for multiple languages
  - Symbols
  - Emojis

https://en.wikipedia.org/wiki/UTF-8

Data Types

Common data types (in C, assuming 16-bit word length):

- **boolean** (1- or 8-bit): true/false (1/0)
- **byte** (8-bit): unsigned, 0–255
- **char** (8-bit): signed, -128–127
- **int** (16-bit): signed, -32768–32767
- **uint** (16-bit): unsigned, 0–65535
- **long** (32-bit): signed, -2147483648–2147483647
- **float** (32-bit): signed, -3.4028235E38–3.4028235E38

Floating Point Numbers

$$12.345 = \underbrace{12345}_{\text{significand}} \times \underbrace{10^{\overbrace{-3}^{\text{exponent}}}}_{\text{base}}$$

Data Type Operations

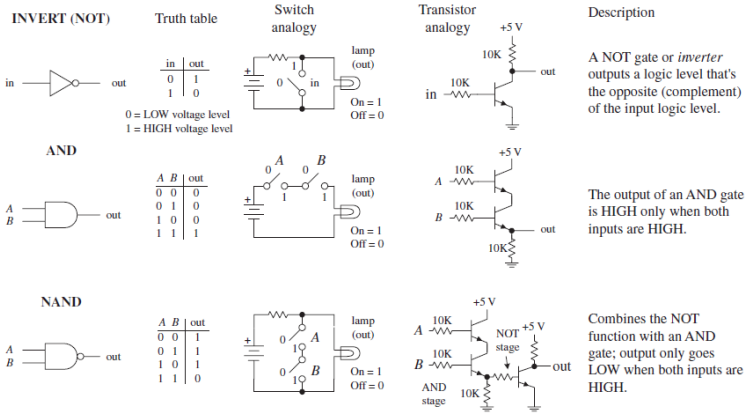
- You **cannot** use different data types in mathematical operations. You must **typecast**.
- Watch out for integer math that will yield a non-integer result.
- If your mathematical operation exceeds the min/max value of the bit depth, the data will "wrap" around.
  - $11111111 + 1 = 100000000$, but...
  - $100000000 \rightarrow 00000000$ (8-bit word)

Declaring Variables with Data Types

- Why not always just use the largest bit-depth floats?!
- Matlab makes everything a `double`.
- Python infers data type.
- `nRF52833` only has 128 kB of RAM.
- Example of variable declarations:

`https://gitlab.oit.duke.edu/mhealthtympanometer/mhealth-tymp-firmware/-/blob/main/mhealth-tymp/src/main.c#L69`

Logic Gates



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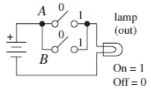
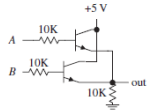
Logic Gates

OR

A	B	out
0	0	0
0	1	1
1	0	1
1	1	1

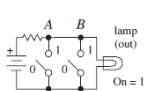


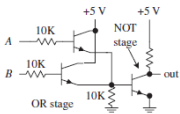


The output of an OR gate will go HIGH if one or both inputs goes HIGH. The output only goes LOW when both inputs are LOW.

NOR

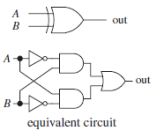
A	B	out
0	0	1
0	1	0
1	0	0
1	1	0





Combines the NOT function with an OR gate; output goes LOW if one or both inputs are LOW, output goes HIGH when both inputs are LOW.

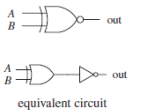
Exclusive OR (XOR)



A	B	out
0	0	0
0	1	1
1	0	1
1	1	0

The output of an XOR gate goes HIGH if the inputs are different from each other. XOR gates only come with two inputs.

Exclusive NOR (XNOR)



A	B	out
0	0	1
0	1	0
1	0	0
1	1	1

Combines the NOT function with an XOR gate; output goes HIGH if the inputs are the same.

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Before next lecture...

Please read the following sections in *Practical Electronics for Inventors*:

- 4.1 Semiconductors
- 4.2 Diodes
- 4.3 Transistors