Character encoding

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1 History and context

1.1 One-byte character sets; Ascii

Somewhere in the depths of prehistory, people got to agree on a standard for character codes under 127, ASCII. Unlike another encoding scheme, EBCDIC, it has a few nice properties.

- All letters are consecutive, making a test 'is this a letter' easy to perform.
- Uppercase and lowercase letters are at a distance of 32.
- The first 31 codes, everything below the space character, as well as position 127, are 'unprintable', and can be used for such purposes as terminal cursor control.
- Unprintable codes are accessible through the control modifier (for this reason they are also called 'control codes'), which zeros bits 2 and 3: hit `Ctrl-[` to get `Esc`[1].

The ISO 646 standard codified 7-bit ASCII, but it left certain character positions (or 'code points') open for national variation. For instance, British usage put a pound sign (£) in the position of the dollar. The ASCII character set was originally accepted as ANSI X3.4 in 1968.

20	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 ~	

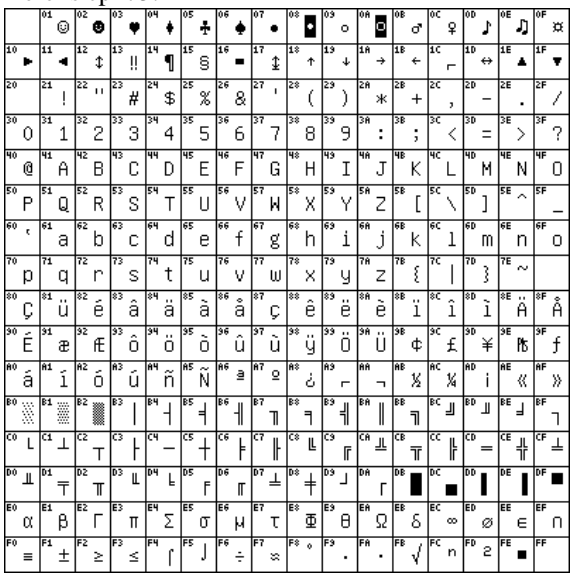
1.2 Code pages

This left the codes with the high bit set ('extended ASCII') undefined, and different manufacturers of computer equipment came up with their own way of filling them in. These standards were called 'code pages', and IBM gave a standard numbering to them. For

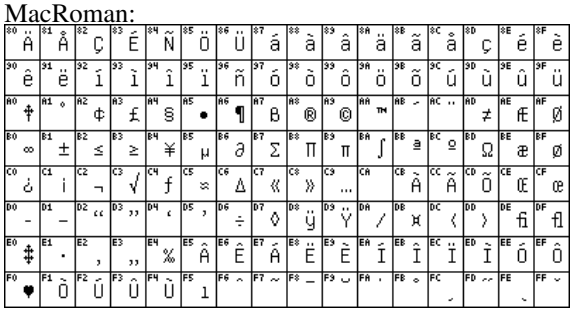
1. The way key presses generate characters is typically controlled in software. This mapping from keyboard scan codes to 7 or 8-bit characters is called a 'keyboard', and can be changed dynamically in most operating systems.

instance, code page 437 is the MS-DOS code page with accented characters for most European languages, 862 is DOS in Israel, 737 is DOS for Greeks.

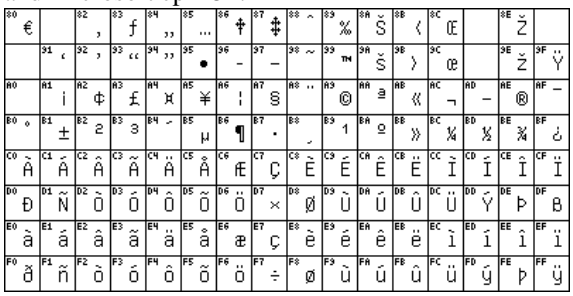
Here is cp473:



MacRoman:



and Microsoft cp1252:



More code pages are displayed on `http://aspell.net/charsets/codepages.html`. These diagrams can be generated from Unicode mapping tables, which look like

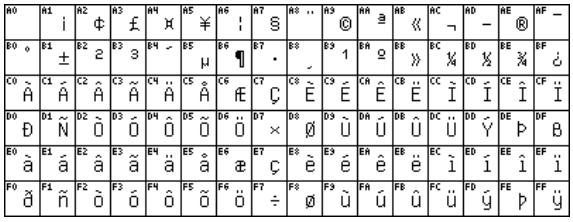
```
=20     U+0020  SPACE
```

```
=21      U+0021  EXCLAMATION MARK
=22      U+0022  QUOTATION MARK
...
=A3      U+00A3  POUND SIGN
=A4      U+20AC  EURO SIGN
=A5      U+00A5  YEN SIGN
...
```

The international variants were standardized as ISO 646-DE (German), 646-DK (Danish), et cetera. Originally, the dollar sign could still be replaced by the currency symbol, but after a 1991 revision the dollar is now the only possibility.

1.3 ISO 8859

The different code pages were ultimately standardized as ISO 8859, with such popular code pages as 8859-1 ('Latin 1') for western European,



8859-2 for eastern, and 8859-5 for Cyrillic.

These ISO standards explicitly left the first 32 extended positions undefined. Microsoft code page 1252 uses ISO 8859-1.

More useful information about ASCII: `http://jimprice.com/jim-asc.htm`. History of ASCII out of telegraph codes: `http://www.wps.com/projects/codes/index.html`. A history, paying attention to multilingual use: `http://tronweb.super-nova.co.jp/characcodehist.html` History as written by the father of ASCII: Bob Bemer `http://www.bobbemer.com/HISTORY.HTM`.

A good inventory of ISO 8859, Latin-1: `http://www.cs.tut.fi/~jkorpela/latin1/index.html`, with a discussion by logical grouping: `http://www.cs.tut.fi/~jkorpela/latin1/4.html`.

1.4 DBCS

Since certain Asian alphabets do not fit in 256 positions, a system called the 'Double Byte Character Set' was invented where some characters were stored in one, others in two bytes. This is very messy, since you can not simply write `s++` or `s--` to traverse a string. Instead you have to use functions from some library that understands these encodings. This system is now only of historical interest.

2 Unicode

The systems above functioned quite well as long as you stuck to one language or writing system. Poor dictionary makers. More or less simultaneously two efforts started that aimed to incorporate all the world's character sets in one standard: Unicode standard (originally 2-byte), and ISO 10646 (oringally 4-byte). Unicode then was extended, so that it has all numbers up to `10FFFF`, which is slightly over a million.

2.1 ISO 10646 and Unicode

Two international standards organizations, the Unicode Consortium and ISO/IEC JTC1/SC2, started designing a universal standard that was to be a superset of all existing character sets. These standards are now synchronized. Unicode has elements that are not in 10646, but they are compatible where it concerns straight character encoding.

ISO 10646 defines UCS, the 'Universal Character Set'. This is in essence a table of official names and code numbers for characters. Unicode adds to this rules for hyphenation, bi-directional writing, and more.

The full Unicode list of code points can be found, broken down by blocks, online at `http://www.fileformat.info/info/unicode/index.htm`, or downloadable at `http://www.unicode.org/charts/`.

2.2 BMP and earlier standards

Characters in Unicode are mostly denoted hexadecimally as `U+wxyz`, for instance `U+0041` is 'Latin Capital Letter A'. The range `U+0000`–`U+007F` (0–127) is identical to US-ASCII (ISO 646 IRV), and `U+0000`–`U+00FF` (0–255) is identical to Latin 1 (ISO 8859-1).

The original 2-byte subset is now called 'BMP' for Basic Multilingual Plane.

From `http://www.hyperdictionary.com/`:

BMP (Basic Multilingual Plane) The first plane defined in Unicode/ISO 10646, designed to include all scripts in active modern use. The BMP currently includes the Latin, Greek, Cyrillic, Devangari, hiragana, katakana, and Cherokee scripts, among others, and a large body of mathematical, APL-related, and other miscellaneous characters. Most of the Han ideographs in current use are present in the BMP, but due to the large number of ideographs, many were placed in the Supplementary Ideographic Plane.

SIP (Supplementary Ideographic Plane) The third plane (plane 2) defined in Unicode/ISO 10646, designed to hold all the ideographs descended from Chinese writing (mainly found in Vietnamese, Korean, Japanese and Chinese) that aren't found in the Basic Multilingual Plane. The BMP was supposed to hold all ideographs in modern use; unfortunately, many Chinese dialects (like Cantonese and Hong Kong Chinese) were overlooked; to write these, characters from the SIP are necessary. This is one reason even non-academic software must support characters outside the BMP.

2.3 Unicode encodings

Unicode is basically a numbered list of characters. When they are used in a file, their numbers can be encoded in a number of ways. To name the obvious example: if only the first 128 positions are used, the long Unicode code point can be truncated to just one byte. Here are a few encodings:

UCS-2 Obsolete: this was the original 'native' two-byte encoding before Unicode was extended.

UTF-32 Little used: this is a four-byte encoding. (UTF stands for 'UCS Transformation Format'.)

UTF-16 This is the BMP.

UTF-8 A one-byte scheme; details below.

UTF-7 Another one-byte scheme, but now the high bit is always off. Certain byte values act as 'escape', so that higher values can be encoded. Like UTF-1 and SCSU, this encoding is only of historical interest.

There is an important practical reason for UTF-8. Encodings such as UCS-2 are wasteful of space, if only traditional ASCII is needed. Furthermore, they would break software that is expecting to walk through a file with `s++` and such. Also, they would introduce many zero bytes in a file, which would play havoc with Unix software that uses null-termination for strings. Then there would be the problem of whether two bytes are stored in low-endian or high-endian order. For this reason it was suggested to store `FE FF` or `FF FE` at the beginning of each file as the 'Unicode Byte Order Mark'. Of course this plays havoc with files such as shell scripts which expect to find `#!` at the beginning of the file.

2.4 UTF-8

UTF-8 is an encoding where the positions up to 127 are encoded 'as such'; higher numbers are encoded in groups of 2 to 6 bytes. (UTF-8 is standardized as RFC 3629.) In a multi-byte group, the first byte is in the range 0xC0–0xFD (192–252). The next up to 5 bytes are in the range 0x80–0xBF (128–191, bit pattern starting with `10`). Note that `8` = `1000` and `B` = `1011`, so the highest two bits are always `10`, leaving six bits for encoding).

U-00000000 – U-0000007F	7 bits	0xxxxxxx	
U-00000080 – U-000007FF	$11 = 5 + 6$	110xxxxx	10xxxxxx
U-00000800 – U-0000FFFF	$16 = 4 + 2 \times 6$	1110xxxx	10xxxxxx 10xxxxxx
U-00010000 – U-001FFFFF	$21 = 3 + 3 \times 6$	11110xxx	10xxxxxx (3 times)
U-00200000 – U-03FFFFFF	$26 = 2 + 4 \times 6$	111110xx	10xxxxxx (4 times)
U-04000000 – U-7FFFFFFF	$31 = 1 + 5 \times 6$	1111110x	10xxxxxx (5 times)

All bites in a multi-byte sequence have their high bit set.

Exercise 1. Show that a UTF-8 parser will not miss more than two characters if a byte becomes damaged (any number of bits arbitrarily changed).

IETF documents such as RFC 2277 require support for this encoding in internet software. Here is a good introduction to UTF-8 use in Unix: `http://www.cl.cam.ac.uk/~mgk25/unicode.html`. The history of it: `http://www.cl.cam.ac.uk/~mgk25/ucs/utf-8-history.txt`.

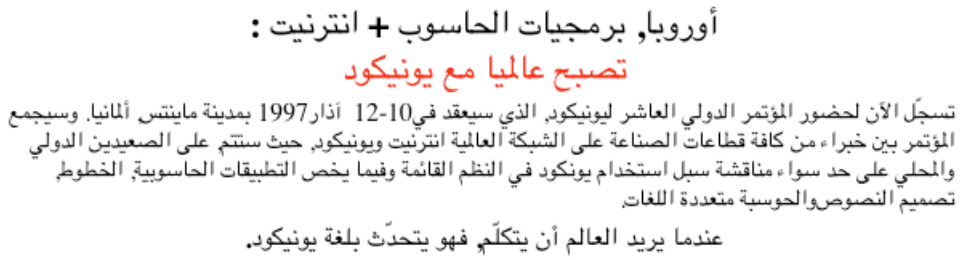
2.5 Unicode tidbits

2.5.1 Line breaking

See `http://www.cs.tut.fi/~jkorpela/unicode/linebr.html` and `http://www.unicode.org/reports/tr14/`

2.5.2 Bi-directional writing

Most scripts are left-to-right, but Arabic and Hebrew run right-to-left. Characters in a file are stored in 'logical order', and usually it is clear in which direction to render them, even if they are used mixed. Letters have a 'strong' directionality: unless overridden, they will be displayed in their natural direction. The first letter of a paragraph with strong direction determines the main direction of that paragraph.



However, when differently directional texts are embedded, some explicit help is needed. The problem arises with letters that have only weak directionality. The following is a sketch of a problematic case.

> Memory: he said "I NEED WATER!", and expired.
> Display: he said "RETAW DEEN I!", and expired.

If the exclamation mark is to be part of the Arabic quotation, then the user can select the text 'I NEED WATER!' and explicitly mark it as embedded Arabic (`<RLE>` is Right-Left Embedding; `<PDF>` Pop Directional Format), which produces the following result:

> Memory: he said "`<RLE>`I NEED WATER!`<PDF>`", and expired.
> Display: he said "!RETAW DEEN I", and expired.

A simpler method of doing this is to place a Right Directional Mark `<RLM>` after the exclamation mark. Since the exclamation mark is now not on a directional boundary, this produces the correct result.

Memory: he said "I NEED WATER!<RLM>", and expired.
Display: he said "!RETAW DEEN I", and expired.

For the full definition, see `http://www.unicode.org/reports/tr9/`.

2.6 Unicode and oriental languages

'Han unification' is the Unicode strategy of saving space in the oriental languages (traditional Chinese, simplified Chinese, Japanese, Korean: 'CJK') by recognizing common characters. This idea is not uncontroversial; see `http://en.wikipedia.org/wiki/Han_unification`.

3 More about character sets and encodings

3.1 Character sets

Informally, the term 'character set' (also 'character code' or 'code') used to mean something like 'a table of bytes, each with a character shape'. With only the English alphabet to deal with that is a good enough definition. These days, much more general cases are handled, mapping one octet into several characters, or several octets into one character. The definition has changed accordingly:

> A '*charset* is a method of converting a sequence of octets into a sequence of characters. This conversion may also optionally produce additional control information such as directionality indicators.

(From RFC 2978) A conversion the other way may not exist, since different octet combinations may map to the same character. Another complicating factor is the possibility of switching between character sets; for instance, ISO 2022-JP is the standard ASCII character set, but the escape sequence `ESC $ @` switches to JIS X 0208-1978.

3.2 From character to encoding in four easy steps

To disentangle the concepts behind encoding, we need to introduce a couple of levels:

ACR Abstract Character Repertoire: the set of characters to be encoded; for example, some alphabet or symbol set. This is an unordered set of characters, which can be fixed (the contents of ISO 8859-1), or open (the contents of Unicode).

CCS Coded Character Set: a mapping from an abstract character repertoire to a set of nonnegative integers. This is what is meant by 'encoding', 'character set definition', or 'code page'; the integer assigned to a character is its 'code point'.
There used to be a drive towards unambiguous abstract character names across repertoires and encodings, but Unicode ended this, as it provides (or aims to provide) more or less a complete list of every character on earth.

CEF Character Encoding Form: a mapping from a set of nonnegative integers that are elements of a CCS to a set of sequences of particular code units. A 'code unit' is an integer of a specific binary width, for instance 8 or 16 bits. A CEF then maps the code points of a coded character set into sequences of code point, and these sequences can be of different lengths inside one code page. For instance

- ASCII uses a single 7-bit unit
- UCS-2 uses a single 16-bit unit
- DBCS uses two 8-bit units
- UTF-8 uses one to four 8-bit units.
- UTF-16 uses a mix of one and two 16-bit code units.

CES Character Encoding Scheme: a reversible transformation from a set of sequences of code units (from one or more CEFs to a serialized sequence of bytes. In cases such as ASCII and UTF-8 this mapping is trivial. With UCS-2 there is a single 'byte order mark', after which the code units are trivially mapped to bytes. On the other hand, ISO 2022, which uses escape sequences to switch between different encodings, is a complicated CES.

Additionally, there are the concepts of

CM Character Map: a mapping from sequences of members of an abstract character repertoire to serialized sequences of bytes bridging all four levels in a single operation. These maps are what gets assigned MIBenum values by IANA; see section **??**.

TES Transfer Encoding Syntax: a reversible transform of encoded data. This data may or may not contain textual data. Examples of a TES are base64, uuencode, and quoted-printable, which all transform a byte stream to avoid certain values.

3.3 A bootstrapping problem

In order to know how to interpret a file, you need to know what character set it uses. This problem also occurs in MIME mail encoding (section **??**), which can use many character sets. Names and numbers for character sets are standardized by IANA: the Internet Assigned Names Authority (`http://www.iana.org/`). However, in what character set do you write this name down?

Fortunately, everyone agrees on (7-bit) ASCII, so that is what is used. A name can be up to 40 characters from us-ascii.

As an example, here is the iana definition of ASCII:

name `ANSI_X3.4-1968`
reference RFC1345,KXS2
MIBenum 3
source ECMA registry
aliases `iso-ir-6`, `ANSI_X3.4-1986`, `ISO_646.irv:1991`, `ASCII`, `ISO646-US`, `US-ASCII (preferred MIME name)`, `us`, `IBM367`, `cp367`, `csASCII`

The `MIBenum` (Management Information Base) is a number assigned by IANA[2]. The full list of character sets is at `http://www.iana.org/assignments/character-sets`, and RFC 3808 is a memo that describes the IANA Charset MIB.

3.4 Character codes in HTML

HTML can access unusual characters in several ways:

2. Apparently these numbers derive from the Printer MIB, RFC 1759.

- With a decimal numerical code: `&#32;` is a space token. (HTML 4 supports hexadecimal codes.)
- With a vaguely symbolic name: `&copy;` is the copyright symbol. See `http://www.cs.tut.fi/~jkorpela/HTML3.2/latin1.html` for a list of symbolic names in Latin-1.
- The more interesting way is to use an encoding such as UTF-8 (section **??**) for the file. For this it would be nice if the server could state that the file is
  `Content-type: text/html;charset=utf-8`
  but it is also all right if the file starts with
  `<META HTTP-EQUIV="Content-Type" CONTENT="text/html;charset=utf-8">`

Description	Char	Code	Entity name
non-breaking space		-->	-->
inverted exclamation	¡	¡ --> ¡	¡ --> ¡
cent sign	¢	¢ --> ¢	¢ --> ¢
pound sterling	£	£ --> £	£ --> £
general currency sign	¤	¤ --> ¤	¤ --> ¤
yen sign	¥	¥ --> ¥	¥ --> ¥
broken vertical bar	¦	¦ --> ¦	¦ --> ¦

It is requirement that user agents can at least parse the `charset` parameter, which means they have to understand us-ascii.

Open this link in your browser, and additionally view the source: `http://www.unicode.org/unicode/iuc10/x-utf8.html`. How well does your software deal with it?

See also section **??**.

3.5 Characters in email

3.6 FTP

FTP is a very old ARPA protocol. It knows 'binary' and 'text' mode, but the text mode is not well defined. Some ftp programs adjust line ends; others, such as `Fetch` on the Mac, actually do code page translation.

3.7 Character encodings in editors and programming languages

Software must be rewritten to use character encodings. Windows NT/2000/XP, including Visual Basic, uses UCS-2 as native string type. Strings are declared of type `wchar_t` instead of `char`, and the programmer uses `wcslen` instead of `strlen`, et cetera. A literal string is created as `L"Hello world"`.

4 Character issues in TEX / LATEX

4.1 Diacritics

Original TEX is not very good at dealing with diacritics. They are implemented as things to put on top of characters, even when, as with the cedilla, they are under the letter. Furthermore, TEX can not hypenate a word with accents, since the accent introduces a space in the

word (technically: an explicit kern). Both problems were remedied to a large extent with the 'Cork font encoding', which contains most accented letters as single characters. This means that accents are correctly placed by design, and also that the word can be hyphenated, since the kern has disappeared.

These fonts with accented characters became possible when TEX version 3 came out around 1990. This introduced full 8-bit compatibility, both in the input side and in the font addressing.

4.2 LATEX input file access to fonts

If an input file for LATEX is allowed to contain all 8-bit octets, we get all the problems of compatibility that plagued regular text files. This is solved by the package `inputenc`:

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

where `codes` is `applemac`, `ansinew`, or various other code pages.

This package makes all unprintable ASCII characters, plus the codes over 127, into active characters. The definitions are then dynamically set depending on the code page that is loaded.

4.3 LATEX output encoding

The `inputenc` package does not solve the whole problem of producing a certain font character from certain keyboard input. It only mapped a byte value to the TEX command for producing a character. To map such commands to actual code point in a font file, the TEX and LATEX formats contain lines such as

```
\chardef\i="10
```

declaring that the dotless-i is at position 16. However, this position is a convention, and other people – type manufacturers – may put it somewhere else.

This is handled by the 'font encoding' mechanism. The various people working on the LATEX font schemes have devised a number of standard font encodings. For instance, the `OT1` encoding corresponds to the original 128-character set. The `T1` encoding is a 256-character extension thereof, which includes most accented characters for Latin alphabet languages.

A font encoding is selected with

```
\usepackage[T1]{fontenc}
```

A font encoding definition contains lines such as

```
\DeclareTextSymbol{\AE}{OT1}{29}
\DeclareTextSymbol{\OE}{OT1}{30}
\DeclareTextSymbol{\O}{OT1}{31}
\DeclareTextSymbol{\ae}{OT1}{26}
\DeclareTextSymbol{\i}{OT1}{16}
```

4.4 Virtual fonts

Exercise 2. What does an `ALT` key do?

Exercise 3. What is EBCDIC? What is the basic idea?

Exercise 4. Find the Unicode definition. Can you find an example of a character that has two functions, but is not defined as two characters? Find two characters that are defined seperately for compatibility, but that are defined equivalent.

Exercise 5. ISO 8859 has the 'non-breaking space' at position `A0`. How does TEX handle the nbsp? How do TEX, HTML, Latin-1, MS Word, et cetera handle multiple spaces? Discuss the pros and cons.

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