

Numeric Representation II

CSCI 2050U - Computer Architecture

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Outline

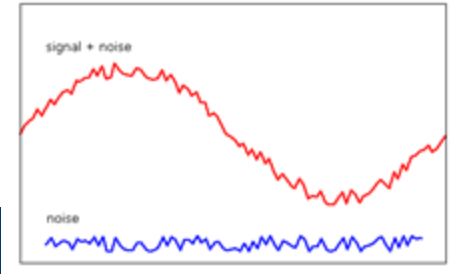
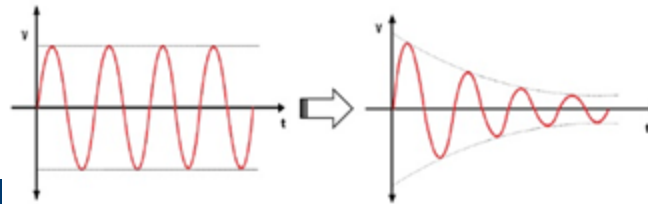
- Binary
- Hexadecimal
- Representing fractional numbers
- Representing characters

Binary

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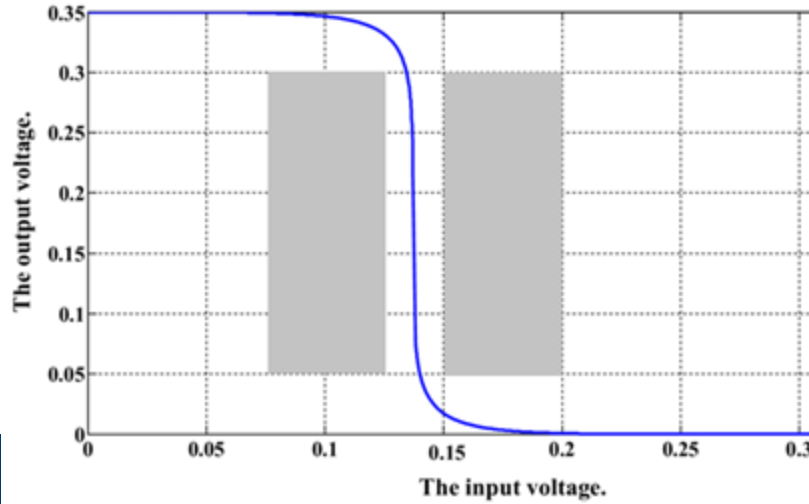
Binary - Why?

- A signal needs to differentiate one value from another
 - Electronic: Voltage or no voltage, current or no current
 - Electromagnetic: Varying frequency, varying amplitude, varying phase
- It might be possible to differentiate more than 2 values
 - e.g. Base 4: 0v, 1.5v, 3v, 4.5v
- Attenuation and noise can make these differences harder to discern
 - Binary maximizes the likelihood of detecting the correct value



Voltage Characteristics

- Let's say we decide that 0.0v is a 0 and 0.35v is a 1
 - What if we receive 0.32v?
- We typically design circuits that are not so black and white:
 - 0: 0.00-0.05v
 - 1: 0.30-0.35v
 - Undefined, otherwise



A Binary (Base 2) System

- A base 2 system would have 2 unique digits (0 and 1)
 - This is an 8-bit (binary digit) binary number:

$$\begin{aligned} 01101101_2 = & 0 \times 2^7 + 1 \times 2^6 + 1 \times 2^5 + \\ & 0 \times 2^4 \\ & + 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + \\ & 1 \times 2^0 \end{aligned}$$

Converting from Binary to Decimal

- Converting from binary to decimal is rather easy:

--	--	--	--	--	--	--	--

Converting from Binary to Decimal

- 1. Add each binary digit to the boxes below:

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

Converting from Binary to Decimal

- 2. Multiply each times the corresponding power of 2:

0	1	1	0	1	1	0	1
x128	x64	x32	x16	x8	x4	x2	x1
0	64	32	0	8	4	0	1

Converting from Binary to Decimal

- 3. Add up the results:

0	1	1	0	1	1	0	1								
x128	x64	x32	x16	x8	x4	x2	x1								
0	+	64	+	32	+	0	+	8	+	4	+	0	+	1	= 109

Converting from Decimal to Binary

- Converting from decimal to binary is also easy:

--	--	--	--	--	--	--	--

Converting from Decimal to Binary

- 1. Write the number into the left-most box

109							
-----	--	--	--	--	--	--	--

Converting from Decimal to Binary

- 2. Divide by the largest possible power of 2

109							
÷128	÷64	÷32	÷16	÷8	÷4	÷2	÷1

Converting from Decimal to Binary

- 3. Write the (integer) quotient in the box, below

109							
÷128	÷64	÷32	÷16	÷8	÷4	÷2	÷1
0							

Converting from Decimal to Binary

- 4. Write the remainder in the box to the right

109	109						
÷128	÷64	÷32	÷16	÷8	÷4	÷2	÷1
0							

Converting from Decimal to Binary

- 5. Repeat for successively smaller powers of 2

109	109	45					
÷128	÷64	÷32	÷16	÷8	÷4	÷2	÷1
0	1						

Converting from Decimal to Binary

- 5. Repeat for successively smaller powers of 2

109	109	45	13				
÷128	÷64	÷32	÷16	÷8	÷4	÷2	÷1
0	1	1					

Converting from Decimal to Binary

- 5. Repeat for successively smaller powers of 2

109	109	45	13	13			
÷128	÷64	÷32	÷16	÷8	÷4	÷2	÷1
0	1	1	0				

Converting from Decimal to Binary

- 5. Repeat for successively smaller powers of 2

109	109	45	13	13	5		
÷128	÷64	÷32	÷16	÷8	÷4	÷2	÷1
0	1	1	0	1			

Converting from Decimal to Binary

- 5. Repeat for successively smaller powers of 2

109	109	45	13	13	5	1	
÷128	÷64	÷32	÷16	÷8	÷4	÷2	÷1
0	1	1	0	1	1		

Converting from Decimal to Binary

- 5. Repeat for successively smaller powers of 2

109	109	45	13	13	5	1	1
÷128	÷64	÷32	÷16	÷8	÷4	÷2	÷1
0	1	1	0	1	1	0	

Converting from Decimal to Binary

- 5. Repeat for successively smaller powers of 2

109	109	45	13	13	5	1	1
÷128	÷64	÷32	÷16	÷8	÷4	÷2	÷1
0	1	1	0	1	1	0	1

Hexadecimal

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Hexadecimal

- Modern computers only use binary
 - Memory addresses
 - Encrypted or compressed data
 - Integers (signed or unsigned)
 - Floating points
 - Text
- Sometimes, us humans need to look at binary data
 - Binary numbers are too long - it is easy to make mistakes

Hexadecimal

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```
0110110110010110
1100010110100011
1011011101000110
0001110110100110
```

Hexadecimal

- Modern computers only use binary
 - Memory addresses
 - Encrypted or compressed data
 - Integers (signed or unsigned)
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```
0110110110010110
1100010110100011
1011011101000110
0001110110100110
```

```
6D96 C5A3 B746 1DA6
```

Hexadecimal

- Hexadecimal is a base-16 number system
- Advantage:
 - As 16 is a power of 2, binary $\leftrightarrow$ hexadecimal
 - We can use a table for conversion:
 - There are no unmapped numbers
 - 2 hex digits per byte (8 bits)
- Disadvantage:
 - We don't have 16 digit symbols
 - Hexadecimal uses 0-9, and A-F

<i>Binary</i>	<i>Hex</i>
0000	0x0
0001	0x1
0010	0x2
0011	0x3
0100	0x4
0101	0x5
0110	0x6
0111	0x7

<i>Binary</i>	<i>Hex</i>
1000	0x8
1001	0x9
1010	0xA
1011	0xB
1100	0xC
1101	0xD
1110	0xE
1111	0xF

Hexadecimal vs. Binary

- Which is easier to read?
 - Hexadecimal: C07E
 - Binary: 1100000001111110

Representing Fractional Numbers

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Representing Fractional Numbers

- Decimal has been extended to include negative powers of 10:

$$109.4075_{10}$$

$$= 1 \times 10^2 + 0 \times 10^1 + 9 \times 10^0$$

$$+ 4 \times 10^{-1} + 0 \times 10^{-2} + 7 \times 10^{-3} + 5 \times 10^{-4}$$

Representing Fractional Numbers

- Binary can be extended to include negative powers of 2 also:

$$01101101.01101_2$$

$$= 0 \times 2^7 + 1 \times 2^6 + 1 \times 2^5 + 0 \times 2^4$$

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

$$+ 0 \times 2^{-1} + 1 \times 2^{-2} + 1 \times 2^{-3} + 0 \times 2^{-4} + 1 \times 2^{-5}$$

Floating Point - Scientific Notation

- In decimal, we often use scientific notation:

32,413,788.729

= 0.32413788729 $\times 10^8$

-0.000005382971

= -0.5382971 $\times 10^{-5}$

Floating Point - Binary

- In binary, we could do the same thing:

01101101.01101

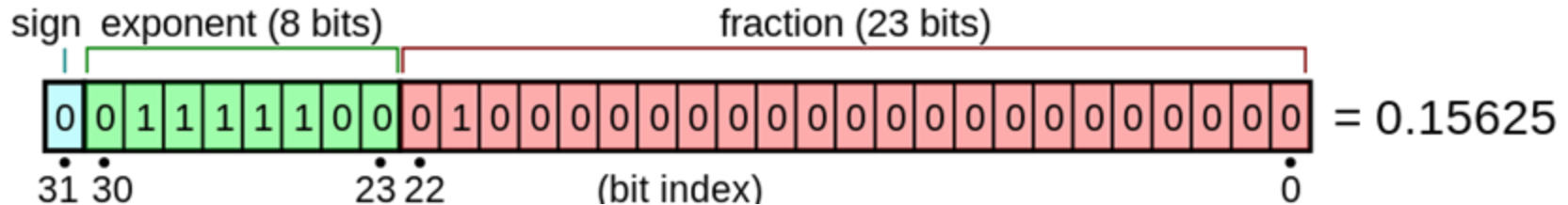
$$= 0.110110101101 \times 2^7$$

Representing Fractional Numbers

- IEEE 754 defines a set of standards for representing floating point numbers
 - Floating point - similar to scientific notation, but with a limited number of digits
 - 32-bit (single precision)
 - 64-bit (double precision)

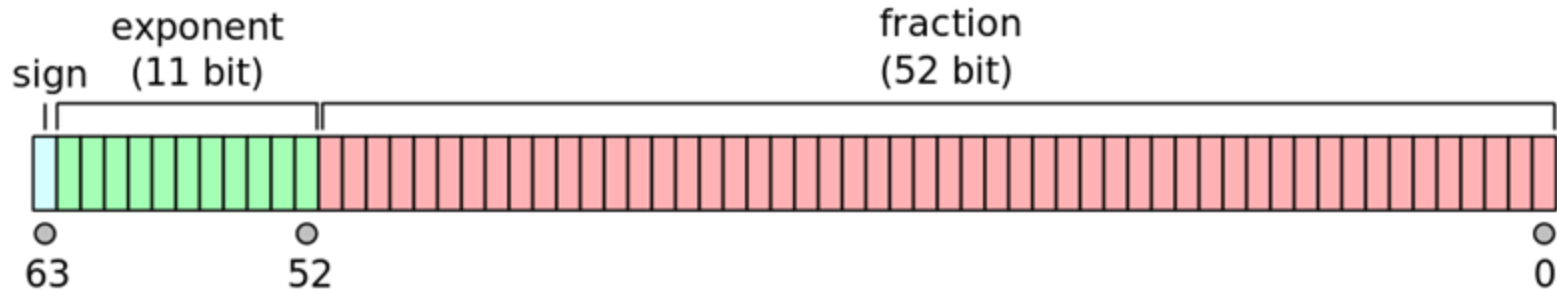
Representing Fractional Numbers

- IEEE 754 single precision format (C++ `float`)
 - Significand - the actual digits
 - Exponent - the power of 2 (i.e. the floating *point*)
 - Sign bit - 1 if negative



Representing Fractional Numbers

- IEEE 754 double precision format (C++ `double`)
 - Significand - the actual digits
 - Exponent - the power of 2 (i.e. the floating *point*)
 - Sign bit - 1 if negative



Representing Characters

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Representing Characters - ASCII

- One early encoding for characters is ASCII
- Each letter, digit, punctuation is represented by an 8-bit number
- Advantages:
 - Uppercase letters are contiguous
 - Lowercase letters are contiguous
 - Digits are contiguous
- Disadvantages:
 - Really only English is supported

Representing Characters - ASCII

Dec	Hex	Bin	Char
0	00	0000000 0	NUL
1	01	0000000 1	SOH
2	02	0000001 0	STX
3	03	0000001 1	ETX
4	04	0000010 0	EOT
5	05	0000010 1	ENQ
6	06	0000011 0	ACK
7	07	0000011 1	BEL

Representing Characters - ASCII

Dec	Hex	Bin	Char	
0	Dec	Hex	Bin	Char
1	8	08	00001000	BS
	9	09	00001001	HT
2			1	
	10	0A	00001010	LF
3			0	
	11	0B	00001011	VT
4			1	
	12	0C	00001100	FF
5			0	
	13	0D	00001101	CR
6			1	
	14	0E	00001110	SO
7			0	
	15	0F	00001111	SI
			1	

Representing Characters - ASCII

Dec	Hex	Bin	Char		
0	Dec	Hex	Bin	Char	
1	8	Dec	Hex	Bin	Char
1	9	16	10	00010000	DLE
2	10	17	11	00010001	DC1
3	11	18	12	00010010	DC2
4	12	19	13	00010011	DC3
5	13	20	14	00010100	DC4
6	14	21	15	00010101	NAK
7	15	22	16	00010110	SYN
		23	17	00010111	ETB

Representing Characters - ASCII

Dec	Hex	Bin	Char		
0	Dec	Hex	Bin	Char	
1	8	Dec	Hex	Bin	Char
	16	Dec	Hex	Bin	Char
2	9	24	18	00011000	CAN
3	10	25	19	00011001	EM
4	11	26	1A	00011010	SUB
5	12	27	1B	00011011	ESC
6	13	28	1C	00011100	FS
7	14	29	1D	00011101	GS
	15	30	1E	00011110	RS
	23	31	1F	00011111	US

Representing Characters - ASCII

Dec	Hex	Bin	Char			
0	Dec	Hex	Bin	Char		
1	8	Dec	Hex	Bin	Char	
	16	Dec	Hex	Bin	Char	
	24	Dec	Hex	Bin	Char	
	32	20	0010000	Space		
2	17	25	33	21	0010000	!
	18	26	34	22	0010001	"
3	11	27	35	23	0010001	#
	12	28	36	24	0010010	\$
4	19	29	37	25	0010010	%
	14	30	38	26	0010011	&
5	13	31	39	27	0010011	'
	20					
6	21					
	22					
7	23					

Representing Characters - ASCII

Dec	Hex	Bin	Char					
0	Dec	Hex	Bin	Char				
1	8	Dec	Hex	Bin	Char			
	16	Dec	Hex	Bin	Char			
	24	Dec	Hex	Bin	Char			
2	9	32	Dec	Hex	Bin	Char		
	17	25	33	40	28	00101000	(	
3	10	18	26	34	41	29	00101001	)
	11	27	35	42	2A	00101010	*	
4	12	20	28	36	43	2B	00101011	+
	13	21	29	37	44	2C	00101100	,
5	14	22	30	38	45	2D	00101101	-
	15	23	31	39	46	2E	00101110	.
6								
7								

Representing Characters - ASCII

Dec	Hex	Bin	Char				
0	Dec	Hex	Bin	Char			
8	Dec	Hex	Bin	Char			
16	Dec	Hex	Bin	Char			
1	9	24	Dec	Hex	Bin	Char	
2	10	25	32	Dec	Hex	Bin	Char
3	11	26	40	Dec	Hex	Bin	Char
4	12	27	48	30	0011000	0	
5	13	28	41	31	0011000	1	
6	14	29	42	32	0011001	2	
7	15	30	43	33	0011001	3	
	23	31	44	34	0011010	4	
			45	35	0011010	5	
			46	36	0011011	6	
			47		0		

Representing Characters - ASCII

Dec	Hex	Bin	Char					
0	Dec	Hex	Bin	Char				
8	Dec	Hex	Bin	Char				
16	Dec	Hex	Bin	Char				
1	9	24	Dec	Hex	Bin	Char		
32	Dec	Hex	Bin	Char				
2	17	25	40	Dec	Hex	Bin	Char	
10	18	33	48	Dec	Hex	Bin	Char	
3	11	26	41	56	38	0011100	8	
4	19	34	49	57	39	0011100	9	
12	20	35	50	58	3A	0011101	:	
5	13	28	43	51		0		
6	14	29	44	52	59	3B	0011101	;
7	15	30	45	53	60	3C	0011110	<
	23	38	46	54	61	3D	0011110	=
	31	39	47	55	62	3E	0011111	>

Representing Characters - ASCII

Dec	Hex	Bin	Char
0	Dec	Hex	Bin
1	8	Dec	Hex
2	9	16	Dec
3	10	17	24
4	11	18	25
5	12	19	26
6	13	20	27
7	14	21	28
	15	22	29
	23	30	31
		32	Dec
		33	Hex
		34	Bin
		35	Char
		36	Dec
		37	Hex
		38	Bin
		39	Char
		40	Dec
		41	Hex
		42	Bin
		43	Char
		44	Dec
		45	Hex
		46	Bin
		47	Char
		48	Dec
		49	Hex
		50	Bin
		51	Char
		52	Dec
		53	Hex
		54	Bin
		55	Char
		56	Dec
		57	Hex
		58	Bin
		59	Char
		60	Dec
		61	Hex
		62	Bin
		63	Char
		64	Dec
		65	Hex
		66	Bin
		67	Char
		68	Dec
		69	Hex
		70	Bin
		71	Char
		72	Dec
		73	Hex
		74	Bin
		75	Char
		76	Dec
		77	Hex
		78	Bin
		79	Char
		80	Dec
		81	Hex
		82	Bin
		83	Char
		84	Dec
		85	Hex
		86	Bin
		87	Char
		88	Dec
		89	Hex
		90	Bin
		91	Char
		92	Dec
		93	Hex
		94	Bin
		95	Char
		96	Dec
		97	Hex
		98	Bin
		99	Char
		100	Dec
		101	Hex
		102	Bin
		103	Char
		104	Dec
		105	Hex
		106	Bin
		107	Char
		108	Dec
		109	Hex
		110	Bin
		111	Char
		112	Dec
		113	Hex
		114	Bin
		115	Char
		116	Dec
		117	Hex
		118	Bin
		119	Char
		120	Dec
		121	Hex
		122	Bin
		123	Char
		124	Dec
		125	Hex
		126	Bin
		127	Char

Dec	Hex	Bin	Char
64	40	01000000	@
65	41	01000001	A
66	42	01000010	B
67	43	01000011	C
68	44	01000100	D
69	45	01000101	E
70	46	01000110	F
71	47	01000111	G

Representing Characters - ASCII

Dec	Hex	Bin	Char
0	Dec	Hex	Bin
1	8	Dec	Hex
2	9	16	Dec
3	10	17	24
4	11	18	25
5	12	19	26
6	13	20	27
7	14	21	28
	15	22	29
	16	23	30
	17	24	31
	18	25	32
	19	26	33
	20	27	34
	21	28	35
	22	29	36
	23	30	37
	24	31	38
	25	32	39
	26	33	40
	27	34	41
	28	35	42
	29	36	43
	30	37	44
	31	38	45
	32	39	46
	33	40	47
	34	41	48
	35	42	49
	36	43	50
	37	44	51
	38	45	52
	39	46	53
	40	47	54
	41	48	55
	42	49	56
	43	50	57
	44	51	58
	45	52	59
	46	53	60
	47	54	61
	48	55	62
	49	56	63
	50	57	64
	51	58	65
	52	59	66
	53	60	67
	54	61	68
	55	62	69
	56	63	70
	57	64	71
	58	65	72
	59	66	73
	60	67	74
	61	68	75
	62	69	76
	63	70	77
	64	71	78
	65	72	79
	66	73	80
	67	74	81
	68	75	82
	69	76	83
	70	77	84
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	72	79	86
	73	80	87
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	82	89	96
	83	90	97
	84	91	98
	85	92	99
	86	93	100
	87	94	101
	88	95	102
	89	96	103
	90	97	104
	91	98	105
	92	99	106
	93	100	107
	94	101	108
	95	102	109
	96	103	110
	97	104	111
	98	105	112
	99	106	113
	100	107	114
	101	108	115
	102	109	116
	103	110	117
	104	111	118
	105	112	119
	106	113	120
	107	114	121
	108	115	122
	109	116	123
	110	117	124
	111	118	125
	112	119	126
	113	120	127
	114	121	128
	115	122	129
	116	123	130
	117	124	131
	118	125	132
	119	126	133
	120	127	134
	121	128	135
	122	129	136
	123	130	137
	124	131	138
	125	132	139
	126	133	140
	127	134	141
	128	135	142
	129	136	143
	130	137	144
	131	138	145
	132	139	146
	133	140	147
	134	141	148
	135	142	149
	136	143	150
	137	144	151
	138	145	152
	139	146	153
	140	147	154
	141	148	155
	142	149	156
	143	150	157
	144	151	158
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	167	174	181
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	171	178	185
	172	179	186
	173	180	187
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	176	183	190
	177	184	191
	178	185	192
	179	186	193
	180	187	194
	181	188	195
	182	189	196
	183	190	197
	184	191	198
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	186	193	200
	187	194	201
	188	195	202
	189	196	203
	190	197	204
	191	198	205
	192	199	206
	193	200	207
	194	201	208
	195	202	209
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	198	205	212
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	200	207	214
	201	208	215
	202	209	216
	203	210	217
	204	211	218
	205	212	219
	206	213	220
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	208	215	222
	209	216	223
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	249	256	263
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	251	258	265
	252	259	266
	253	260	267
	254	261	268
	255	262	269
	256	263	270
	257	264	271
	258	265	272
	259	266	273
	260	267	274
	261	268	275
	262	269	276
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	264	271	278
	265	272	279
	266	273	280
	267	274	281
	268	275	282
	269	276	283
	270	277	284
	271	278	285
	272	279	286
	273	280	287
	274	281	288
	275	282	289
	276	283	290
	277	284	291
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	299	306	313
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	301	308	315
	302	309	316
	303	310	317
	304	311	318
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	306	313	320
	307	314	321
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	369	376	383
	370	377	384
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	372	379	386
	373	380	387
	374	381	388
	375		

23

5-1XX/cor

Dec	Hex	Bin	Char		
64	Dec	Hex	Bin	Char	
65	72	80	50	01010000	P
	73	81	51	01010001	Q
66	74	82	52	01010010	R
	75	83	53	01010011	S
67	76	84	54	01010100	T
	77	85	55	01010101	U
68	78	86	56	01010110	V
	79	87	57	01010111	W

23

5-1XX/cor

5-1XX/cor

Representing Characters - ASCII

Dec	Hex	Bin	Char
0	Dec	Hex	Bin
1	8	Dec	Hex
2	9	16	Dec
3	10	17	24
4	11	18	25
5	12	19	26
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	37	44	51
	38	45	52
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	43	50	57
	44	51	58
	45	52	59
	46	53	60
	47	54	61
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	78	85	92
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	372	379	386
	373	380	387
	374	381	388
	375		

Representing Characters - ASCII

Dec	Hex	Bin	Char
0	Dec	Hex	Bin
1	8	Dec	Hex
2	9	16	Dec
3	10	17	24
4	11	18	25
5	12	19	26
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Representing Characters - ASCII

Dec	Hex	Bin	Char	
0	Dec	Hex	Bin	Char
8	Dec	Hex	Bin	Char
16	Dec	Hex	Bin	Char
24	Dec	Hex	Bin	Char
32	Dec	Hex	Bin	Char
40	Dec	Hex	Bin	Char
48	Dec	Hex	Bin	Char
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72		1		
80		0		
88		1		
96		0		
104		1		
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120		0		
128		1		
136		0		
144		1		
152		0		
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184		0		
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216		0		
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232		0		
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264		0		
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1608		0		
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1688		0		
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1992		0		
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2008		0		
2016		1		
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2792		0		
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3352		0		
3360		1		
3368		0		
3376		1		
3384		0		
3392		1		

Representing Characters - ASCII

Dec	Hex	Bin	Char
0	Dec	Hex	Bin
1	8	Dec	Hex
2	9	16	Dec
3	10	17	24
4	11	18	25
5	12	19	26
6	13	20	27
7	14	21	28
	15	22	29
	16	23	30
	17	24	31
	18	25	32
	19	26	33
	20	27	34
	21	28	35
	22	29	36
	23	30	37
	24	31	38
	25	32	39
	26	33	40
	27	34	41
	28	35	42
	29	36	43
	30	37	44
	31	38	45
	32	39	46
	33	40	47
	34	41	48
	35	42	49
	36	43	50
	37	44	51
	38	45	52
	39	46	53
	40	47	54
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	42	49	56
	43	50	57
	44	51	58
	45	52	59
	46	53	60
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	64	71	78
	65	72	79
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	82	89	96
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	85	92	99
	86	93	100
	87	94	101
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	210	217	224
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	213	220	227
	214	221	228
	215	222	229
	216	223	230
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	220	227	234
	221	228	235
	222	229	236
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	224	231	238
	225	232	239
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	250	257	264
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	368	375	382
	369	376	383
	370	377	384
	371	378	385
	372	379	386
	373	380	387
	374	381	388
	375		

Representing Characters - Other Encodings

- Unicode
 - Supports most writing systems, math symbols, emojis
 - Can store these characters in one of two ways:
 - UTF-8: Stores unicode characters using 8-32 characters
 - English (8-bit) and latin (16-bit) characters are prioritized
 - UTF-16: Stores unicode characters using 16-32 characters

Wrap-up

- Binary
- Hexadecimal
- Representing fractional numbers
- Representing characters

What is next?

- Error detection and correction
- Prefix codes
- Huffman's algorithm