SY110
Digital Data: Bits & Bytes

Major Brian Hawkins, USMC

U.S. Naval Academy

Fall AY 2018

Outline

Bits and Bytes

Behind the scenes

- Information systems store digital data as a series of 0's and 1's – otherwise known as *bits*!
- A bit (*Binary digit*) can only take on the value of 0 or 1
- A sequence of eight bits is called a *byte*

Digital Data Prefixes

Because a computer can process **many** bits and bytes, we need shorthand to refer to large quantities of them. Note that these quantities are **base 2**, and not the usual **base 10**.

- kilo (k) $= 2^{10} = 1,024 \approx 1,000$
- mega (M) $= 2^{20} = 1,048,576 \approx 1,000,000$
- giga (G) $= 2^{30} = 1,073,741,824 \approx 1,000,000,000$
- tera (T) $= 2^{40} = 1,099,511,627,776 \approx 1,000,000,000,000$

Bits and Bytes

Bits vs Bytes

Bits are abbreviated (b), while bytes are abbreviated (B).

Examples

- A kilobyte (kB) is 2^{10} bytes, which is 8×2^{10} bits $= 2^{13}$ bits
  - 8 bits in a byte, and $8 = 2^3$
- A terabit (Tb) is 2^{40} bits, which is $(2^{40} \div 8)$ bytes $= 2^{37}$ bytes
- How many bits in 6 megabytes (MB)?

Binary Numbers

All digital data – whether stored on your computer's hard drive, loaded in memory, or being transmitted across WiFi or Ethernet – is made up of 8-bit bytes

- Music, text documents, video
- All can be expressed in terms of numbers, which can be converted into 0's and 1's

Converting binary and decimal

In base 10...

We can write the number 1705 as

$$1705_{10} = 1 \times 10^3 + 7 \times 10^2 + 0 \times 10^1 + 5 \times 10^0$$

In base 2...

We can write the number 25 as

$$25_{10} = \underline{1} \times 2^4 + \underline{1} \times 2^3 + \underline{0} \times 2^2 + \underline{0} \times 2^1 + \underline{1} \times 2^0 = 11001_2$$

Decimal to binary conversion

To convert a decimal number (base 10) to binary (base 2), follow the steps below. We'll use 42 as an example:

1. Find the largest power of 2 that is less than or equal to the decimal number we're converting. In our case, $2^5 = 32$ is the largest, because $2^6 = 64 > 42$.
2. Draw the 6 places with their associated power of 2 positions underneath them, and put a "1" in the 2^5 position.

1					
2^5	2^4	2^3	2^2	2^1	2^0

3. We now have to convert $42 - 32 = 10$ to binary. Repeat the process; the largest power of 2 less than or equal to 10 is $8 = 2^3$, so put a 1 in the 2^3 position and place a 0 in the 2^4 place.

1	0	1			
2^5	2^4	2^3	2^2	2^1	2^0

Decimal to binary conversion

1. We're left with $10 - 8 = 2$ to convert to binary, and clearly $2 = 2^1$. So we put a 1 in the 2^1 place, and a 0 in the 2^2 place because we didn't need to use it.

2^5	2^4	2^3	2^2	2^1	2^0
1	0	1	0	1	

2. $2 - 2 = 0$, so we place a 0 in the 2^0 position.

2^5	2^4	2^3	2^2	2^1	2^0
1	0	1	0	1	0

- So our answer is 101010!
- How else could we have known the 2^0 entry would be 0?

Binary to decimal conversion

What if we want to convert binary to decimal? Let's take 110110 as our example.

1. Draw the power of 2 places below each binary digit, like so:

1	1	0	1	1	0
2^5	2^4	2^3	2^2	2^1	2^0

2. For each entry, multiply the bit value times the power of 2 below it:

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

$$= 32 + 16 + 4 + 2 = 54$$

Important notes

- As we learned a second ago, a byte is 8 bits
- What decimal numbers can we represent using a byte?
- What is 00000000?
- What is 11111111?

Hexadecimal

With a large amount of data, looking at binary can become cumbersome. Oftentimes, we represent bytes of data as 2 *hexadecimal* digits. (Hexadecimal is the base 16 numbering system – each digit can be 0 to 15, where a = 10, b = 11, c = 12, d = 13, e = 14, and f = 15).

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

Using the table above, we see that the sequence 11010010 is d2 in hexadecimal. To convert 3f, we use the chart to obtain 00111111. Oftentimes, hex values are written with a '0x' preceeding them, as in '0xd2' to convey to the reader that it is a hexadecimal value.

ASCII Character Encoding

The most fundamental type of data stored on an information system is *plain text*. Most character encoding schemes are based on or extended from ASCII – the American Standard Code for Information Interchange.

PRINTABLE CHARACTERS								
DEC	HEX	CHARACTER	DEC	HEX	CHARACTER	DEC	HEX	CHARACTER
32	0x20	<SPACE>	64	0x40	@	96	0x60	`
33	0x21	!	65	0x41	A	97	0x61	a
34	0x22	"	66	0x42	B	98	0x62	b
35	0x23	#	67	0x43	C	99	0x63	c
36	0x24	$	68	0x44	D	100	0x64	d
37	0x25	%	69	0x45	E	101	0x65	e
38	0x26	&	70	0x46	F	102	0x66	f
39	0x27	'	71	0x47	G	103	0x67	g
40	0x28	(	72	0x48	H	104	0x68	h
41	0x29	)	73	0x49	I	105	0x69	i
42	0x2A	*	74	0x4A	J	106	0x6A	j
43	0x2B	+	75	0x4B	K	107	0x6B	k
44	0x2C	,	76	0x4C	L	108	0x6C	l
45	0x2D	-	77	0x4D	M	109	0x6D	m
46	0x2E	.	78	0x4E	N	110	0x6E	n
47	0x2F	/	79	0x4F	O	111	0x6F	o
48	0x30	0	80	0x50	P	112	0x70	p
49	0x31	1	81	0x51	Q	113	0x71	q
50	0x32	2	82	0x52	R	114	0x72	r
51	0x33	3	83	0x53	S	115	0x73	s
52	0x34	4	84	0x54	T	116	0x74	t
53	0x35	5	85	0x55	U	117	0x75	u
54	0x36	6	86	0x56	V	118	0x76	v
55	0x37	7	87	0x57	W	119	0x77	w
56	0x38	8	88	0x58	X	120	0x78	x
57	0x39	9	89	0x59	Y	121	0x79	y
58	0x3A	:	90	0x5A	Z	122	0x7A	z

ASCII Character Encoding

Each (printable) ASCII character has a value between 32-127, and we represent them as 1 byte. 'X' is decimal value 88 in ASCII, which, as a byte, is 01011000.

PRINTABLE CHARACTERS								
DEC	HEX	CHARACTER	DEC	HEX	CHARACTER	DEC	HEX	CHARACTER
32	0x20	<SPACE>	64	0x40	@	96	0x60	`
33	0x21	!	65	0x41	A	97	0x61	a
34	0x22	"	66	0x42	B	98	0x62	b
35	0x23	#	67	0x43	C	99	0x63	c
36	0x24	$	68	0x44	D	100	0x64	d
37	0x25	%	69	0x45	E	101	0x65	e
38	0x26	&	70	0x46	F	102	0x66	f
39	0x27	'	71	0x47	G	103	0x67	g
40	0x28	(	72	0x48	H	104	0x68	h
41	0x29	)	73	0x49	I	105	0x69	i
42	0x2A	*	74	0x4A	J	106	0x6A	j
43	0x2B	+	75	0x4B	K	107	0x6B	k
44	0x2C	,	76	0x4C	L	108	0x6C	l
45	0x2D	-	77	0x4D	M	109	0x6D	m
46	0x2E	.	78	0x4E	N	110	0x6E	n
47	0x2F	/	79	0x4F	O	111	0x6F	o
48	0x30	0	80	0x50	P	112	0x70	p
49	0x31	1	81	0x51	Q	113	0x71	q
50	0x32	2	82	0x52	R	114	0x72	r
51	0x33	3	83	0x53	S	115	0x73	s
52	0x34	4	84	0x54	T	116	0x74	t
53	0x35	5	85	0x55	U	117	0x75	u
54	0x36	6	86	0x56	V	118	0x76	v
55	0x37	7	87	0x57	W	119	0x77	w
56	0x38	8	88	0x58	X	120	0x78	x
57	0x39	9	89	0x59	Y	121	0x79	y
58	0x3A	:	90	0x5A	Z	122	0x7A	z

Questions

Questions?