

# Unicode and UTF-8

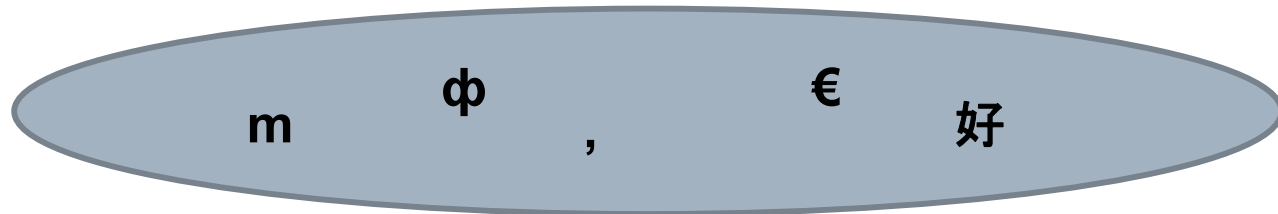
Computer Science and Engineering ■ College of Engineering ■ The Ohio State University

## Lecture 33

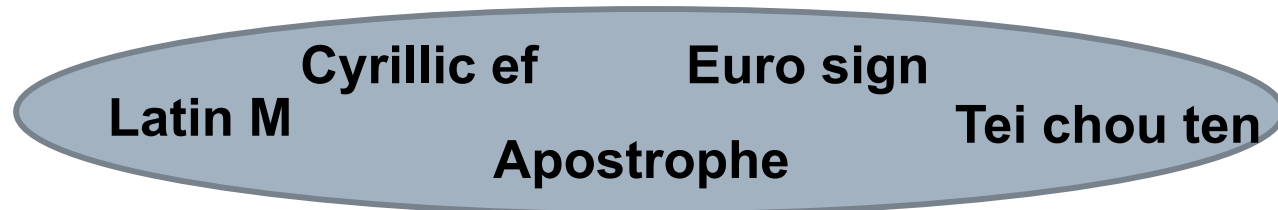
*A standard for the discrete  
representation of written text*

# The Big Picture

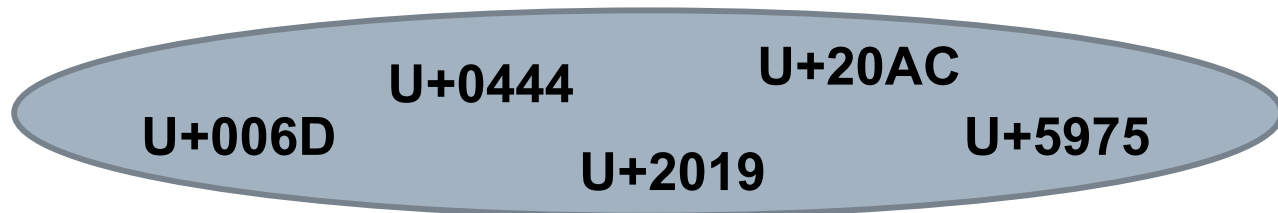
glyphs



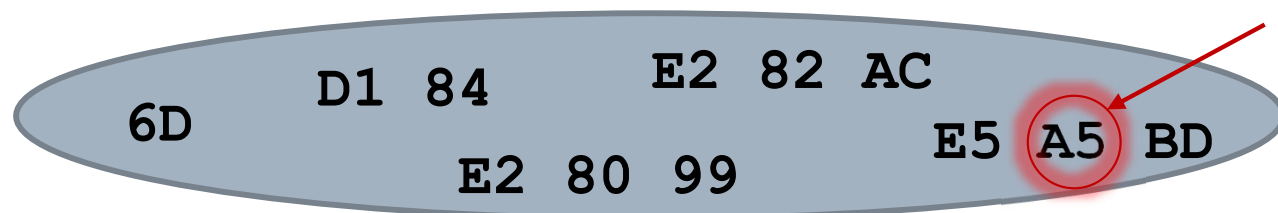
characters



code  
points



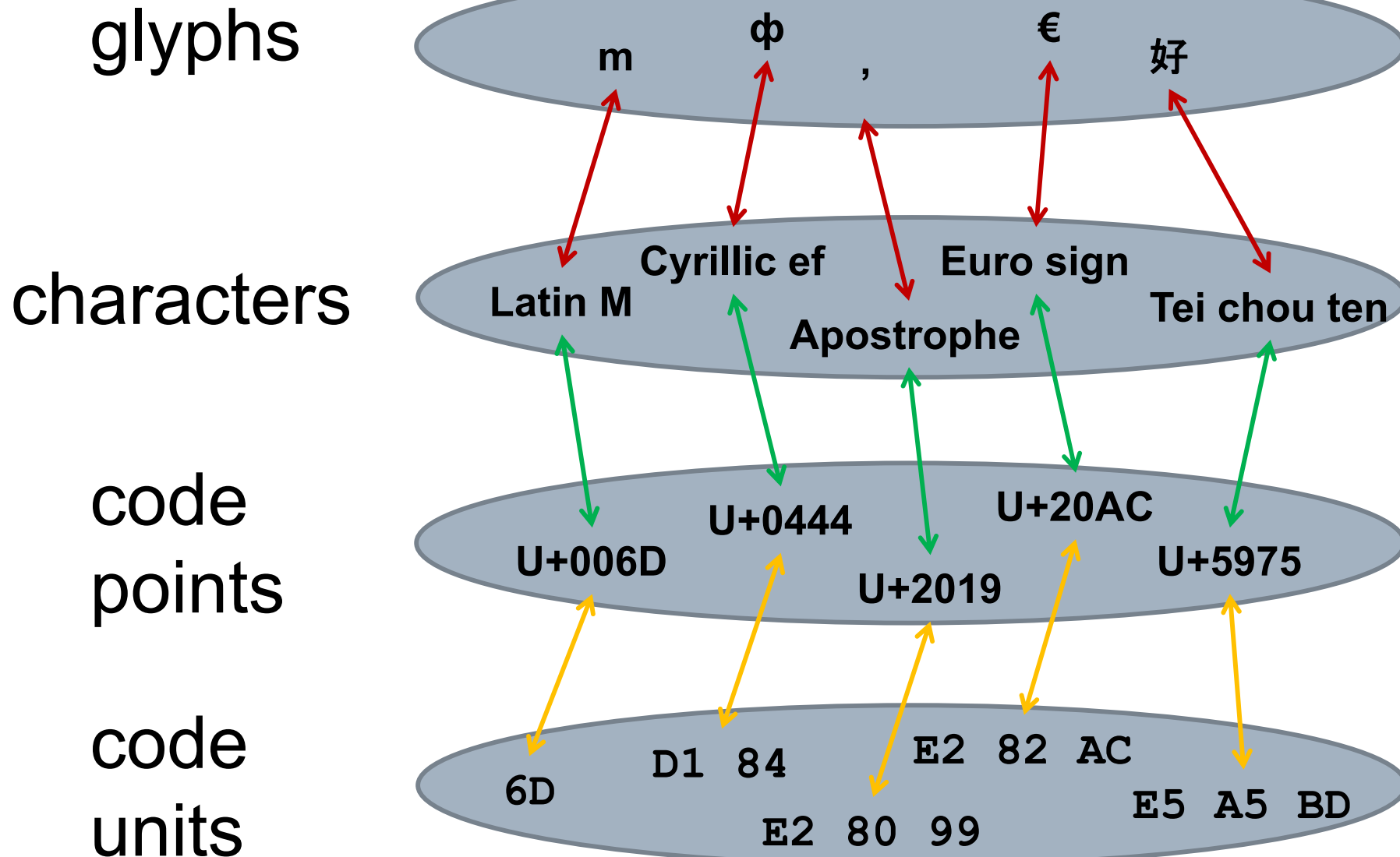
code  
units

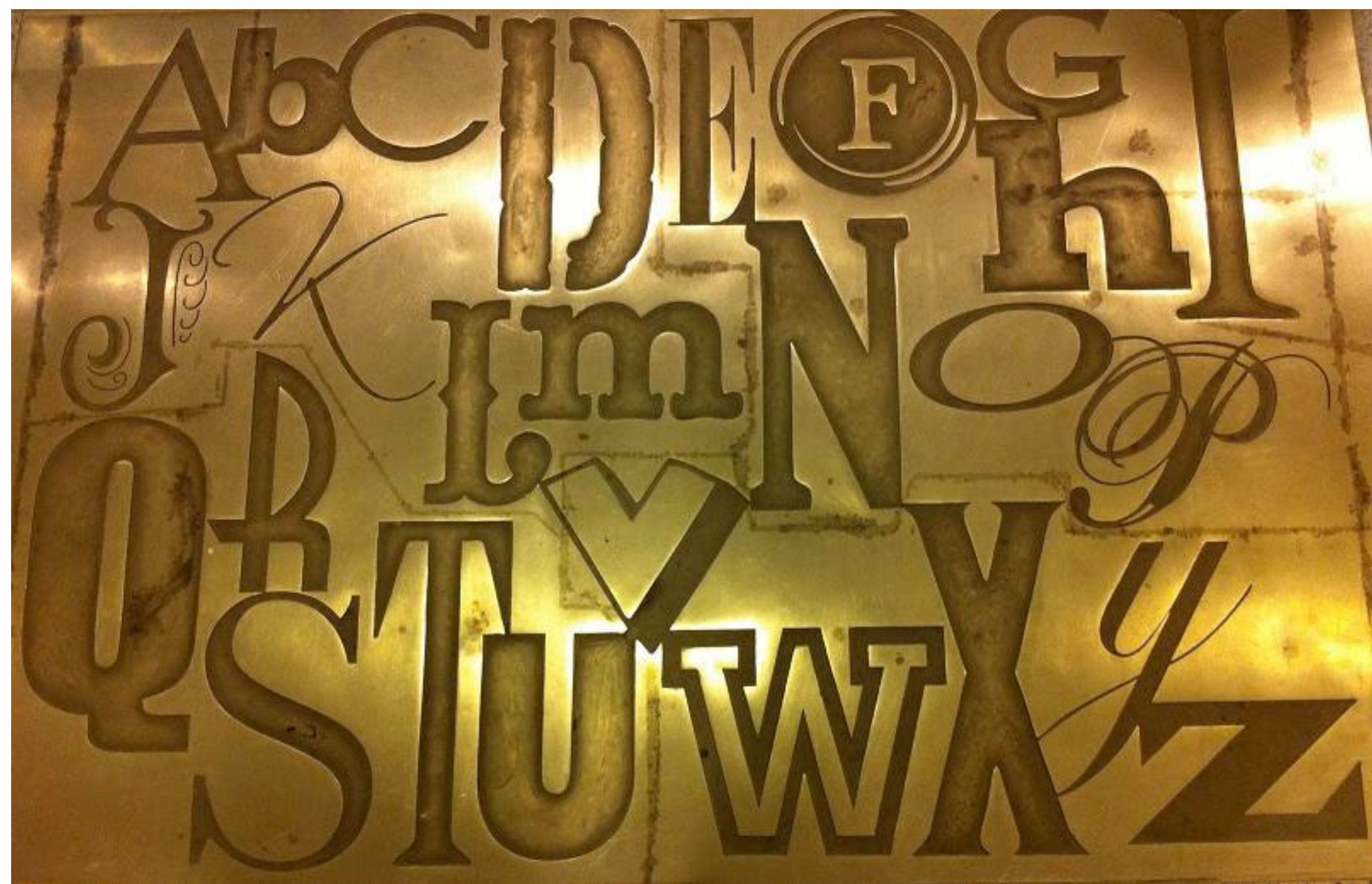


code unit



# The Big Picture





Ласкаво просимо!

Добро пожаловать

مرحبا بكم Willkommen 歡迎

Benvenuti ようこそ

환영합니다 Bienvenue

ຍິນດີຕ້ອນຮັບ

WELKOM Soo dhawow

BIENVENIDOS



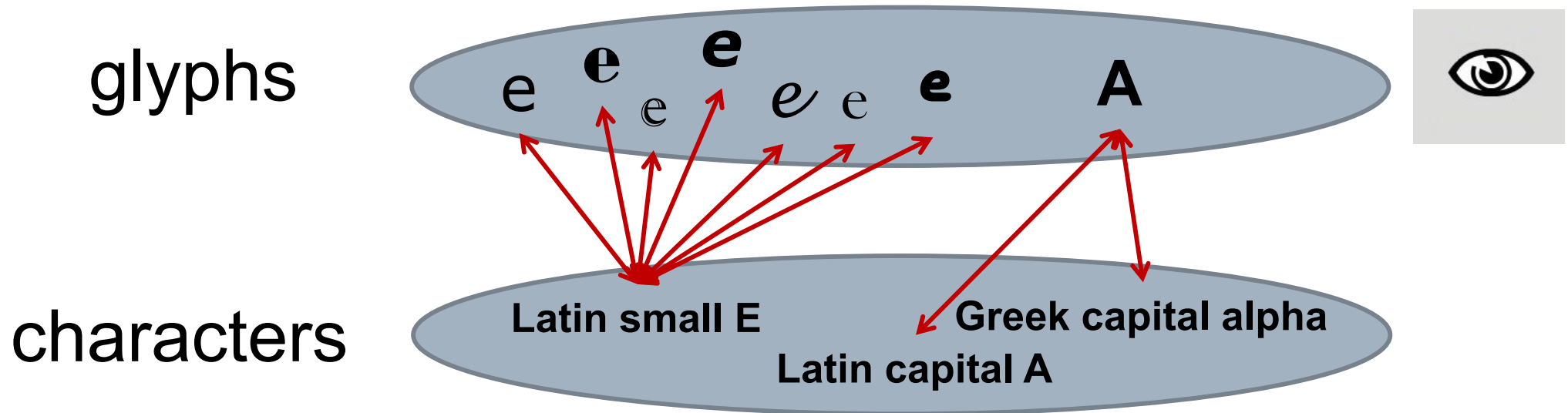
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# Text: A Sequence of Glyphs

- 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 many *glyphs*
  - Example: Latin E can be e, **e**, e, **e**, e, **e**, e...
- One *glyph* can be different *characters*
  - 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

# Glyphs vs Characters



# Security Issue

- Visual homograph: Two different characters that look the same
  - Would you click here: [www.paypal.com](http://www.paypal.com) ?

















# Security Issue

- Visual homograph: Two different characters that look the same
  - Would you click here: [www.paypal.com](http://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 Code Points

- Each character is assigned a unique *code point*
- A code point is defined by an integer value, and is also 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 '23, v15.1 (see [unicode.org](https://unicode.org)):
  - Contains 149,813 code points  
[emoji-versions.html](https://unicode.org/emoji-versions.html)
  - Covers 161 scripts (and counting...)  
[unicode.org/charts/](https://unicode.org/charts/)

# Example Recent Addition (v11)

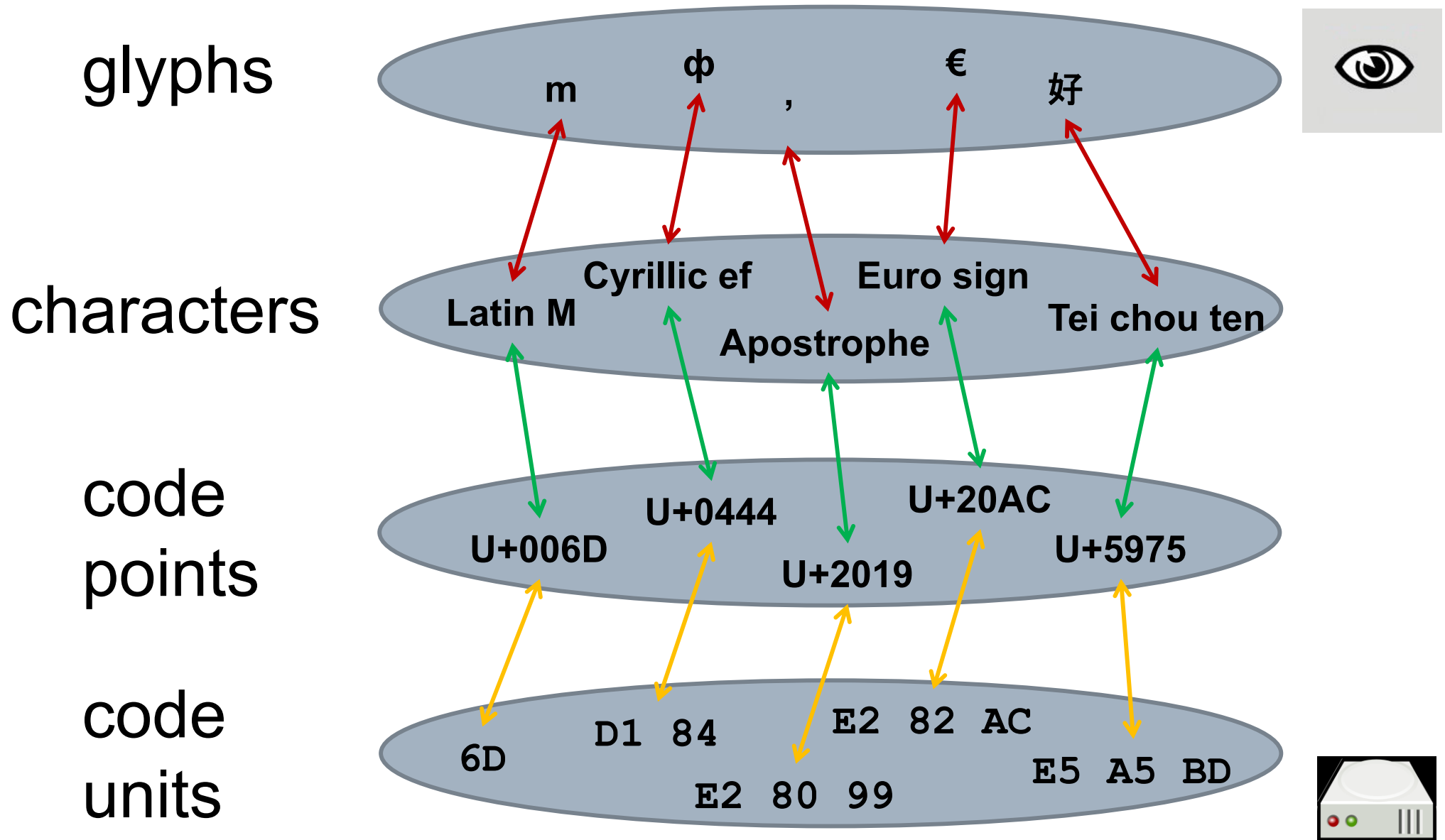
0	1	2	3	4
	•	••	•••	••••
5	6	7	8	9
				
10	11	12	13	14
				
15	16	17	18	19
				

## Mayan numerals

1D2E0		MAYAN NUMERAL ZERO
1D2E1	•	MAYAN NUMERAL ONE
1D2E2	••	MAYAN NUMERAL TWO
1D2E3	•••	MAYAN NUMERAL THREE
1D2E4	••••	MAYAN NUMERAL FOUR
1D2E5		MAYAN NUMERAL FIVE
1D2E6		MAYAN NUMERAL SIX
1D2E7		MAYAN NUMERAL SEVEN
1D2E8		MAYAN NUMERAL EIGHT
1D2E9		MAYAN NUMERAL NINE
1D2EA		MAYAN NUMERAL TEN
1D2EB		MAYAN NUMERAL ELEVEN
1D2EC		MAYAN NUMERAL TWELVE
1D2ED		MAYAN NUMERAL THIRTEEN
1D2EE		MAYAN NUMERAL FOURTEEN
1D2EF		MAYAN NUMERAL FIFTEEN
1D2F0		MAYAN NUMERAL SIXTEEN
1D2F1		MAYAN NUMERAL SEVENTEEN
1D2F2		MAYAN NUMERAL EIGHTEEN
1D2F3		MAYAN NUMERAL NINETEEN

# Unicode: Mapping to Code Points

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# Organization

- Code points are grouped into categories
  - Basic Latin, Cyrillic, Arabic, Cherokee, Currency, Mathematical Operators, ...
- Standard allows for 17 x 2<sup>16</sup> code points
  - 0 to 1,114,111 (*i.e.*, > 1 million)
  - U+0000 to U+10FFFF
- Each group of 2<sup>16</sup> called a *plane*
  - U+nnnnn, same green ==> same plane
- Plane 0 called *basic multilingual plane* (BMP)
  - Has (practically) everything you could need
  - Convention: code points in BMP written U+nnnn (ie with leading 0's if needed)
  - Others code points written without leading 0's

# Basic Multilingual Plane

00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F	<div><div>Latin scripts and symbols</div><div>Linguistic scripts</div><div>Other European scripts</div><div>Middle Eastern and Southwest Asian scripts</div><div>African scripts</div><div>South Asian scripts</div><div>Southeast Asian scripts</div><div>East Asian scripts</div><div>Unified CJK Han</div><div>Canadian Aboriginal scripts</div><div>Symbols</div><div>Diacritics</div><div>UTF-16 surrogates and private use</div><div>Miscellaneous characters</div><div>Unallocated code points</div></div>
10	11	12	13	14	15	16	17	18	19	1A	1B	1C	1D	1E	1F	
20	21	22	23	24	25	26	27	28	29	2A	2B	2C	2D	2E	2F	
30	31	32	33	34	35	36	37	38	39	3A	3B	3C	3D	3E	3F	
40	41	42	43	44	45	46	47	48	49	4A	4B	4C	4D	4E	4F	
50	51	52	53	54	55	56	57	58	59	5A	5B	5C	5D	5E	5F	
60	61	62	63	64	65	66	67	68	69	6A	6B	6C	6D	6E	6F	
70	71	72	73	74	75	76	77	78	79	7A	7B	7C	7D	7E	7F	
80	81	82	83	84	85	86	87	88	89	8A	8B	8C	8D	8E	8F	
90	91	92	93	94	95	96	97	98	99	9A	9B	9C	9D	9E	9F	
A0	A1	A2	A3	A4	A5	A6	A7	A8	A9	AA	AB	AC	AD	AE	AF	
B0	B1	B2	B3	B4	B5	B6	B7	B8	B9	BA	BB	BC	BD	BE	BF	
C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	CA	CB	CC	CD	CE	CF	
D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	DA	DB	DC	DD	DE	DF	
E0	E1	E2	E3	E4	E5	E6	E7	E8	E9	EA	EB	EC	ED	EE	EF	
F0	F1	F2	F3	F4	F5	F6	F7	F8	F9	FA	FB	FC	FD	FE	FF	

# Supplemental Plane (plane 1)

100	101	102	103	104	105	106	107	108	109	10A	10B	10C	10D	10E	10F
110	111	112	113	114	115	116	117	118	119	11A	11B	11C	11D	11E	11F
120	121	122	123	124	125	126	127	128	129	12A	12B	12C	12D	12E	12F
130	131	132	133	134	135	136	137	138	139	13A	13B	13C	13D	13E	13F
140	141	142	143	144	145	146	147	148	149	14A	14B	14C	14D	14E	14F
150	151	152	153	154	155	156	157	158	159	15A	15B	15C	15D	15E	15F
160	161	162	163	164	165	166	167	168	169	16A	16B	16C	16D	16E	16F
170	171	172	173	174	175	176	177	178	179	17A	17B	17C	17D	17E	17F
180	181	182	183	184	185	186	187	188	189	18A	18B	18C	18D	18E	18F
190	191	192	193	194	195	196	197	198	199	19A	19B	19C	19D	19E	19F
1A0	1A1	1A2	1A3	1A4	1A5	1A6	1A7	1A8	1A9	1AA	1AB	1AC	1AD	1AE	1AF
1B0	1B1	1B2	1B3	1B4	1B5	1B6	1B7	1B8	1B9	1BA	1BB	1BC	1BD	1BE	1BF
1C0	1C1	1C2	1C3	1C4	1C5	1C6	1C7	1C8	1C9	1CA	1CB	1CC	1CD	1CE	1CF
1D0	1D1	1D2	1D3	1D4	1D5	1D6	1D7	1D8	1D9	1DA	1DB	1DC	1DD	1DE	1DF
1E0	1E1	1E2	1E3	1E4	1E5	1E6	1E7	1E8	1E9	1EA	1EB	1EC	1ED	1EE	1EF
1F0	1F1	1F2	1F3	1F4	1F5	1F6	1F7	1F8	1F9	1FA	1FB	1FC	1FD	1FE	1FF

Non-Latin European scripts

Cuneiform

American scripts

African scripts

Latin script

Middle Eastern and Southwest Asian scripts

Hieroglyphs

South and Central Asian scripts

Southeast Asian scripts

Symbols

Indonesian and Oceanic scripts

East Asian scripts

Notational systems

Unallocated code points

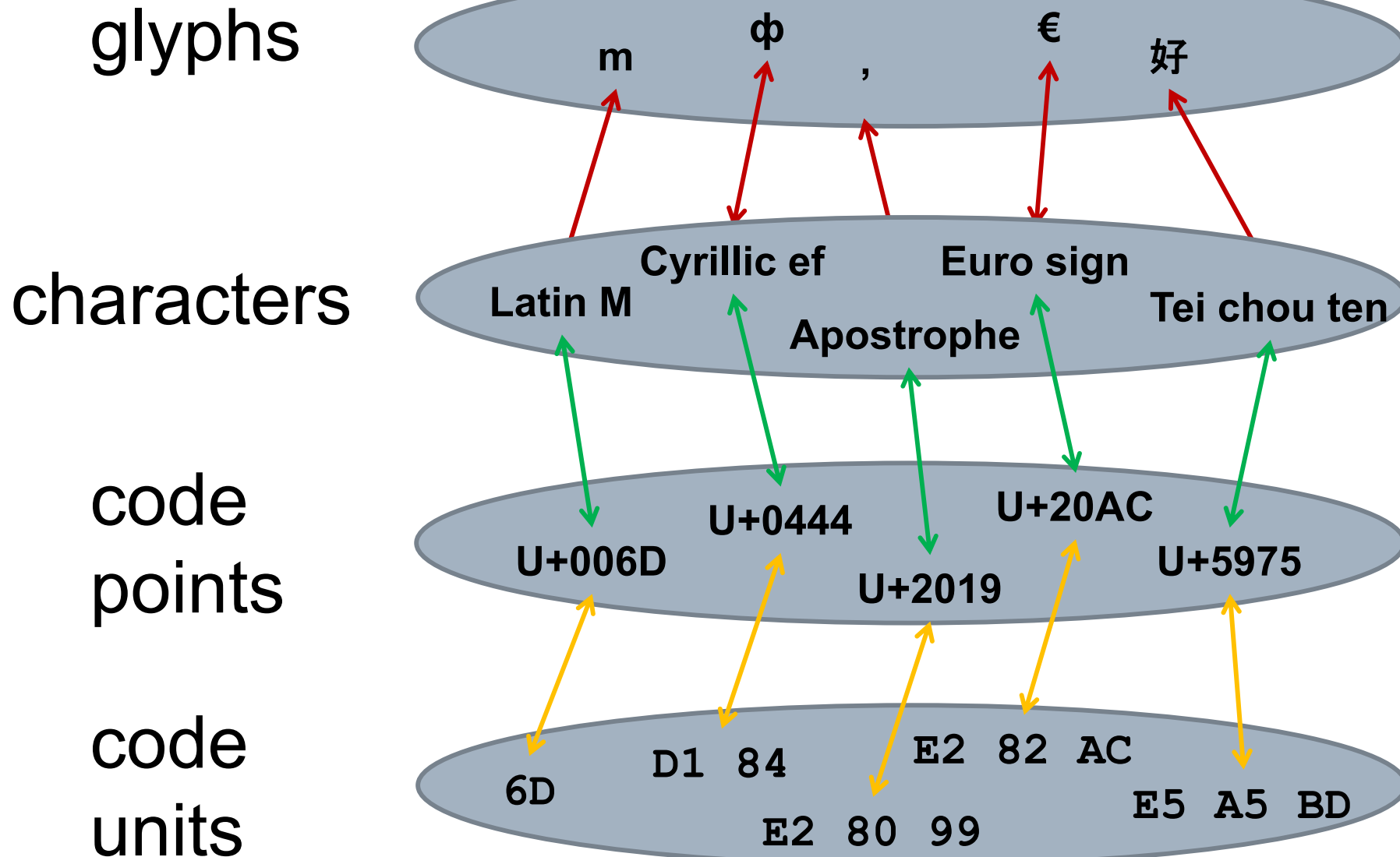
As of Unicode 14.0

# UTF-8

- ❑ Encoding of code point (integer) in a sequence of bytes (octets)
  - Standard: all caps, with hyphen (UTF-8)
- ❑ 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: just a *sequence* of octets

D0 BF D1 80 D0 B8 D0 B2 D0 B5 D1 82...
- ❑ Other encodings exist!
  - Eg UTF-16 use 16 bits (more general term: *code unit*)

# UTF-8: Code Points & Octets



# UTF-8 Encoding Recipe

- 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

- Generalization: An encoding of length  $k$ :
  - First byte starts with  $k$  **1**'s, then **0**
    - Example **1110** 0110 ==> first byte of a 3-byte encoding
  - Subsequent  $k-1$  bytes each start with **10**
  - Remaining bits are payload
- Example: E2 82 AC
  - 1110**0010 **10**0000010 **10**101100
  - Payload: 0x20AC (*i.e.*, U+20AC, €)
- Consequence: Stream is *self-synchronizing*
  - A dropped byte affects only that character

# UTF-8 Encoding Summary

Unicode	Byte1	Byte2	Byte3	Byte4	example
U+0000-U+007F	0xxxxxxx				'\$' U+0024 → 00 <u>100</u> 100 → 0x24
U+0080-U+07FF	110yyyxx	10xxxxxx			'¢' U+00A2 → 110000 <u>10</u> , 10 <u>1000</u> 10 → 0xC2, 0xA2
U+0800-U+FFFF	1110yyyy	10yyyyxx	10xxxxxx		'€' U+20AC → 111000 <u>10</u> , 100000 <u>10</u> , 10 <u>1011</u> 00 → 0xE2, 0x82, 0xAC
U+10000-U+10FFFF	11110zzz	10zzyyyy	10yyyyxx	10xxxxxx	'𐀀' U+10000 → 11110000, 10100 <u>100</u> , 101011 <u>01</u> , 10 <u>1000</u> 10 → 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

- Not all octet sequences are legal encodings
  - “overlong” encodings are illegal
  - example: C0 AF
    - = 1100 0000 1010 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*

# Recall: URL encoding

- Concrete invariant (convention)
  - No space, ;, :, & in representation
  - To represent these characters, use %hh instead (hh is ASCII code in hex)
    - %20 for space
  - Q: What about % in abstract value?
- Recall: *correspondence relation*

# Other (Older) Encodings

- 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
  - Use more than 1 encoding!
    - Must specify data + encoding used

# 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

# ISO-8859 family (eg -1 Latin)

	-0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-A	-B	-C	-D	-E	-F	
0-			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-		!	"	#	\$	%	&	'	(	)	*	+	,	-	.	/	
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	{		}	~		
8-																	
9-																	
A-		ı	ç	£	¤	¥	¦	§	¨	©	ª	«	¬	®	¯		
B-	°	±	²	³	´	µ	¶	·	¸	¹	º	»	¼	½	¾	¿	
C-	À	Á	Â	Ã	Ä	Å	Æ	Ç	È	É	Ê	Ë	Ì	Í	Î	Ï	
D-	Ð	Ñ	Ò	Ó	Ô	Õ	Ö	×	Ø	Ù	Ú	Û	Ü	Ý	Þ	ß	
E-	à	á	â	ã	ä	å	æ	ç	è	é	ê	ë	ì	í	î	ï	
F-	ð	ñ	ò	ó	ô	õ	ö	÷	ø	ù	ú	û	ü	ý	þ	ÿ	

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	<u>NUL</u>	<u>SOH</u>	<u>STX</u>	<u>ETX</u>	<u>EOT</u>	<u>ENQ</u>	<u>ACK</u>	<u>BEL</u>	<u>BS</u>	<u>HT</u>	<u>LF</u>	<u>VT</u>	<u>FF</u>	<u>CR</u>	<u>SO</u>	<u>SI</u>
1x	<u>DLE</u>	<u>DC1</u>	<u>DC2</u>	<u>DC3</u>	<u>DC4</u>	<u>NAK</u>	<u>SYN</u>	<u>ETB</u>	<u>CAN</u>	<u>EM</u>	<u>SUB</u>	<u>ESC</u>	<u>FS</u>	<u>GS</u>	<u>RS</u>	<u>US</u>
2x	<u>SP</u>	!	"	#	\$	%	&	'	(	)	*	+	,	-	.	/
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	{		}	~	<u>DEL</u>
8x	€		,	f	„	„	†	^	%	Š	‹	œ		Ž		
9x		‘	’	”	•	–	—	~	™	š	›	œ		ž	ÿ	
Ax	<u>NBSP</u>	ı	¢	£	¤	¥	¦	§	¨	©	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

<u>Name</u>	<u>Labels</u>
<u>The Encoding</u>	
<u>UTF-8</u>	"unicode-1-1-utf-8"
	"utf-8"
	"utf8"
<u>windows-1252</u>	"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  $\leftrightarrow$  16-bit code unit
  - Simple, but leads to bloat of ASCII text
- Later added code points *outside* of BMP
  - A pair of words (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 and UTF-16

```
let x = "\u{1f916}"      // robot face
x.codePointAt(0).toString(16)
x.length                 // number of code units
x.charCodeAt(0).toString(16);
x.charAt(0);             // char from 1 code unit
```

## □ Ruby and string 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) }
```

# Basic Multilingual Plane

00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F	
10	11	12	13	14	15	16	17	18	19	1A	1B	1C	1D	1E	1F	
20	21	22	23	24	25	26	27	28	29	2A	2B	2C	2D	2E	2F	
30	31	32	33	34	35	36	37	38	39	3A	3B	3C	3D	3E	3F	
40	41	42	43	44	45	46	47	48	49	4A	4B	4C	4D	4E	4F	
50	51	52	53	54	55	56	57	58	59	5A	5B	5C	5D	5E	5F	
60	61	62	63	64	65	66	67	68	69	6A	6B	6C	6D	6E	6F	
70	71	72	73	74	75	76	77	78	79	7A	7B	7C	7D	7E	7F	
80	81	82	83	84	85	86	87	88	89	8A	8B	8C	8D	8E	8F	
90	91	92	93	94	95	96	97	98	99	9A	9B	9C	9D	9E	9F	
A0	A1	A2	A3	A4	A5	A6	A7	A8	A9	AA	AB	AC	AD	AE	AF	
B0	B1	B2	B3	B4	B5	B6	B7	B8	B9	BA	BB	BC	BD	BE	BF	
C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	CA	CB	CC	CD	CE	CF	
D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	DA	DB	DC	DD	DE	DF	
E0	E1	E2	E3	E4	E5	E6	E7	E8	E9	EA	EB	EC	ED	EE	EF	
F0	F1	F2	F3	F4	F5	F6	F7	F8	F9	FA	FB	FC	FD	FE	FF	

Latin scripts and symbols

Linguistic scripts

Other European scripts

Middle Eastern and Southwest Asian scripts

African scripts

South Asian scripts

Southeast Asian scripts

East Asian scripts

Unified CJK Han

Canadian Aboriginal scripts

Symbols

Diacritics

UTF-16 surrogates and private use

Miscellaneous characters

Unallocated code points

# 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” in ~~Twitter~~ X)
  - U+1F3F4 U+200D U+2620
  - WAVING BLACK FLAG, ZWJ, SKULL AND CROSSBONES



# To Ponder

- What is a “text” file? (vs “binary”)
  - Given a file, how can you tell which it is?
- A JavaScript program reads in a 5MB file of English prose into a string. How much memory does the string need?
- How many characters does `s` contain?

```
let s = . . . // JavaScript
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