Chapter 8: Bits and the "Why" of Bytes: Representing Information Digitally

Fluency with Information Technology
Third Edition

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Digitizing Discrete Information

- *Digitize*: Represent information with digits (normally base 10 numerals 0 through 9)
- Limitation of Digits
  - Alternative Representation: Any set of symbols could represent phone number digits, as long as the keypad is labeled accordingly
- Symbols, Briefly
  - Digits have the advantage of having short names (easy to say)
    - But computer professionals are shortening symbol names (exclamation point is pronounced "bang")

Figure 8.1. Three symbol assignments for a telephone keypad.

Ordering Symbols

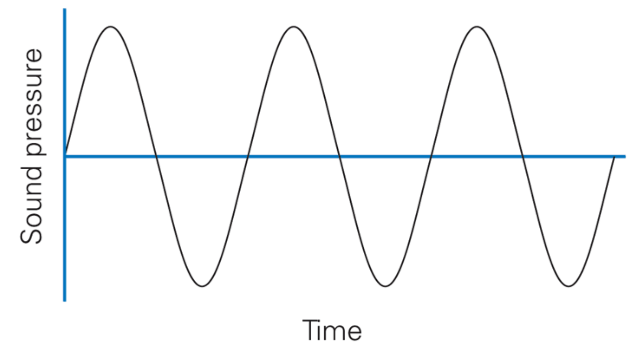
- Advantage of digits for encoding info is that items can be listed in numerical order
- To use other symbols, we need an ordering system (*collating sequence*)
  - Agreed order from smallest to largest value
- In choosing symbols for encoding, consider how symbols interact with things being encoded

The Fundamental Representation of Information

- The fundamental patters used in IT come when the physical world meets the logical world
- The most fundamental form of information is the presence or absence of a physical phenomenon
- In the logical world, the concepts of true and false are important
  - By associating true with the presence of a phenomenon and false with its absence, we use the physical world to implement the logical world, and produce information technology

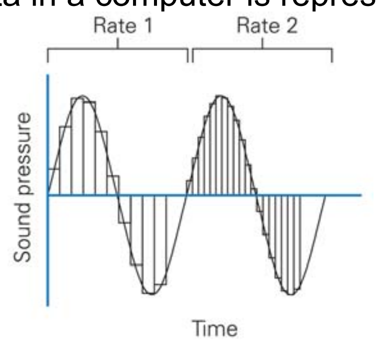
Analog vs. Digital

- Analog is continuous data/information
  - Sound waves



Analog vs. Digital

- Digital is discrete data/information
  - Many distinct samples of data
  - Stored in binary (0's and 1's)
    - All data in a computer is represented in binary



The PandA Representation

- *PandA* is the mnemonic for "presence and absence"
- It is *discrete* (distinct or separable)—the phenomenon is present or it is not (true or false; 1 or 0). There in no continuous gradation in between.

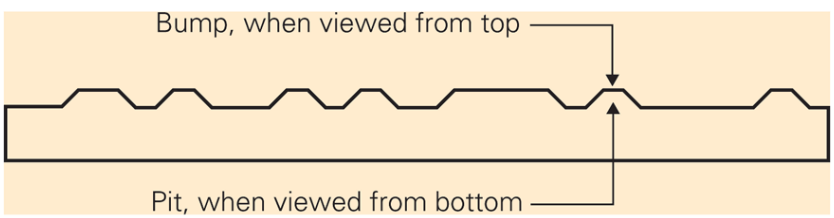
A Binary System

- Two patterns make a *binary system*
  - Base 2 (0 or 1)
- The basic binary unit is known as a *"bit"* (short for binary digit)
- 8 bits are grouped together to form a *byte*
  - Memory accessed by byte addresses
- We can give any names to these two patterns as long as we are consistent
  - PandA (Presence and Absence can represent 1 and 0, respectively)

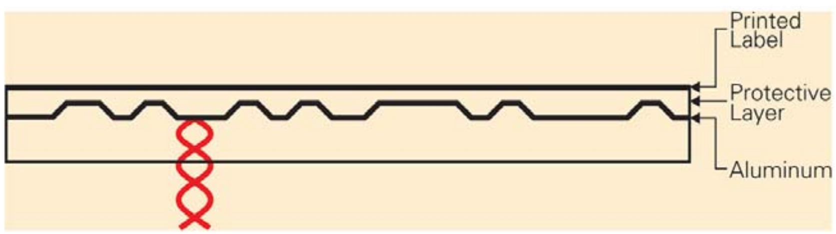
Table 8.1 Possible interpretations of the two PandA patterns

Present	Absent
True	False
1	0
On	Off
Yes	No
+	–
Black	White
For	Against
Yang	Yin
Lisa	Bart
. . .	. . .

Encoding Bits on a CD-ROM



Encoding Bits on a CD-ROM



Bits in Computer Memory

- Memory is arranged inside a computer in a very long sequence of bits (places where a phenomenon can be set and detected)
- Analogy: Sidewalk Memory
  - Each sidewalk square represents a memory slot (bit), and stones represent the presence or absence
  - If a stone is on the square, the value is 1, if not the value is 0

Figure 8.2 Sidewalk sections as a sequence of bits (1010 0010).

Alternative PandA Encodings

- There are other ways to encode two states using physical phenomena
  - Use stones on all squares, but black stones for one state and white for the other
  - Use multiple stones of two colors per square, saying more black than white means 0 and more white than black means 1
  - Stone in center for one state, off-center for the other
  - etc.

Combining Bit Patterns

- Since we only have two patterns, we must combine them into sequences to create enough symbols to encode necessary information
- Binary (PandA) has 2 patterns, arranging them into n-length sequences, we can create 2^n symbols

Table 8.2 Number of symbols when the number of possible patterns is two

n	2^n	Symbols
1	2^1	2
2	2^2	4
3	2^3	8
4	2^4	16
5	2^5	32
6	2^6	64
7	2^7	128
8	2^8	256
9	2^9	512
10	2^{10}	1,024

Hex Explained

- Recall in Chapter 4, we specified custom colors in HTML using hex digits
  - e.g., <font color ="#FF8E2A">
  - *Hex* is short for hexadecimal, base 16
- Why use hex? Writing the sequence of bits is long, tedious, and error-prone

The 16 Hex Digits

- 0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F
  - A = 10, B = 11, ... , F = 15
- Sixteen values can be represented perfectly by 4-bit sequences ($2^4 = 16$)
- Changing hex digits to bits and back again:
  - Given a sequence of bits, group them in 4's and write the corresponding hex digit
    - 0101 1100
      5 C
  - Given hex, write the associated group of 4 bits

Hex (0-9,A-F)

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

Digitizing Text

- Early binary representation—1 and 0—encoded numbers and keyboard characters
- Now representation for sound, video, and other types of information are also important
- For encoding text, what symbols should be included?
  - We want to keep the list small enough to use fewer bits, but we don't want to leave out critical characters

Assigning Symbols

- 26 uppercase and 26 lowercase Roman letters, 10 Arabic numerals, 10 arithmetic characters, 20 punctuation characters (including space), and 3 non-printable characters (new line, tab, backspace) = 95 characters, enough to represent English
- For 95 symbols, we need 7-bit sequences
  - $2^6 = 64$ $2^7 = 128$
- A standard 7-bit code is *ASCII(American Standard Code for Information Interchange)*

Decimal ASCII Character Set

Decimal - Character

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

Hexadecimal ASCII Character Set

Hexadecimal - Character

00 NUL	01 SOH	02 STX	03 ETX	04 EOT	05 ENQ	06 ACK	07 BEL
08 BS	09 HT	0A NL	0B VT	0C NP	0D CR	0E SO	0F SI
10 DLE	11 DC1	12 DC2	13 DC3	14 DC4	15 NAK	16 SYN	17 ETB
18 CAN	19 EM	1A SUB	1B ESC	1C FS	1D GS	1E RS	1F US
20 SP	21 !	22 "	23 #	24 $	25 %	26 &	27 '
28 (	29)	2A *	2B +	2C ,	2D -	2E .	2F /
30 0	31 1	32 2	33 3	34 4	35 5	36 6	37 7
38 8	39 9	3A :	3B ;	3C <	3D =	3E >	3F ?
40 @	41 A	42 B	43 C	44 D	45 E	46 F	47 G
48 H	49 I	4A J	4B K	4C L	4D M	4E N	4F O
50 P	51 Q	52 R	53 S	54 T	55 U	56 V	57 W
58 X	59 Y	5A Z	5B [	5C \	5D]	5E ^	5F _
60 `	61 a	62 b	63 c	64 d	65 e	66 f	67 g
68 h	69 i	6A j	6B k	6C l	6D m	6E n	6F o
70 p	71 q	72 r	73 s	74 t	75 u	76 v	77 w
78 x	79 y	7A z	7B {	7C |	7D }	7E ~	7F DEL

Extended ASCII: An 8-bit Code

- By the mid-1960's, it became clear that 7-bit ASCII was not enough to represent text from languages other than English
- IBM extended ASCII to 8 bits (256 symbols)
- Called "*Extended ASCII*," the first half is original ASCII with a 0 added at the beginning of each group of bits
- Handles most Western languages and additional useful symbols

ASCII	0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111
0000	NU	SH	SX	EX	ET	EQ	AK	BL	BS	HT	LF	VT	FF	CR	SO	SI
0001	DL	D1	D2	D3	D4	NK	SY	EI	CN	EM	SB	EC	FS	GS	RS	US
0010		!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
0011	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
0100	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
0101	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
0110	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
0111	p	q	r	s	t	u	v	w	x	y	z	{	|	}	~	DT
1000	80	81	82	83	IN	NL	SS	ES	HS	HJ	VS	PD	PV	RI	S2	S3
1001	DC	P1	P2	SE	CC	MW	SP	EP	98	99	9A	CS	ST	OS	PM	AP
1010	A0	¡	¢	£		¥	¦	§	¨	©	♀	«	¬	-	®	¯
1011	°	±	²	³	´	µ	¶	·	¸	¹	♂	»	¼	½	¾	¿
1100	À	Á	Â	Ã	Ä	Å	Æ	Ç	È	É	Ê	Ë	Ì	Í	Î	Ï
1101	Ð	Ñ	Ò	Ó	Ô	Õ	Ö	×	Ø	Ù	Ú	Û	Ü	Ý	Þ	ß
1110	à	á	â	ã	ä	å	æ	ç	è	é	ê	ë	ì	í	î	ï
1111	ð	ñ	ò	ó	ô	õ	ö	÷	ø	ù	ú	û	ü	ý	þ	ÿ

Figure 8.3 ASCII, The American Standard Code for Information Interchange.

ASCII Coding of Phone Numbers

- How would a computer represent in its memory, the phone number 888 555 1212?
- Encode each digit with its ASCII byte

Unicode

- Several languages around the world have more than 256 individual characters
- Unicode uses 16 bits; 2^{16} = 65536 characters
  - 1st 7 bits (128 chars) are ASCII chars
  - Different locales – different characters beyond 1st 7 bits

NATO Broadcast Alphabet

- The code for broadcast communication is purposefully inefficient, to be distinctive when spoken amid noise

Table 8.4 NATO broadcast alphabet designed not to be minimal

A	Alpha	H	Hotel	O	Oscar	V	Victor
B	Bravo	I	India	P	Papa	W	Whiskey
C	Charlie	J	Juliet	Q	Quebec	X	X-ray
D	Delta	K	Kilo	R	Romeo	Y	Yankee
E	Echo	L	Lima	S	Sierra	Z	Zulu
F	Foxtrot	M	Mike	T	Tango		
G	Golf	N	November	U	Uniform		

The Oxford English Dictionary

- Extended ASCII encodes letters and characters well, but most documents contain more than just text.
  - Format information like font, font size, justification
- Formatting characters could be added to ASCII, but that mixes the content with the description of its form (*metadata*)
- Metadata is represented using tags, as in HTML

Using Tags to Encode

- Oxford English Dictionary (OED) printed version is 20 volumes
- We could type the entire contents as ASCII characters (in about 120 years), but searching would be difficult
  - Suppose you search for the word "set." It is included in many other words like closet, horsetail, settle, etc.
  - How will the software know what characters comprise the definition of set?
    - Incorporate metadata

Structure Tags

- Special set of tags was developed to specify OED's structure
  - <hw> means headword, the word being defined
  - Other tags label pronunciation <pr>, phonetic notation <ph>, parts of speech <ps>
- The tags do not print. They are there only to specify structure so the computer knows what part of the dictionary it is looking at

byte (baIt). *Computers*. [Arbitrary, prob. influenced by bit sb.[4] and bite sb.] A group of eight consecutive bits operated on as a unit in a computer.

1964 ***Blaauw*** & ***Brooks*** in *IBM Systems Jrnl.* III. 122 An 8-bit unit of information is fundamental to most of the formats [of the System/360]. A consecutive group of *n* such units constitutes a field of length *n*. Fixed-length fields of length one, two, four, and eight are termed bytes, halfwords, words, and double words respectively. **1964** *IBM Jrnl. Res. & Developm.* VIII. 97/1 When a byte of data appears from an I/O device, the CPU is seized, dumped, used and restored. **1967** ***P. A. Stark*** *Digital Computer Programming* xix. 351 The normal operations in fixed point are done on four bytes at a time. **1968** *Dataweek* 24 Jan. 1/1 Tape reading and writing is at from 34,160 to 192,000 bytes per second.


```
<e><hg><hw>byte</hw> <pr><ph>baIt</ph></pr></hg>. <la> Computers</la>. <etym>
Arbitrary, prob. influenced by <xr><x>bit</x></xr> <ps>n.<hm>4</hm></ps>and
<xr><x>bite</x> <ps>n.</ps></xr></etym> <s4>A group of eight consecutive bits
operated on as a unit in a computer.</s4><qp><q><qd>1964</qd><a>Blaauw</a>
&amp. <a>Brooks</a><bib>in</bib> <w>IBM Systems Jrnl.</w> <lc>III.122</lc>
<qt>An 8-bit unit of information is fundamental to most of the formats <ed>of
the System/360</ed>.&es.A consecutive group of <i>n</i> such units constitutes
a field of length <i>n</i>.&es.Fixed-length fields of length one, two, four,
and eight are termed bytes, halfwords, words, and double words respectively.
</qt></q><q><qd>1964</qd> <w>IBM Jrnl. Res. &amp. Developm. </w> <lc>VIII.
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<w>Digital Computer Programming</w> <lc>xix. 351</lc> <qt>The normal operations
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<w> Dataweek</w> <lc>24 Jan. 1/1</lc> <qt>Tape reading and writing is at from
34,160 to 192,000 bytes per second.</qt></q></qp></e>
```


Figure 8.4 The OED entry for the word byte, together with the representation of the entry in its digitized form with tags.

Why "BYTE"

- Why is BYTE spelled with a Y?
- The Engineers at IBM were looking for a word for a quantity of memory between a bit and a word (usually 32 bits). Bite seemed appropriate, but they changed the i to a y, to minimize typing errors.

Table 8.3 Sixteen symbols of the 4-bit PandA representation

Symbol	Binary	Physical Bits	Hex	Symbol	Binary	Physical Bits	Hex
AAAA	0000		0	PAAA	1000		8
AAAP	0001		1	PAAP	1001		9
AAPA	0010		2	PAPA	1010		A
AAPP	0011		3	PAPP	1011		B
APAA	0100		4	PPAA	1100		C
APAP	0101		5	PPAP	1101		D
APPA	0110		6	PPPA	1110		E
APPP	0111		7	PPPP	1111		F