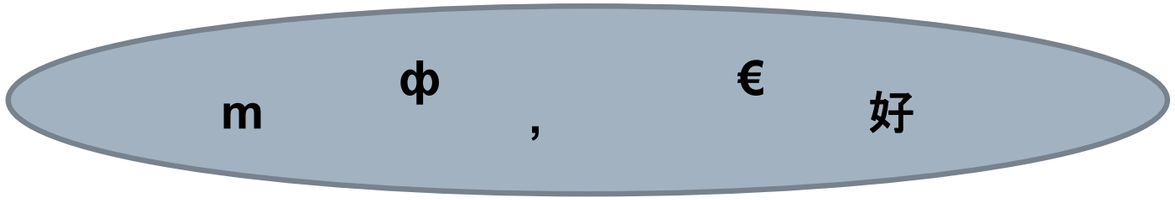
Unicode and UTF-8

Lecture 41

A standard for the discrete representation of written text

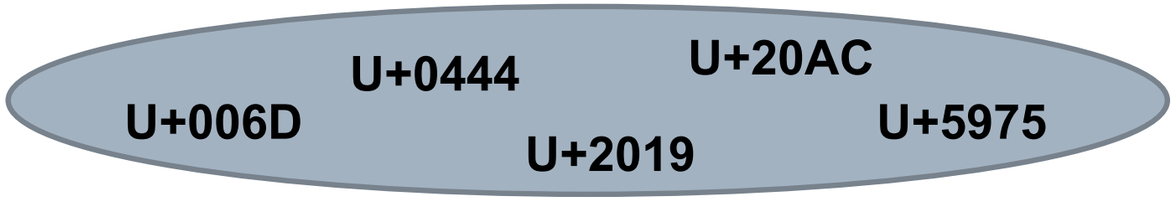
The Big Picture: Sets

glyphs

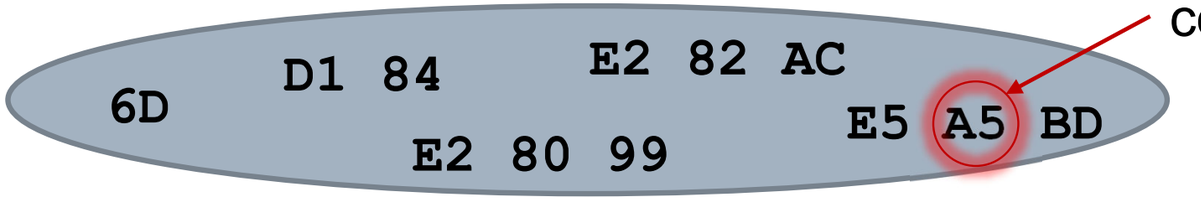


characters

code points

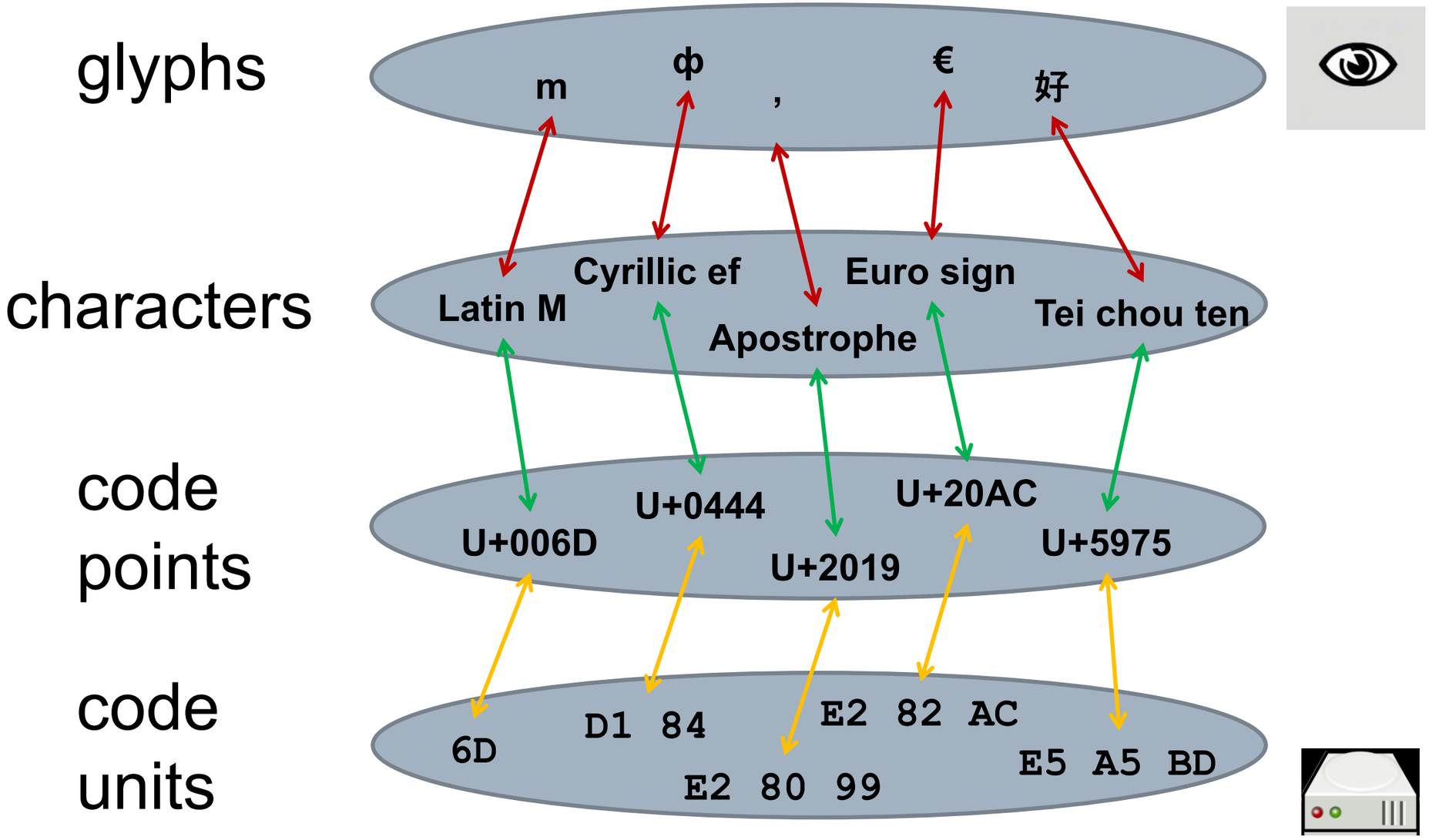


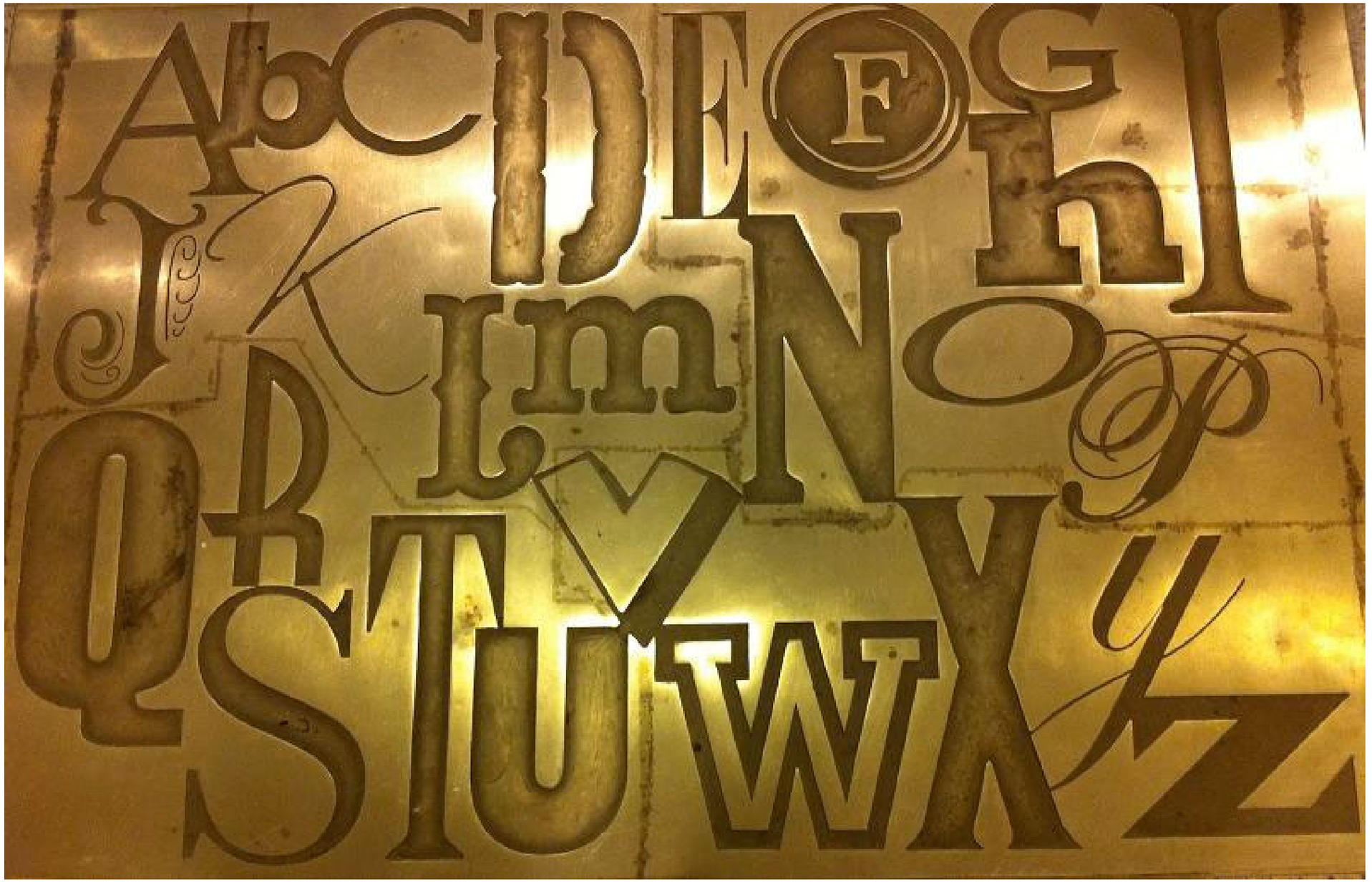
code units



code unit

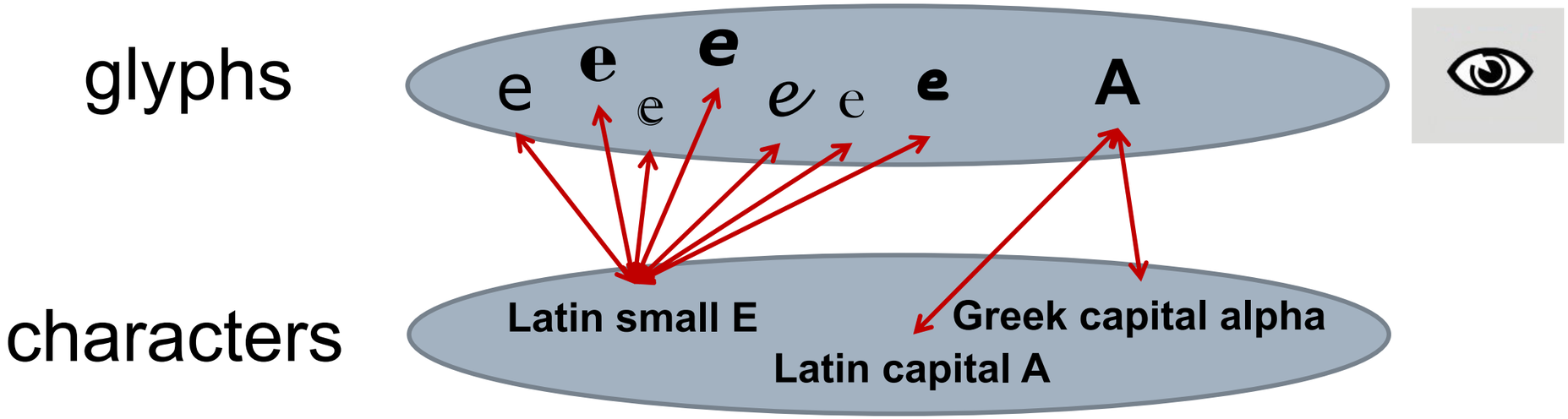
The Big Picture: Mappings




AbCDEFGhI
JKlmNOp
QRSTUVWXYZ


Ласкаво просимо!
Добро пожаловать
مرحبابكم Willkommen 歡迎
Benvenuti ようこそ
환영합니다 Bienvenue
ยินดีต้อนรับ
WELKOM Soo dhawow
BIENVENIDOS
THE OHIO STATE UNIVERSITY
UNIVERSITY LIBRARIES

Glyphs vs Characters



Text: A Sequence of Glyphs

- Glyph: "An individual mark on a written medium that contributes to the meaning of what is written."
  - See foyer floor in main library
- One *character* can have different *glyphs*
  - Example: Latin Small E could be e, e, **e**, e, *e*…
- One *glyph* can be different *characters*
  - 0 is both Digit Zero and (capital) Latin 0
  - A is both (capital) Latin A and Greek Alpha
- One unit of text can consist of *multiple* glyphs
  - An accented letter (é) is two glyphs
  - The ligature of f+i (fi) is two glyphs

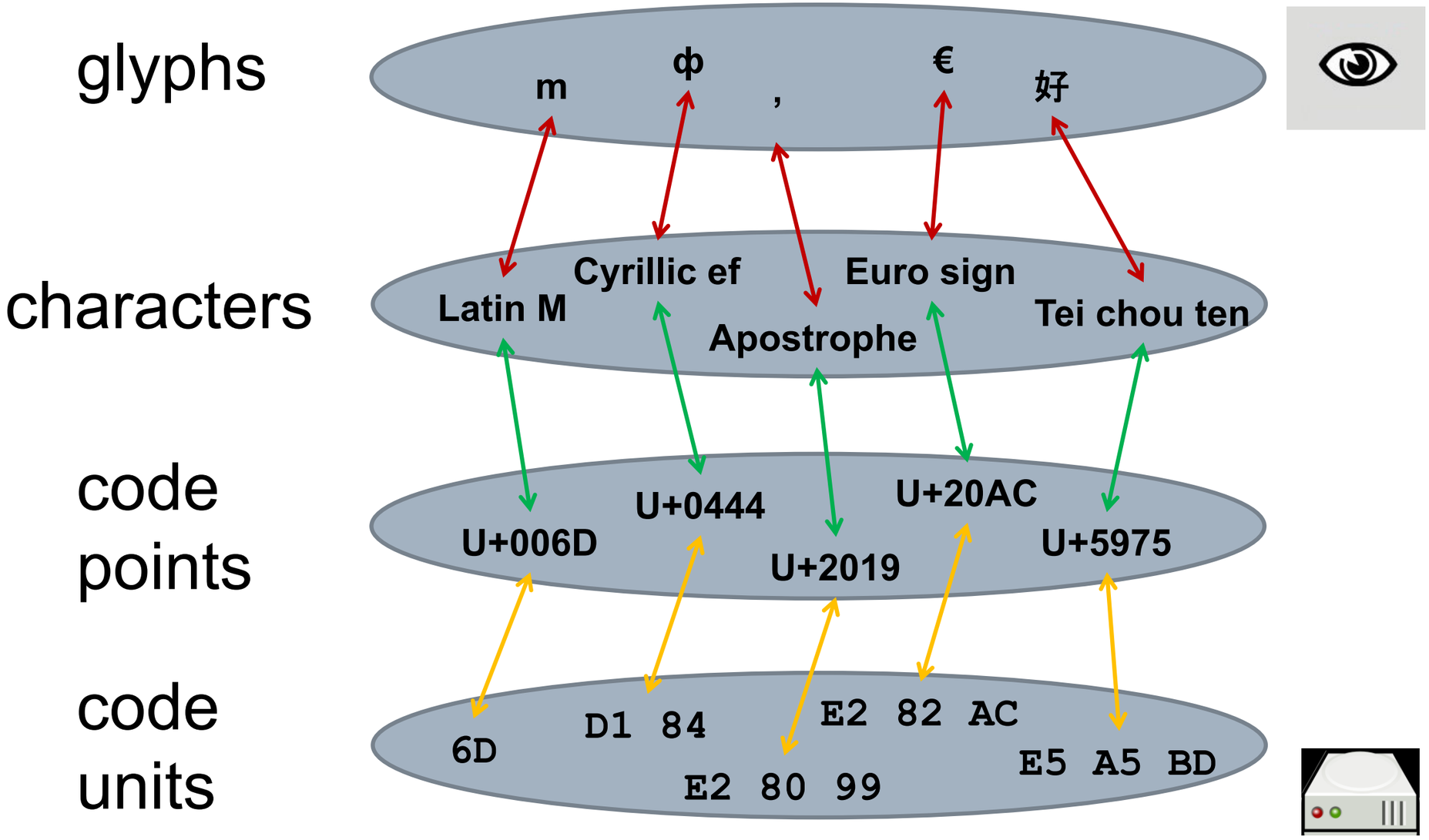
Security Issue: Eyes Deceive

- Visual homograph: Two different characters that look the same
  - Would you click here: www.paypal.com ?

Security Issue: Eyes Deceive (Cont'd)

- Visual homograph: Two different characters that look the same
  - Would you click here: www.paypal.com ?
  - Oops! The second ‘a’ is actually CYRILLIC SMALL LETTER A
  - This site successfully registered in 2005
- Other examples: combining characters
  - ñ = LATIN SMALL LETTER N WITH TILDE
  - ñ = LATIN SMALL LETTER N + COMBINING TILDE
- “Solution”
  - Heuristics that warn users when languages are mixed and homographs are possible

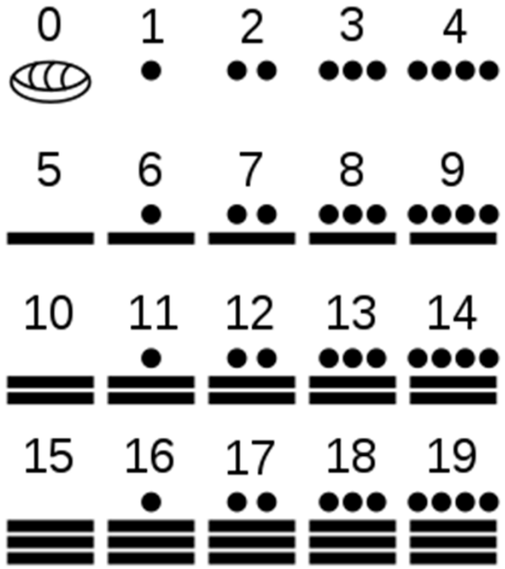
Unicode: Characters, Code Points



Unicode Code Points

- Each character is assigned a unique *code point*
- A code point is defined by an integer value, and is given a name
  - one hundred and nine (109, or 0x6d)
  - LATIN SMALL LETTER M
- Convention: Write code points as U+hex
  - Example: U+006D
- As of Sept '24, v16.0 (see unicode.org):
  - Contains 154,998 code points
    emoji-versions.html
  - Covers 168 scripts (and counting…)
    unicode.org/charts/

Example Recent Addition (v11)



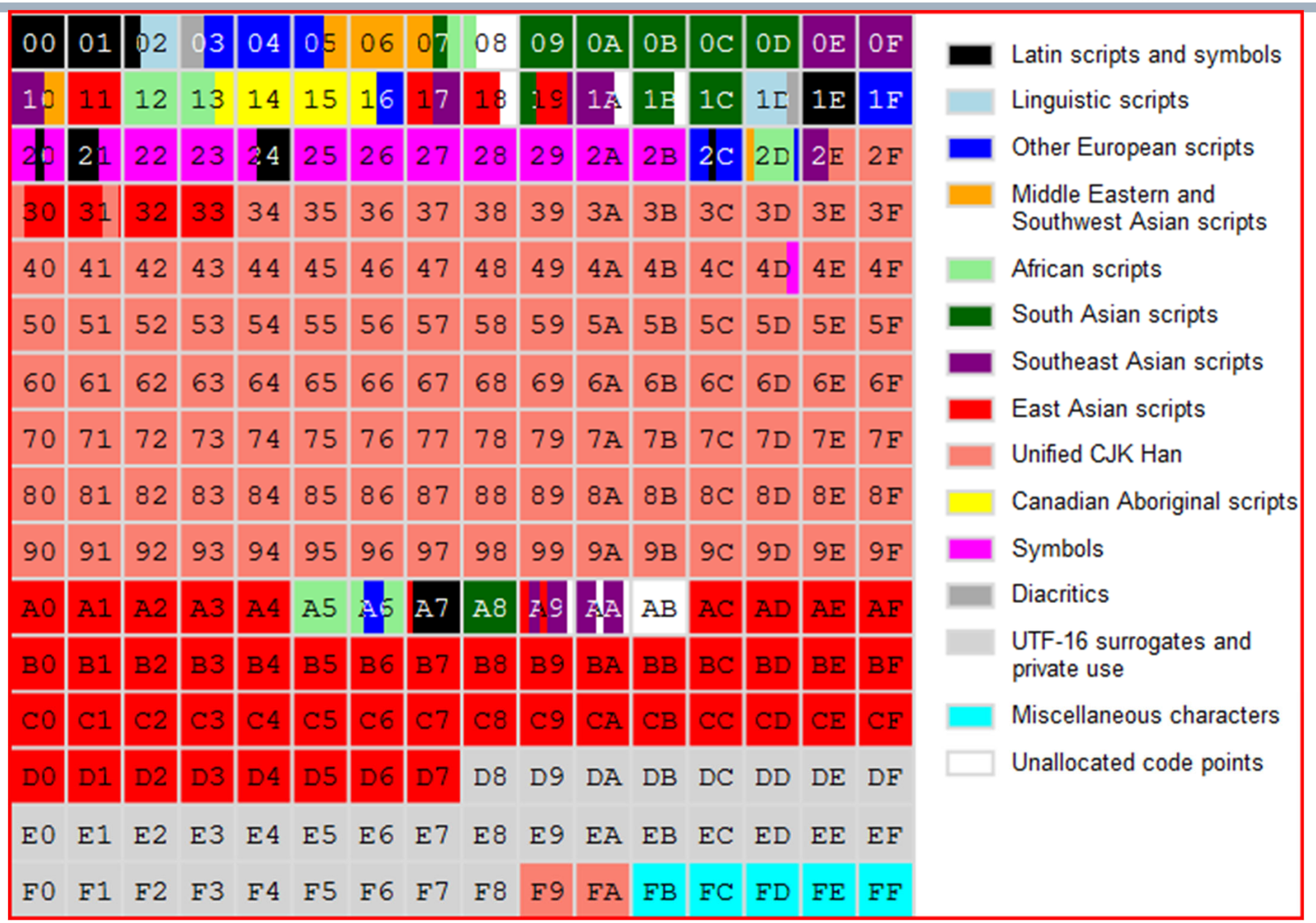
Mayan numerals

1D2E0	𝋠	MAYAN NUMERAL ZERO
1D2E1	𝋡	MAYAN NUMERAL ONE
1D2E2	𝋢	MAYAN NUMERAL TWO
1D2E3	𝋣	MAYAN NUMERAL THREE
1D2E4	𝋤	MAYAN NUMERAL FOUR
1D2E5	𝋥	MAYAN NUMERAL FIVE
1D2E6	𝋦	MAYAN NUMERAL SIX
1D2E7	𝋧	MAYAN NUMERAL SEVEN
1D2E8	𝋨	MAYAN NUMERAL EIGHT
1D2E9	𝋩	MAYAN NUMERAL NINE
1D2EA	𝋪	MAYAN NUMERAL TEN
1D2EB	𝋫	MAYAN NUMERAL ELEVEN
1D2EC	𝋬	MAYAN NUMERAL TWELVE
1D2ED	𝋭	MAYAN NUMERAL THIRTEEN
1D2EE	𝋮	MAYAN NUMERAL FOURTEEN
1D2EF	𝋯	MAYAN NUMERAL FIFTEEN
1D2F0	𝋰	MAYAN NUMERAL SIXTEEN
1D2F1	𝋱	MAYAN NUMERAL SEVENTEEN
1D2F2	𝋲	MAYAN NUMERAL EIGHTEEN
1D2F3	𝋳	MAYAN NUMERAL NINETEEN

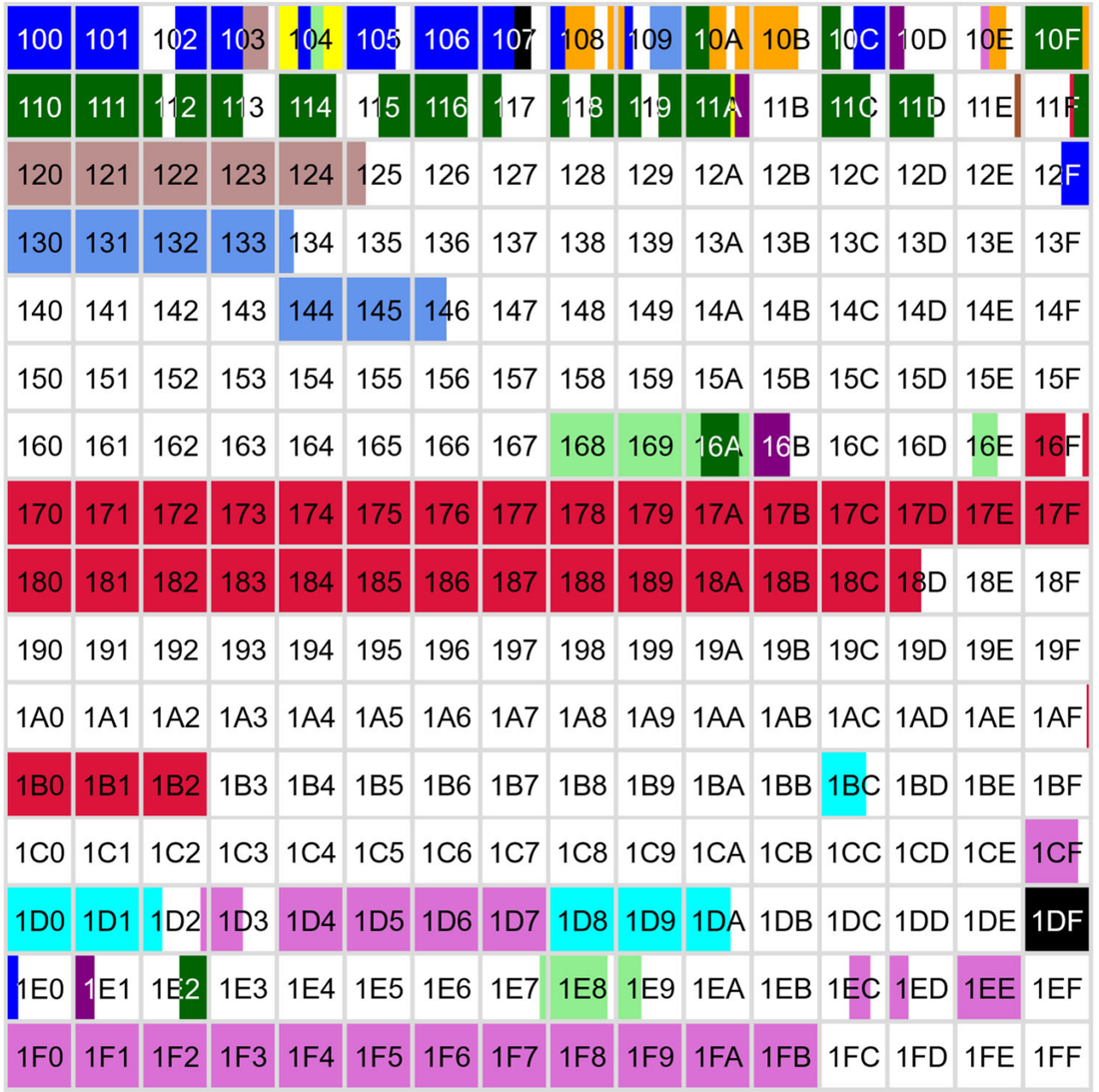
Organization

- Code points are grouped into categories
  - Basic Latin, Cyrillic, Arabic, Cherokee, Currency, Mathematical Operators, …
- Unicode allows for 17 x 2^{16} code points
  - 0 to 1,114,111 (*i.e.*, > 1 million)
  - U+0000 to U+10FFFF
- Each block of 2^{16} code points is a *plane*
  - U+nnnnnn, same green ==> same plane
  - ~64,000 code points per plane
- Plane 0 is the *basic multilingual plane* (BMP)
  - Has (practically) everything you could need
  - Convention: code points in BMP written U+nnnn (ie 4 digits, leading 0's if needed)
  - Others code points written without leading 0's

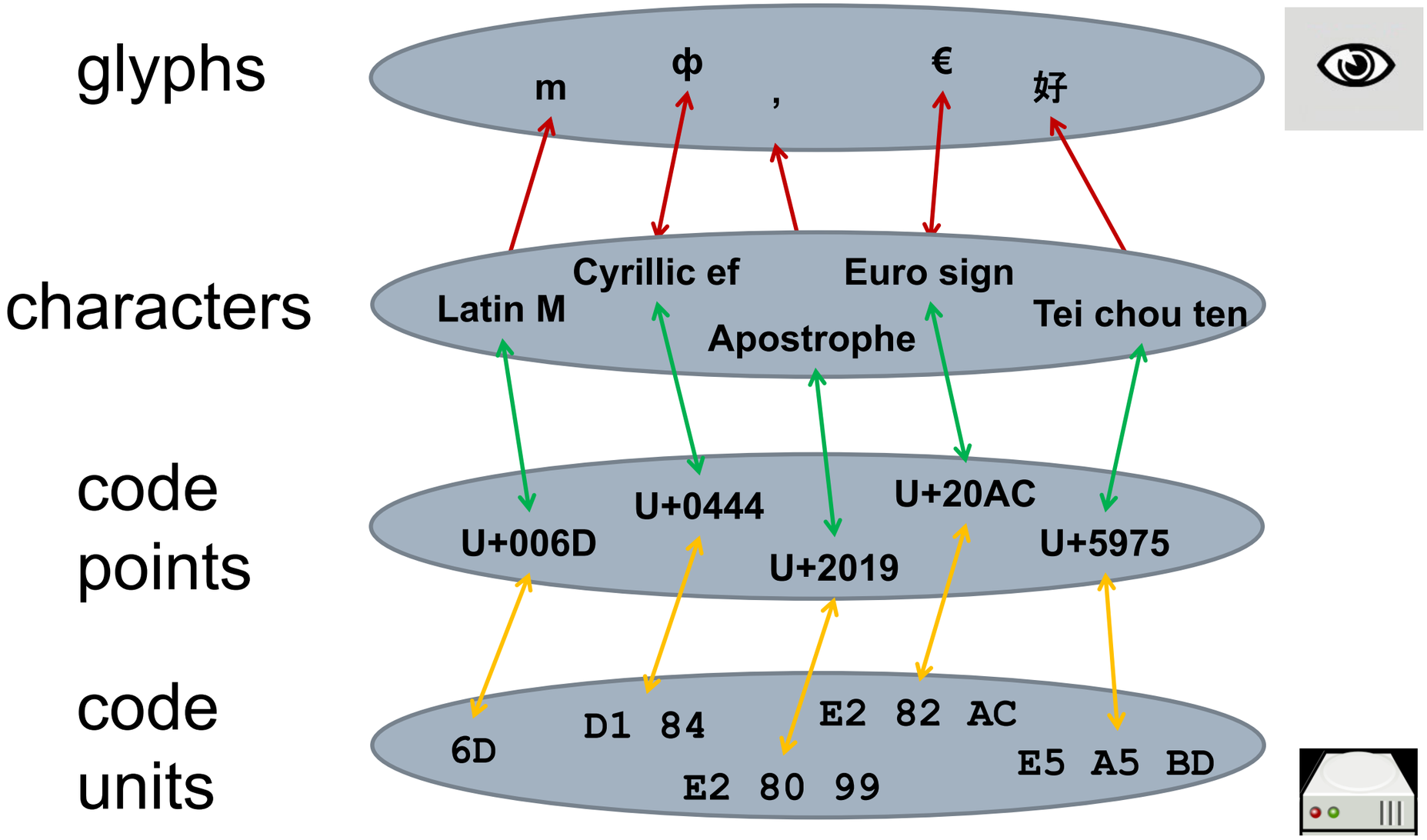
Basic Multilingual Plane



Supplemental Plane (plane 1)



UTF-8: Code Points & Octets



UTF-8

- Encodes each code point (integer) as a sequence of bytes (octets)
- Variable length
  - Some code points require 1 octet
  - Others require 2, 3, or 4
- Consequence: Can not infer number of characters from size of file!
- No endian-ness: a *sequence* of octets

  `D0 BF D1 80 D0 B8 D0 B2 D0 B5 D1 82...`
- Other encodings exist!
  - Eg UTF-16 uses 2 bytes per code point (more general term: *code unit*)

UTF-8 Encoding Recipe: 1 and 2-Bytes

- 1-byte encodings
  - First bit is 0
  - Example: **0**110 1101 (encodes U+006D)
- 2-byte encodings
  - First byte starts with **110**…
  - Second byte starts with **10**…
    - Example: **110**1 0000 **10**11 1111
    - Payload: 110**1 0000** 10**11 1111**
= 100 0011 1111
= 0x043F
    - Code point: U+043F
i.e. п, Cyrillic small letter pe

UTF-8 Encoding Recipe: Longer Encodings

- Generalization: An encoding of length k:
  - First byte starts with k **1**'s, then a **0**
    - Example **1110** 0110 ==> first byte of a 3-byte encoding
  - Subsequent k-1 bytes each start with **10**
  - Remaining bits are the payload
- Example: E2 82 AC

  11100010 10000010 10101100
  - Payload: 0x20AC (*i.e.*, U+20AC, €)
- Consequence: Stream is *self-synchronizing*
  - Losing a byte affects only one character

UTF-8 Encoding Summary

Unicode	Byte1	Byte2	Byte3	Byte4	example
U+0000–U+007F	0xxxxxxx				'$' U+0024 → 00100100 → 0x24
U+0080–U+07FF	110yyyxx	10xxxxxx			'¢' U+00A2 → 11000010,10100010 → 0xC2,0xA2
U+0800–U+FFFF	1110yyyy	10yyyyxx	10xxxxxx		'€' U+20AC → 11100010,10000010,10101100 → 0xE2,0x82,0xAC
U+10000–U+10FFFF	11110zzz	10zzyyyy	10yyyyxx	10xxxxxx	'𤭢' U+024B62 → 11110000,10100100,10101101,10100010 → 0xF0,0xA4,0xAD,0xA2

(from wikipedia)

Your Turn

- For the following UTF-8 encoding, what is the corresponding code point(s)?
  - F0 A4 AD A2

- For the following Unicode code point, what is its UTF-8 encoding?
  - U+20AC

Security Issue: Multiplicity of Encodings

- Not all octet sequences are legal encodings
  - "overlong" encodings are illegal
  - example: C0 AF
    = **110**0 00**00** **10**10 1111
    = U+002F (encoding should be 2F)
- Classic security bug (IIS 2001)
  - Should reject URL requests with "../.."
    - Looked for 2E 2E 2F 2E 2E (in encoding)
  - Accepted "..%c0%af.." (doesn't contain x2F)
    - 2E 2E C0 AF 2E 2E is ok to allow through
  - After accepting, server then decoded
    - 2E 2E C0 AF 2E 2E decoded into "../.."
- Moral: String is a sequence of *code units*
  - But we care about *code points*

Other (Older) Encodings: ASCII

- In the beginning…
- Character sets were small
  - ASCII: only 128 characters (ie 2^7)
  - 1 byte/character, leading bit always 0

ASCII: 128 Codes

ASCII Code Chart

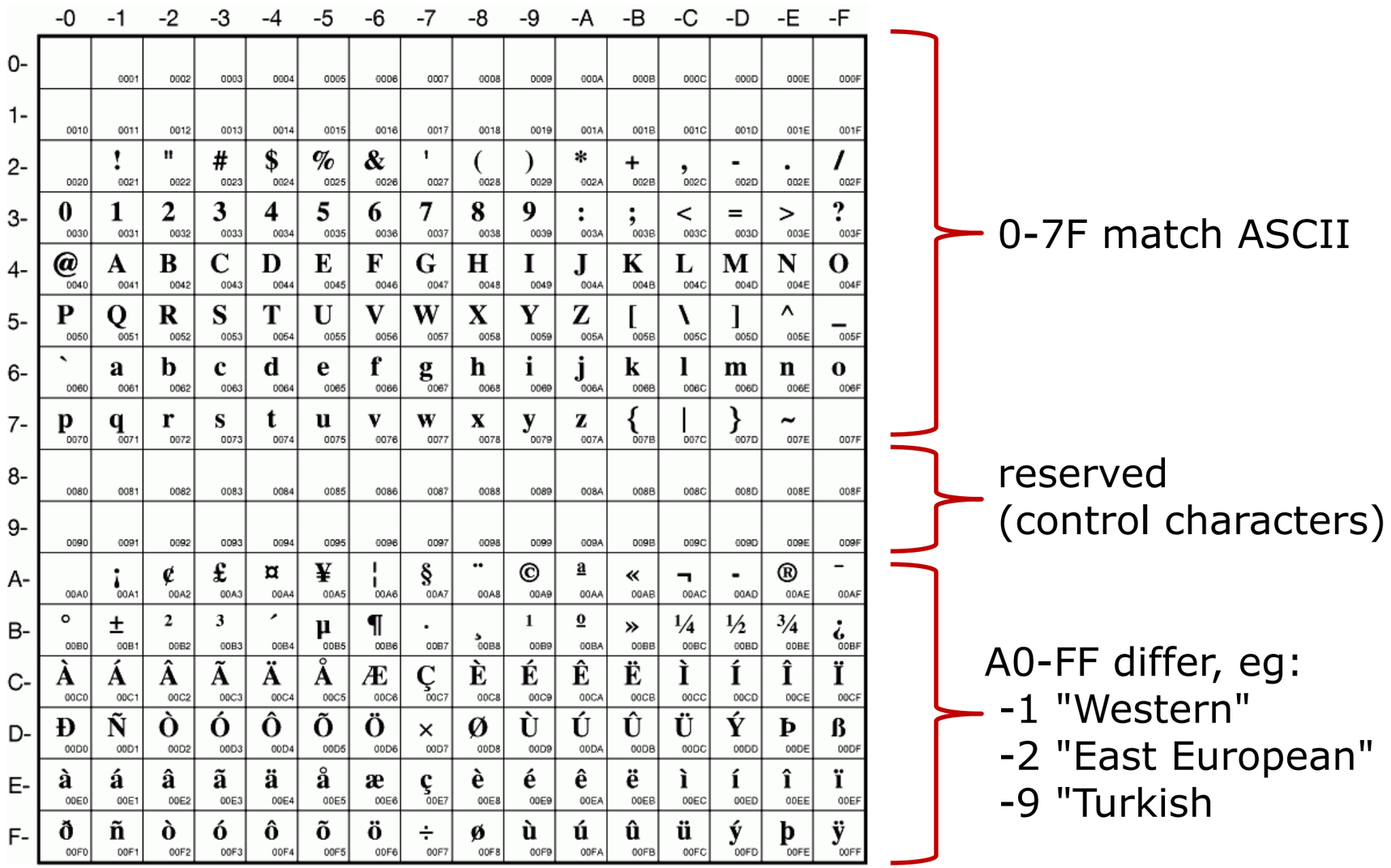
	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0	NUL	SOH	STX	ETX	EOT	ENQ	ACK	BEL	BS	HT	LF	VT	FF	CR	SO	SI
1	DLE	DC1	DC2	DC3	DC4	NAK	SYN	ETB	CAN	EM	SUB	ESC	FS	GS	RS	US
2		!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
3	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
4	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
5	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
6	`	a	b	c	d	e	f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

6D = Latin small m

Other (Older) Encodings: Code Pages

- In the beginning…
- Character sets were small
  - ASCII: only 128 characters (ie 2^7)
  - 1 byte/character, leading bit always 0
- Globalization means more characters…
  - But 1 byte/character seems fundamental
- Solutions:
  - Use that leading bit!
    - Text data now looks just like binary data
    - 256 characters
  - Use more than 1 encoding!
    - Must specify data + encoding used
    - Each encoding gives 256 characters

ISO-8859 family (eg -1 Latin)



	-0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-A	-B	-C	-D	-E	-F
0-	0000	0001	0002	0003	0004	0005	0006	0007	0008	0009	000A	000B	000C	000D	000E	000F
1-	0010	0011	0012	0013	0014	0015	0016	0017	0018	0019	001A	001B	001C	001D	001E	001F
2-	0020	! 0021	" 0022	# 0023	$ 0024	% 0025	& 0026	' 0027	(0028	) 0029	* 002A	+ 002B	, 002C	- 002D	. 002E	/ 002F
3-	0 0030	1 0031	2 0032	3 0033	4 0034	5 0035	6 0036	7 0037	8 0038	9 0039	: 003A	; 003B	< 003C	= 003D	> 003E	? 003F
4-	@ 0040	A 0041	B 0042	C 0043	D 0044	E 0045	F 0046	G 0047	H 0048	I 0049	J 004A	K 004B	L 004C	M 004D	N 004E	O 004F
5-	P 0050	Q 0051	R 0052	S 0053	T 0054	U 0055	V 0056	W 0057	X 0058	Y 0059	Z 005A	[005B	\ 005C	] 005D	^ 005E	_ 005F
6-	` 0060	a 0061	b 0062	c 0063	d 0064	e 0065	f 0066	g 0067	h 0068	i 0069	j 006A	k 006B	l 006C	m 006D	n 006E	o 006F
7-	p 0070	q 0071	r 0072	s 0073	t 0074	u 0075	v 0076	w 0077	x 0078	y 0079	z 007A	{ 007B	| 007C	} 007D	~ 007E	007F
8-	0080	0081	0082	0083	0084	0085	0086	0087	0088	0089	008A	008B	008C	008D	008E	008F
9-	0090	0091	0092	0093	0094	0095	0096	0097	0098	0099	009A	009B	009C	009D	009E	009F
A-	00A0	¡ 00A1	¢ 00A2	£ 00A3	¤ 00A4	¥ 00A5	¦ 00A6	§ 00A7	¨ 00A8	© 00A9	ª 00AA	« 00AB	¬ 00AC	- 00AD	® 00AE	¯ 00AF
B-	° 00B0	± 00B1	2 00B2	3 00B3	´ 00B4	µ 00B5	¶ 00B6	· 00B7	¸ 00B8	1 00B9	º 00BA	» 00BB	¼ 00BC	½ 00BD	¾ 00BE	¿ 00BF
C-	À 00C0	Á 00C1	Â 00C2	Ã 00C3	Ä 00C4	Å 00C5	Æ 00C6	Ç 00C7	È 00C8	É 00C9	Ê 00CA	Ë 00CB	Ì 00CC	Í 00CD	Î 00CE	Ï 00CF
D-	Ð 00D0	Ñ 00D1	Ò 00D2	Ó 00D3	Ô 00D4	Õ 00D5	Ö 00D6	× 00D7	Ø 00D8	Ù 00D9	Ú 00DA	Û 00DB	Ü 00DC	Ý 00DD	Þ 00DE	ß 00DF
E-	à 00E0	á 00E1	â 00E2	ã 00E3	ä 00E4	å 00E5	æ 00E6	ç 00E7	è 00E8	é 00E9	ê 00EA	ë 00EB	ì 00EC	í 00ED	î 00EE	ï 00EF
F-	ð 00F0	ñ 00F1	ò 00F2	ó 00F3	ô 00F4	õ 00F5	ö 00F6	÷ 00F7	ø 00F8	ù 00F9	ú 00FA	û 00FB	ü 00FC	ý 00FD	þ 00FE	ÿ 00FF

0-7F match ASCII

reserved
(control characters)

A0-FF differ, eg:
-1 "Western"
-2 "East European"
-9 "Turkish

Windows Family (eg 1252 Latin)

Windows-1252 (CP1252)																
	x0	x1	x2	x3	x4	x5	x6	x7	x8	x9	xA	xB	xC	xD	xE	xF
0x	NUL	SOH	STX	ETX	EOT	ENQ	ACK	BEL	BS	HT	LF	VT	FF	CR	SO	SI
1x	DLE	DC1	DC2	DC3	DC4	NAK	SYN	ETB	CAN	EM	SUB	ESC	FS	GS	RS	US
2x	SP	!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
3x	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
4x	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
5x	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
6x	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
7x	p	q	r	s	t	u	v	w	x	y	z	{	|	}	~	DEL
8x	€		‚	ƒ	„	…	†	‡	ˆ	‰	Š	‹	Œ		Ž	
9x		‘	’	“	”	•	–	—	˜	™	š	›	œ		ž	Ÿ
Ax	NBSP	¡	¢	£	¤	¥	¦	§	¨	©	ª	«	¬		®	¯
Bx	°	±	²	³	´	µ	¶	·	¸	¹	º	»	¼	½	¾	¿
Cx	À	Á	Â	Ã	Ä	Å	Æ	Ç	È	É	Ê	Ë	Ì	Í	Î	Ï
Dx	Ð	Ñ	Ò	Ó	Ô	Õ	Ö	×	Ø	Ù	Ú	Û	Ü	Ý	Þ	ß
Ex	à	á	â	ã	ä	å	æ	ç	è	é	ê	ë	ì	í	î	ï
Fx	ð	ñ	ò	ó	ô	õ	ö	÷	ø	ù	ú	û	ü	ý	þ	ÿ

92 = apostrophe

HTML 5 Standard

Name	Labels
The Encoding	
UTF-8	"unicode-1-1-utf-8"
	"utf-8"
	"utf8"
windows-1252	"ansi_x3.4-1968"
	"ascii"
	"cp1252"
	"cp819"
	"csisolatin1"
	"ibm819"
	"iso-8859-1"
	~~"iso-ir-100"~~
	"iso8859-1"
	"iso88591"
	"iso_8859-1"

Early Unicode and UTF-16

- Unicode started as 2^{16} code points
  - The BMP of modern Unicode
  - Bottom 256 code points match ISO-8859-1
- Simple 1:1 encoding (UTF-16)
  - Code point <--> 16-bit code unit (ie 2 bytes)
  - Simple, but doubles storage needed for ASCII
- Later, code points outside of BMP added
  - A pair of words (aka "surrogate pairs") carry 20-bit payload split, 10 bits in each word
  - First: **1101 10**xx xxxx xxxx (xD800-DBFF)
  - Second: **1101 11**yy yyyy yyyy (xDC00-DFFF)
- Consequence: U+D800 to U+DFFF became reserved code points in Unicode
  - And now we are stuck with this legacy, even for UTF-8

Demo

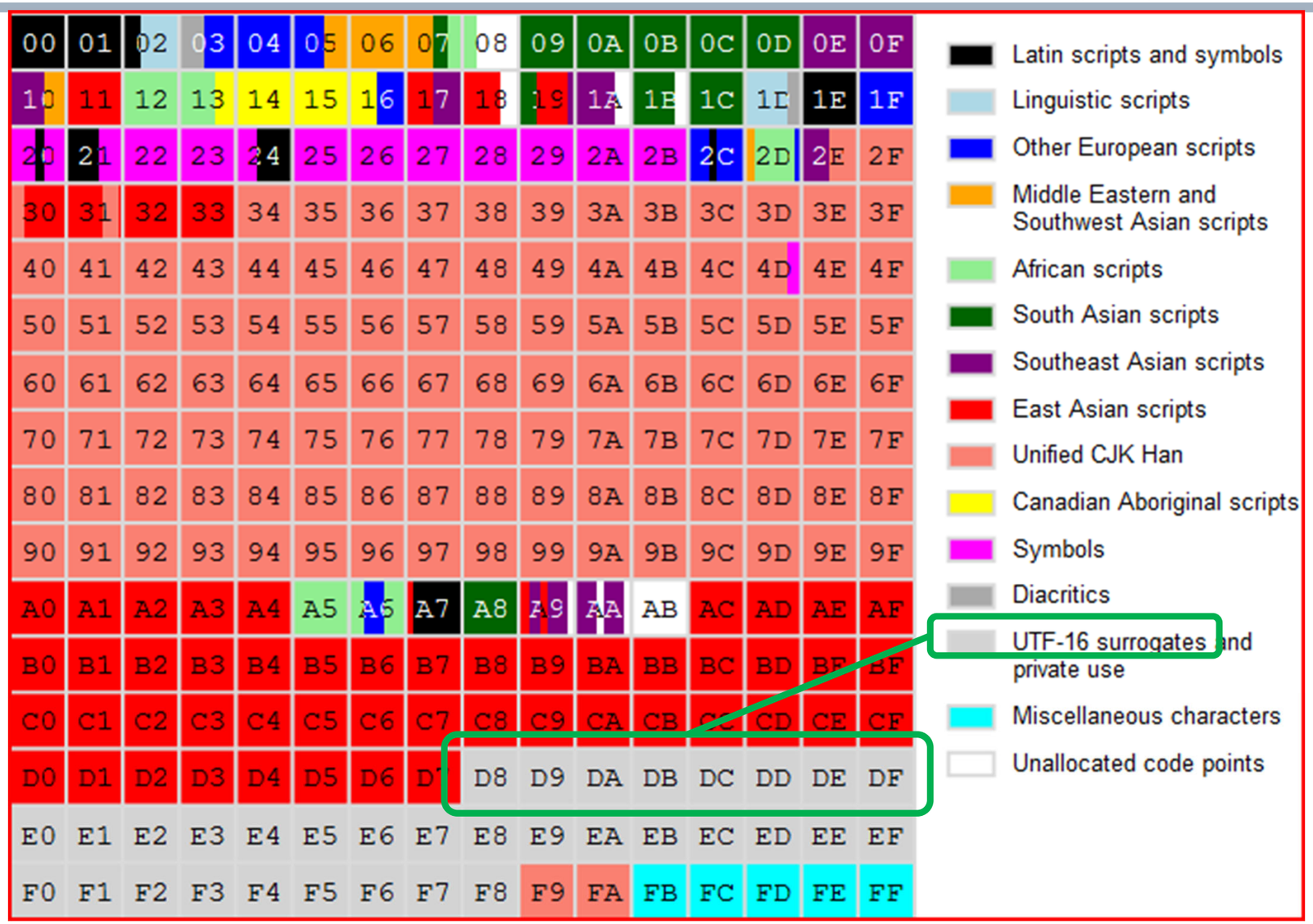
- JavaScript uses UTF-16

```
let x = "\u{1f916}hi" // robot face + hi
x.length        //=> 4 (number of code units)
x.charAt(0)     //=> char from 1st code unit
x.charAt(2)     // surprise?
[...x][2]       // spread = linear time
{...x}          // spreads code units
```

- Ruby supports multiple encodings

```
x = "\u{1f916}"
x.length
x.bytes.map { |b| b.to_s(2) }
x.encoding
x.encode! Encoding::UTF_16
x.bytes.map { |b| b.to_s(16) }
```

Recall: Basic Multilingual Plane



UTF-16 and Endianness

- A multi-byte representation must distinguish between big & little endian
  - Example: 00 25 00 25 00 25
  - "%%%" if LE, "— — —" if BE
- One solution: Specify encoding in name
  - UTF-16BE or UTF-16LE
- Another solution: require *byte order mark* (BOM) at the start of the file
  - U+FEFF (ZERO WIDTH NO BREAK SPACE)
  - There is *no* U+FFFE code point
  - So FE FF ➔ BigE, while FF FE ➔ LittleE
  - Not considered part of the text

BOM and UTF-8

- Should we add a BOM to the start of UTF-8 files too?
  - UTF-8 encoding of U+FEFF is EF BB BF
- Advantages:
  - Forms magic-number for UTF-8 encoding
- Disadvantages:
  - Not backwards-compatible to ASCII
  - Existing programs may no longer work
  - *E.g.*, In Unix, shebang (#!, *i.e.* 23 21) at *start* of file is significant: file is a script

    `#! /bin/bash`

ZWJ: Zero Width Joiner

- Using U+FEFF as ZWNBSP deprecated
  - Reserved for BOM uses (at start of file)
- Alternative: U+200D (“zwidge”)
- Joined characters may be rendered as a single glyph
  - Co-opted for use with emojis
- Example: 1 character?
  - U+1F3F4 U+200D U+2620

```
let x = "\u{1F3F4}\u{200D}\u{2620}"
```

  - WAVING BLACK FLAG, ZWJ, SKULL AND CROSSBONES



To Ponder: Simple Text

- What is a "text" file? (vs "binary" file)
  - Given a file, how can you tell which it is?
- A JavaScript program reads in a 5MB file of ASCII text, storing it in the string **`f`**
  - How many characters are in **`f`**?
  - How much memory does **`f`** occupy?
- How many characters are in string **`s`**?

```
let s = ... // a JavaScript string
console.assert(s.length == 7) // true
```

- Which is better: UTF-8 or UTF-16?
- What's so scary about:

```
..%c0%af..
```

Summary

- Text vs binary
  - In pre-historic times: most significant bit
  - Now: data is data
- Unicode code points
  - Integers U+0000..U+10FFFF
  - BMP: Basic Multilingual Plane
- UTF-8
  - A variable-length, self-synchronizing encoding of unicode code points
  - Backwards compatible with ISO 8859-1, and hence with ASCII too