Character Encoding

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Hello world

01001000 01100101 01101100 01101100 01101111 00100000 01010111 01101111 01110010 01101100 01100100

Exercise

- Recall the binary and hexadecimal system and convert first few binary octets to their hexadecimal representation.

Introduction

Outline

- ASCII
- 8-bit extensions
- Unicode
- and some related topics:
  - end of line
  - byte-order mark
  - alternative solution to character encoding – escaping

Problem statement

- Today's computers use binary digits
- No natural relation between numbers and characters of an alphabet $\implies$ convention needed
- No convention $\implies$ chaos
- Too many conventions $\implies$ chaos
- (recall A. S. Tanenbaum: *The nice thing about standards is that you have so many to choose from.*)

Btw why binary computers?

- the answer is actually not that straightforward
- three distinct voltage values certainly possible too (experimental ternary computers assembled in 1950s), as well as any other higher base
- mostly physical and electro-technical reasons, rather than mathematical or information-theoretical reasons:
  - two voltage values technically very easy to distinguish – basically just charge vs. no charge opposition on a transistor's gate (and hence it is fast)
  - only very simple circuitry needed for two-valued logic (and hence it is fast)

Basic notions – Character

a character

- is an abstract notion, not something tangible
- has no numerical representation nor graphical form
- e.g. “capital A with grave accent”
- you need an encoding to associate a character with a numerical representation
- you need a font to associate a character with a concrete visual realization

Basic notions – Character set

a character set (or a character repertoire)

- a set of logically distinct characters
- relevant for a certain purpose (e.g., used in a given language or in group of languages)
- not neccessarily related to computers

a coded character set:

- a unique number (typically non-negative integer) assigned to each character: code point
- relevant for a certain purpose (e.g., used in a given language or in group of languages)
- not neccessarily related to computers

Basic notions – Glyph and Font

- a glyph – a visual representation of a character
- a font – a set of glyphs of characters

Basic notions – Character encoding

character encoding

- the way how (coded) characters are mapped to (sequences of) bytes
- both in the declarative and procedural sense
    - a conversion table
    - a conversion process

8-bit encodings

ASCII

- In the beginning there was the Word. And the Word was encoded in 7-bit ASCII. (well, if we ignore the history before 1950's)

ASCII

- ASCII = American Standard Code for Information Interchange (1963)
  - 7 bits (0–127)
  - 33 control characters (0–31,127) such as Escape, Line Feed, Bell
  - the remaining 95 characters (32–126): printable characters such as space, numerals, upper and lower case characters.

ASCII Code Chart

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

ASCII, cont.

- now with decimal and octal codes (credit: www.pragimtech.com)

ASCII Table

Dec	Hex	Oct	Char	Dec	Hex	Oct	Char	Dec	Hex	Oct	Char	Dec	Hex	Oct	Char
0	0	0		32	20	40	[space]	64	40	100	@	96	60	140	`
1	1	1		33	21	41	!	65	41	101	A	97	61	141	a
2	2	2		34	22	42	"	66	42	102	B	98	62	142	b
3	3	3		35	23	43	#	67	43	103	C	99	63	143	c
4	4	4		36	24	44	$	68	44	104	D	100	64	144	d
5	5	5		37	25	45	%	69	45	105	E	101	65	145	e
6	6	6		38	26	46	&	70	46	106	F	102	66	146	f
7	7	7		39	27	47	'	71	47	107	G	103	67	147	g
8	8	10		40	28	50	(	72	48	110	H	104	68	150	h
9	9	11		41	29	51	)	73	49	111	I	105	69	151	i
10	A	12		42	2A	52	*	74	4A	112	J	106	6A	152	j
11	B	13		43	2B	53	+	75	4B	113	K	107	6B	153	k
12	C	14		44	2C	54	,	76	4C	114	L	108	6C	154	l
13	D	15		45	2D	55	-	77	4D	115	M	109	6D	155	m
14	E	16		46	2E	56	.	78	4E	116	N	110	6E	156	n
15	F	17		47	2F	57	/	79	4F	117	O	111	6F	157	o
16	10	20		48	30	60	0	80	50	120	P	112	70	160	p
17	11	21		49	31	61	1	81	51	121	Q	113	71	161	q
18	12	22		50	32	62	2	82	52	122	R	114	72	162	r
19	13	23		51	33	63	3	83	53	123	S	115	73	163	s
20	14	24		52	34	64	4	84	54	124	T	116	74	164	t
21	15	25		53	35	65	5	85	55	125	U	117	75	165	u
22	16	26		54	36	66	6	86	56	126	V	118	76	166	v
23	17	27		55	37	67	7	87	57	127	W	119	77	167	w
24	18	30		56	38	70	8	88	58	130	X	120	78	170	x
25	19	31		57	39	71	9	89	59	131	Y	121	79	171	y
26	1A	32		58	3A	72	:	90	5A	132	Z	122	7A	172	z
27	1B	33		59	3B	73	;	91	5B	133	[	123	7B	173	{
28	1C	34		60	3C	74	<	92	5C	134	\	124	7C	174	|
29	1D	35		61	3D	75	=	93	5D	135	]	125	7D	175	}
30	1E	36		62	3E	76	>	94	5E	136	^	126	7E	176	~
31	1F	37		63	3F	77	?	95	5F	137	_	127	7F	177	

Exercise

Given that A's code point in ASCII is 65, and a's code point is 97.

- What is the binary representation of 'A' in ASCII? (and what's its hexadecimal representation)
- What is the binary representation of 'a' in ASCII?

Is it clear now why there are the special characters inserted between upper and lower case letters?

ASCII, cont.

- ASCII's main advantage – simplicity: one character – one byte
- ASCII's main disadvantage – no way to represent national alphabets
- Anyway, ASCII is one of the most successful software standards ever developed!

How to represent the end of line

- “newline” == “end of line” == “EOL”
- ASCII symbols LF (line feed, 0x0A) and/or CR (carriage return, 0x0D), depending on the operation system:
  - LF is used in UNIX systems
  - CR+LF used in Microsoft Windows
  - CR used in Mac OS

A "how-many" question

- ASCII is clearly not enough for Czech
- but how many additional characters do we actually need for Czech?

Another "how-many" question

How many questions would be needed if we want to keep several languages in the same code space?

- find pieces of text from the following languages: Czech, French, German, Spanish, Greek, Icelandic, Russian (at least a few paras for each)
- store them into plain text files
- count how many different signs in total appear in the files
- try to solve it using only a bash command pipeline (hint: you may use e.g. '`grep -o .`' or `sed 's/./&\n/g'`)

8-bit encodings

- Supersets of ASCII, using octets 128–255 (still keeping the 1 character – 1 byte relation)
- International Standard Organisation: ISO 8859 (1980's)
- West European Languages: ISO 8859-1 (ISO Latin 1)
- For Czech and other Central/East European languages: anarchy
  - ISO 8859-2 (ISO Latin 2)
  - Windows 1250
  - KOI-8
  - Brothers Kamenický
  - other proprietary "standards" by IBM, Apple etc.

How to inspect the raw content of a file?

- The encoding of a text file must be known in order to display the text correctly.
- Is there an encoding-less way to view a file?
- Yes, you can view the hexadecimal codes of characters: `hexdump -C`

Unicode

Unicode

- The Unicode Consortium (1991)
- the Unicode standard defined as ISO 40646
- nowadays: all the world's living languages
- highly different writing systems: Arabic, Sanscrit, Chinese, Japanese, Korean
- ambition: 250 writing systems for hundreds of languages
- Unicode assigns each character a unique code point
- example: "LATIN CAPITAL LETTER A WITH ACUTE" goes to U+00C1
- Unicode defines a character set as well as several encodings

Common Unicode encodings

- UTF-32
  - 4 bytes for any character
- UTF-16
  - 2 bytes for each character in Basic Multilingual Plane
  - other characters 4 bytes
- UTF-8
  - 1-6 bytes per character

UTF-8 and ASCII

- a killer feature of UTF-8: an ASCII-encoded text is encoded in UTF-8 at the same time!
- the actual solution:
  - the number of leading 1's in the first byte determines the number of bytes in the following way:
    - zero ones (i.e., 0xxxxxxx): a single byte needed for the character (i.e., identical with ASCII)
    - two or more ones: the total number of bytes needed for the character
  - continuation bytes: 10xxxxxx
- a reasonable space-time trade-off
- but above all: this trick radically facilitated the spread of Unicode

UTF-8 and Czech

- We are lucky with Czech: characters of the Czech alphabet consume at most 2 bytes

Exercise: does this or that character exist in Unicode?

- check http://shapecatcher.com/

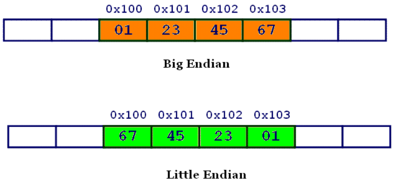
Misc

Byte order mark (BOM)

- BOM = a Unicode character: U+FEFF
- a special Unicode character, possibly located at the very beginning of a text stream
- optional
- used for several different purposes:
  - specifies byte order – endianess (little or big endian)
  - specifies (with a high level of confidence) that the text stream is encoded in one of the Unicode encodings
  - distinguishes Unicode encodings
- BOM in the individual encodings:
  - UTF-8: 0xEF,0xBB,0xBF
  - UTF-16: 0xFE followed by 0xFF for big endian, the other way round for little endian
  - UTF-32 – rarely used

If you can’t recall endianess

- Little and big endian are two ways of storing multibyte data-types (int, float, etc).
- In little endian machines, last byte of binary representation of the multibyte data-type is stored first.
- suppose an integer stored in 4 bytes:



CREDIT: https://www.geeksforgeeks.org/

Exercise

- using any text editor, store the Czech word *žlutý* into a text file in UTF-8
- using the `iconv` command, convert this file into four files corresponding the these encodings:
  - cp1250
  - iso-8859-2
  - utf-16
  - utf-32
- look at the size of these 5 files (using e.g. `ls * -l`) and explain all size differences
- use `hexdump` to show the hexadecimal (“encoding-less”) content of the files
- check out what the `file` command guesses

Exercise on character identity

- Create a UTF-8 encoded file containing the Latin letter "A", the Greek letter "A", and the Cyrilic letter "A", and view the file using `hexdump -C`.
- This might be a source of confusion when working with multilingual data.

Some myths and misunderstandings about character encoding

The following statements are wrong:

- ASCII is an 8-bit encoding.
- Unicode is a character encoding.
- Unicode can only support 65,536 characters.
- UTF-16 encodes all characters with 2 bytes.
- Case mappings are 1-1.
- This is just a plain text file, no encoding.
- This file is encoded in Unicode.
- It is the filesystem who knows the encoding of this file.
- File encoding can be absolutely reliably detected by this utility.

Detection of a file's encoding

100% accuracy impossible, but

- in some situations some encodings can be rejected with certainty
  - e.g. Unicode encodings do not allow some byte sequences
- if you have a prior knowledge (or expectation distribution) concerning the language of the text, then some encodings might be highly improbable
  - e.g. ISO-8859-1 improbable for Czech
- BOM can help too
- rule of thumb: many modern solutions default to UTF-8 if no encoding is specified
- the `file` command works reasonably well in most cases

Specification of a file's encoding – encoding declaration

- however, "reasonably well" is not enough, we need certainty
- for most plain-text-based file formats (including source codes of programming languages) there are clear rules how encodings should be specified
  - HTML4 vs HTML5

    ```
    <meta http-equiv="Content-Type" content="text/html;charset=ISO-8859-2">
    ```

    ```
    <meta charset="iso-8859-2">
    ```

    (btw notice the misnomer: "charset" stands for an encoding here, not for a character set (explain why))
  - XML

    ```
    <?xml version="1.0" encoding="UTF-8"?>
    ```

  - LaTeX

    ```
    \usepackage[utf8]{inputenc}
    ```

Encoding declaration, cont.

- some editors have their own encoding declaration style, such Emacs's

  ```
  # -*- coding: <encoding-name> -*-
  ```

  or VIM's

  ```
  # vim:fileencoding=<encoding-name>
  ```

Exercise

Try to fool the `file` command

- try to construct a file whose encoding is detected incorrectly by `file`

Summary

1. In spite of some relicts of chaos in the real world, the problem of character encoding has been solved almost exhaustively, esp. compared to the previous 8-bit solutions.
2. However, some new complexity has been induced (more or less inevitably), such as more a complex notion of character equivalence – Latin vs. Greek Vs. Cyrilic capital letter A.
3. Whenever possible, try to stick to Unicode (with UTF-8 being its prominent encoding).
4. Make sure you perfectly understand how Unicode is handled in your favourite programming languages and in your editors.