

Lecture 2: Binary representation

CMPE 120: Computer Organization and Architecture

Olivia Weng

Logistics

- Office hours have been announced on Piazza and on the syllabus (canvas view only)
 - Olivia:
 - Tuesdays, 4 - 5pm, ENG 283H
 - Fridays, 9 - 10am, Zoom (link on Piazza & syllabus)
 - TA Vikasni:
 - Thursdays, 7 - 8pm, Zoom (link on Piazza & syllabus)
 - TA Shinika:
 - Fridays, 6 - 7pm, Zoom (link on Piazza & syllabus)
- HW0 due this Thursday

Testing out iClicker (again)

- Join Section 01: <https://join.iclicker.com/BXFG>



Testing out iClicker (again)

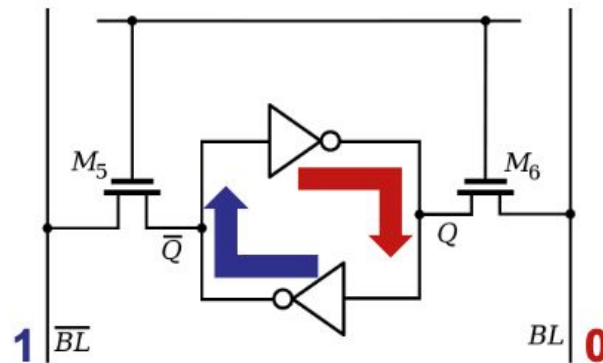
- Join Section 02: <https://join.iclicker.com/RMQT>



How do we store a string of characters inside a computer?

How do computers store characters?

- SRAM cell
 - SRAM = Static random access memory
 - Stores state of a **single bit: 0 or 1**
 - High state: 1
 - Low state: 0
- Why?
 - **Cheap**: made of sand (silicon)
 - **Fast**: read/write billions of times per second
 - **Accurate**: nearly always correctly returns the stored bit
 - **Small**: fit billions inside a computer chip



$$00 = 0 = A$$

$$01 = 1 = B$$

$$10 = C$$

$$11 = D$$

How can we use bits **0/1** to represent **characters**?

How can we use bits 0/1 to represent characters?

- Binary (0/1) number system
 - Use only 0 and 1 to represent numbers!
- Assign a number to each character
 - ASCII Encoding: [0-127] represents all English characters

↳ representation

ASCII Table

Dec	Hx	Oct	Char	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL (null)	32	20	040	 Space		64	40	100	@ @		96	60	140	` <b>`	
1	1	001	SOH (start of heading)	33	21	041	! !		65	41	101	A A		97	61	141	a a	
2	2	002	STX (start of text)	34	22	042	" "		66	42	102	B B		98	62	142	b b	
3	3	003	ETX (end of text)	35	23	043	# #		67	43	103	C C		99	63	143	c c	
4	4	004	EOT (end of transmission)	36	24	044	$ \$		68	44	104	D D		100	64	144	d d	
5	5	005	ENQ (enquiry)	37	25	045	% %		69	45	105	E E		101	65	145	e e	
6	6	006	ACK (acknowledge)	38	26	046	& &		70	46	106	F F		102	66	146	f f	
7	7	007	BEL (bell)	39	27	047	' '		71	47	107	G G		103	67	147	g g	
8	8	010	BS (backspace)	40	28	050	((		72	48	110	H H		104	68	150	h h	
9	9	011	TAB (horizontal tab)	41	29	051	))		73	49	111	I I		105	69	151	i i	
10	A	012	LF (NL line feed, new line)	42	2A	052	* *		74	4A	112	J J		106	6A	152	j j	
11	B	013	VT (vertical tab)	43	2B	053	+ +		75	4B	113	K K		107	6B	153	k k	
12	C	014	FF (NP form feed, new page)	44	2C	054	, ,		76	4C	114	L L		108	6C	154	l l	
13	D	015	CR (carriage return)	45	2D	055	- -		77	4D	115	M M		109	6D	155	m m	
14	E	016	SO (shift out)	46	2E	056	. .		78	4E	116	N N		110	6E	156	n n	
15	F	017	SI (shift in)	47	2F	057	/ /		79	4F	117	O O		111	6F	157	o o	
16	10	020	DLE (data link escape)	48	30	060	0 0		80	50	120	P P		112	70	160	p p	
17	11	021	DC1 (device control 1)	49	31	061	1 1		81	51	121	Q Q		113	71	161	q q	
18	12	022	DC2 (device control 2)	50	32	062	2 2		82	52	122	R R		114	72	162	r r	
19	13	023	DC3 (device control 3)	51	33	063	3 3		83	53	123	S S		115	73	163	s s	
20	14	024	DC4 (device control 4)	52	34	064	4 4		84	54	124	T T		116	74	164	t t	
21	15	025	NAK (negative acknowledge)	53	35	065	5 5		85	55	125	U U		117	75	165	u u	
22	16	026	SYN (synchronous idle)	54	36	066	6 6		86	56	126	V V		118	76	166	v v	
23	17	027	ETB (end of trans. block)	55	37	067	7 7		87	57	127	W W		119	77	167	w w	
24	18	030	CAN (cancel)	56	38	070	8 8		88	58	130	X X		120	78	170	x x	
25	19	031	EM (end of medium)	57	39	071	9 9		89	59	131	Y Y		121	79	171	y y	
26	1A	032	SUB (substitute)	58	3A	072	: :		90	5A	132	Z Z		122	7A	172	z z	
27	1B	033	ESC (escape)	59	3B	073	; ;		91	5B	133	[[		123	7B	173	{ {	
28	1C	034	FS (file separator)	60	3C	074	< <		92	5C	134	\ \		124	7C	174	| 	
29	1D	035	GS (group separator)	61	3D	075	= =		93	5D	135	]]		125	7D	175	} }	
30	1E	036	RS (record separator)	62	3E	076	> >		94	5E	136	^ ^		126	7E	176	~ ~	
31	1F	037	US (unit separator)	63	3F	077	? ?		95	5F	137	_ _		127	7F	177	 DEL	

Source: www.LookUpTables.com

A: ✓
B: X

How to represent numbers in binary?

- Two (binary) electrical states
 - High (on) = 1
 - Low (off) = 0

- A **number** is an array of RAM cells in binary states:

0	0	1	0	1	0	0	1
---	---	---	---	---	---	---	---

= #?

How to represent numbers in binary? *Base 2*

- What number is this?

<u>0</u>	<u>0</u>	<u>1</u>	<u>0</u>	<u>1</u>	<u>0</u>	<u>0</u>	<u>1</u>
2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0

$$\underline{128}$$

$$\begin{aligned} &\Rightarrow 1 \times 10^2 + 2 \times 10^1 + 8 \times 10^0 \\ &\Rightarrow 1 \times 100 + 2 \times 10 + 8 \times 1 \\ &\Rightarrow 100 + 20 + 8 \\ &= 128 \end{aligned}$$

$$0 + 0 + 1 \times 2^5 + 0 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 1 \times 2^0$$

$$\Rightarrow 1 \times 32 + 1 \times 8 + 1 \times 1$$

$$\Rightarrow 32 + 8 + 1 = 41$$

Base 10

How to represent numbers in binary?

- What does each bit's **binary state** mean?
 - Recall:
 - **High** (on) = 1
 - **Low** (off) = 0

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

= 41

How to represent numbers in binary?

- What number is this?

-
-
- | | |
|----|-----|
| A. | 125 |
| B. | 135 |
| C. | 162 |
| D. | 146 |

→

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

$$1 \times 2^7 + 1 \times 2^4 + 1 \times 2^1$$

$$\Rightarrow 128 + 16 + 2 = 146$$

How to represent numbers in binary?

- What number is this?

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

= 146

How to represent numbers in binary?

- What number is this?

→

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
0	0	0	0	0	1	1	0

$4 + 2 = 6$

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
0	1	0	1	0	1	0	0

$$1 \times 2^6 + 1 \times 2^4 + 1 \times 2^2$$

$$64 + 16 + 4 = 84$$

- A. 6 & 84
- B. 5 & 84
- C. 4 & 72
- D. 1 & 68

How to represent numbers in binary?

- What number is this?

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
0	0	0	0	0	1	1	0

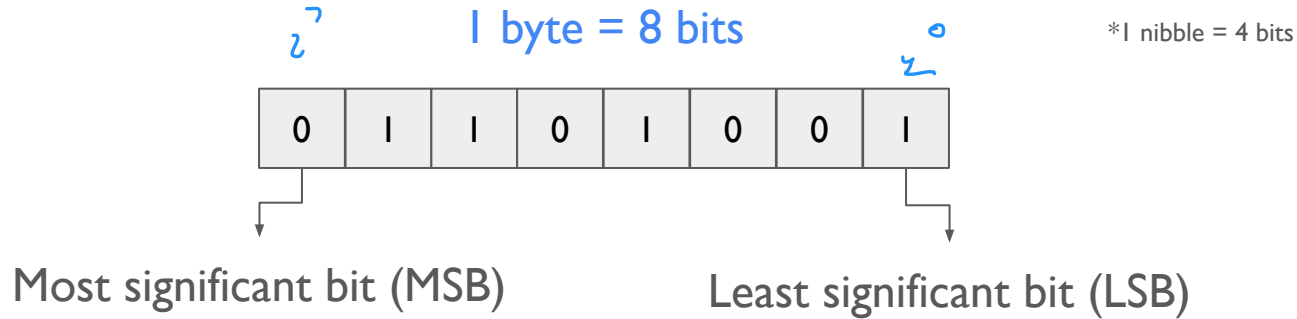
= 6

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
0	1	0	1	0	1	0	0

= 84

How to represent numbers in binary?

- Some binary definitions:



- Why is it called **MSB/LSB**?

How many values can be represented in binary?

1 bit

0
1 } = 2

$$2^1 = 2 \text{ val}$$

2 bits

0 0
0 1
1 0
1 1 } = 4

$$2^2 = 4 \text{ val}$$

3 bits

0 0 0
0 0 1
0 1 0
⋮
⋮
⋮

$$\begin{aligned} &\underline{2} \times \underline{2} \times \underline{2} \\ &= 2^3 = 8 \end{aligned}$$

How many values can be represented in binary?

1 bit

Binary	Value
0	0
1	1

$2^1 \text{ bit} = 2 \text{ values}$

2 bits

Binary	Value
00	0
01	1
10	2
11	3

$2^2 \text{ bits} = 4 \text{ values}$

3 bits

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

$2^3 \text{ bits} = 8 \text{ values}$

Demo I

- `hello world!`
- `print_abcd_char_and_int()`
- `uint8_t bin8_to_dec(char bin_arr[])`