COS 217: Introduction to Programming Systems

Program Design Decisions
&
C Language Design (Logical Data)

PRINCETON UNIVERSITY

Agenda

Simple C Programs

- charcount
  - character I/O
- upper (ctype library)
  - portability concerns
  - char details
- upper1 (switch statements, enums, functions)
  - internal documentation (i.e., comments)

Two big differences from Java

- Variable declarations
- Logical operators

Recall: The charcount Program

The program:

charcount.c

```
#include <stdio.h>
/* Write to stdout the number of
   chars in stdin. Return 0. */
int main(void) {
   int c;
   int charCount = 0;
   c = getchar();
   while (c != EOF) {
      charCount++;
      c = getchar();
   }
   printf("%d\n", charCount);
   return 0;
}
```

stdio.h Features (types, constants, variables)

```
$ man stdio.h
NAME
       stdio.h -- standard buffered input/output

SYNOPSIS
       #include <stdio.h>

DESCRIPTION
The <stdio.h> header shall define the following data types through typedef:
       FILE          A structure containing information about a file.
       size_t        As described in <stddef.h>.

The  <stdio.h>  header  shall  define the following macro which shall expand to an
integer constant expression with type int and a negative value:
       EOF           End-of-file return value.

The <stdio.h> header shall define the following macros which shall expand to
expressions of type ``pointer to FILE'' that point to the FILE objects associated,
respectively, with the standard error, input, and output streams:
       stderr        Standard error output stream.
       stdin         Standard input stream.
       stdout        Standard output stream.
```

stdio.h Features (functions)

```
$ man stdio.h
...
The following shall be declared as functions and may also be defined as macros.
Function prototypes shall be provided.
           int      fclose(FILE *);
           int      feof(FILE *);
           int      fflush(FILE *);
           int      fgetc(FILE *);
           FILE    *fopen(const char *restrict, const char *restrict);
           int      fprintf(FILE *restrict, const char *restrict, ...);
           int      fscanf(FILE *restrict, const char *restrict, ...);
           int      getc(FILE *);
           int      getchar(void);
           int      printf(const char *restrict, ...);
           int      putc(int, FILE *);
           int      putchar(int);
           int      scanf(const char *restrict, ...);
```

Character Input/Output (I/O) in C

Design of C:

- Does not provide I/O facilities in the language
- Instead provides I/O facilities in standard library, declared in stdio.h
  - Constant: EOF
  - Data type: FILE (described later in course)
  - Variables: stdin, stdout, and stderr
  - Functions: …

Reading characters

- getchar() function with return type wider than char (specifically, int)
- Returns EOF (a special non-character int) to indicate failure
- Reminder: there is no such thing as "the EOF character”

Writing characters

- putchar() function accepting one parameter
- For symmetry with getchar(), parameter is an int

iClicker Question

Q: There are other ways to **charcount** – which is best?

A.

```
for (c = getchar(); c != EOF; c = getchar())
   charCount++;
```

B.

```
while ((c = getchar()) != EOF)
   charCount++;
```

C.

```
for (;;)
{  c = getchar();
   if (c == EOF)
      break;
   charCount++;
}
```

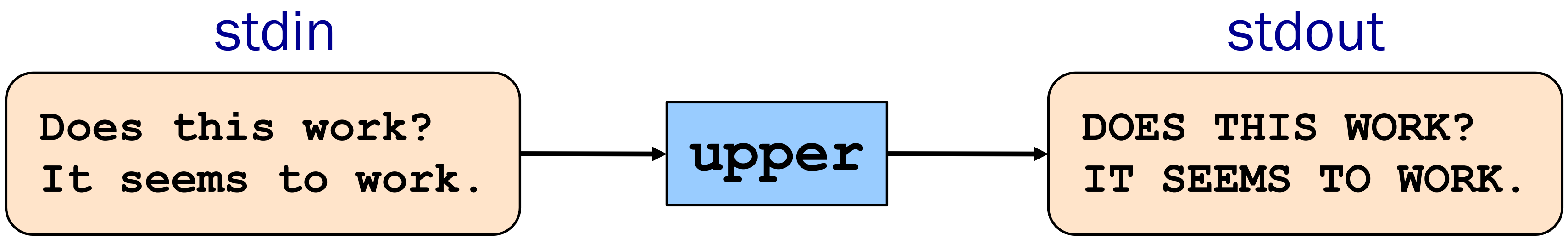
D.

```
c = getchar();
while (c != EOF)
{  charCount++;
   c = getchar();
}
```

Recall: The `upper` Program

Functionality

- Read all chars from stdin
- Convert each lower-case alphabetic char to upper case
  - Leave other kinds of chars alone
- Write result to stdout



stdin

```
Does this work?
It seems to work.
```

stdout

```
DOES THIS WORK?
IT SEEMS TO WORK.
```

What we need: character representation, I/O

The C char Data Type

char is 1 byte – designed to hold a single character, but used for more

Mapping from char values to characters on pretty much all machines:

ASCII (American Standard Code for Information Interchange) (/'æski/)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	NUL									HT	LF					
16																
32	SP	!	"	#	$	%	&	'	(	)	*	+	,	-	.	/
48	0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
64	@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
80	P	Q	R	S	T	U	V	W	X	Y	Z	[	\	]	^	_
96	`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
112	p	q	r	s	t	u	v	w	x	y	z	{	|	}	~	

Notes: Many non-printing characters left blank in table above

Lower-case and upper-case letters are 32 apart

upper Version 1

```
#include <stdio.h>
int main(void)
{
   int c;
   while ((c = getchar()) != EOF) {
      if ((c >= 97) && (c <= 122))
         c -= 32;
      putchar(c);
   }
   return 0;
}
```

What’s wrong?

EBCDIC

Extended Binary Coded Decimal Interchange Code (/'ɛbsɪdɪk/)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	NUL					HT										
16																
32						LF										
48																
64	SP											.	<	(	+	|
80	&										!	$	*	)	;	
96	-	/									¦	,	%	_	>	?
112										`	:	#	@	'	=	"
128		a	b	c	d	e	f	g	h	i		{				
144		j	k	l	m	n	o	p	q	r		}				
160		~	s	t	u	v	w	x	y	z						
176																
192		A	B	C	D	E	F	G	H	I						
208		J	K	L	M	N	O	P	Q	R						
224	\		S	T	U	V	W	X	Y	Z						
240	0	1	2	3	4	5	6	7	8	9						

Partial map

Character Literals

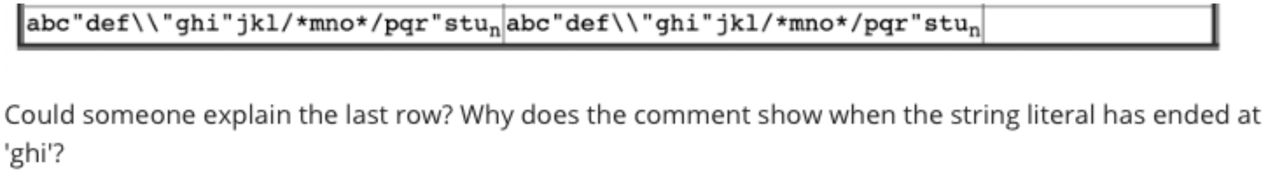
Single quote syntax: 'a' is a value of type char with the value 97

Use backslash to write special characters

- Examples (with numeric equivalents in ASCII, EBCDIC):

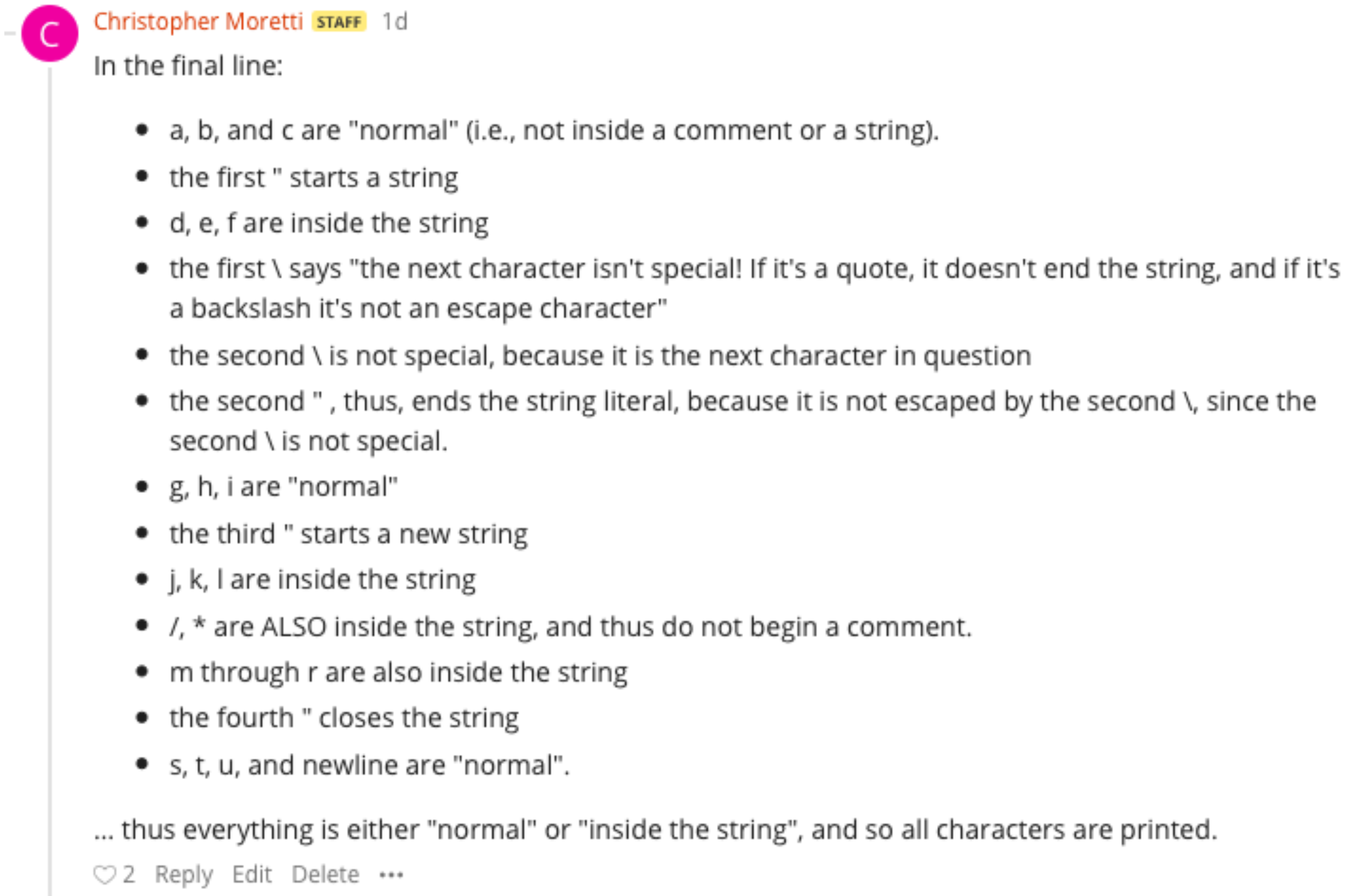
```
'a'    the a character (97, 129)
'A'    the A character (65, 193)
'0'    the zero character (48, 240)
'\0'   the NUL (nullbyte) character (0, 0)
'\n'   the newline character (10, 37)
'\t'   the horizontal tab character (9, 5)
'\\'   the backslash character (92, 224)
'\''   the single quote character (39, 125)
'"'    the double quote character (34, 127)
```

An A1 FAQ:



abc"def\\"ghi"jkl/*mno*/pqr"stu$_n$	abc"def\\"ghi"jkl/*mno*/pqr"stu$_n$	

Could someone explain the last row? Why does the comment show when the string literal has ended at 'ghi'?



Christopher Moretti STAFF 1d

In the final line:

- a, b, and c are "normal" (i.e., not inside a comment or a string).
- the first " starts a string
- d, e, f are inside the string
- the first \ says "the next character isn't special! If it's a quote, it doesn't end the string, and if it's a backslash it's not an escape character"
- the second \ is not special, because it is the next character in question
- the second " , thus, ends the string literal, because it is not escaped by the second \, since the second \ is not special.
- g, h, i are "normal"
- the third " starts a new string
- j, k, l are inside the string
- /, * are ALSO inside the string, and thus do not begin a comment.
- m through r are also inside the string
- the fourth " closes the string
- s, t, u, and newline are "normal".

... thus everything is either "normal" or "inside the string", and so all characters are printed.

upper Version 2

```
#include <stdio.h>
int main(void)
{
   int c;
   while ((c = getchar()) != EOF) {
      if ((c >= 'a') && (c <= 'z'))
         c += 'A' - 'a';
      putchar(c);
   }
   return 0;
}
```

Arithmetic on chars?

What's wrong now?

EBCDIC

Extended Binary Coded Decimal Interchange Code

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	NUL					HT										
16																
32						LF										
48																
64	SP											.	<	(	+	|
80	&										!	$	*	)	;	
96	-	/									|	,	%	_	>	?
112										`	:	#	@	'	=	"
128		a	b	c	d	e	f	g	h	i		{				
144		j	k	l	m	n	o	p	q	r		}				
160		~	s	t	u	v	w	x	y	z						
176																
192		A	B	C	D	E	F	G	H	I						
208		J	K	L	M	N	O	P	Q	R						
224	\		S	T	U	V	W	X	Y	Z						
240	0	1	2	3	4	5	6	7	8	9						

Partial map

Note: Lower case not contiguous; same for upper case

upper Version 3

```
#include <stdio.h>
#include <ctype.h>
int main(void)
{
   int c;
   while ((c = getchar()) != EOF) {
      if (islower(c))
         c = toupper(c);
      putchar(c);
   }
   return 0;
}
```

iClicker Question

Q: Is the **if** statement really necessary?

A. Gee, I don’t know.
Let me check
the man page
(again)!

```
#include <stdio.h>
#include <ctype.h>
int main(void)
{
   int c;
   while ((c = getchar()) != EOF) {
      if (islower(c))
         c = toupper(c);
      putchar(c);
   }
   return 0;
}
```

ctype.h Functions

```
$ man toupper
NAME
      toupper, tolower - convert letter to upper or lower case

SYNOPSIS
      #include <ctype.h>
      int toupper(int c);
      int tolower(int c);

DESCRIPTION
      toupper() converts the letter c to upper case, if possible.
      tolower() converts the letter c to lower case, if possible.

      If c is not an unsigned char value, or EOF, the behavior of
      these functions is undefined.

RETURN VALUE
      The value returned is that of the converted letter,
      or c if the conversion was not possible.
```

iClicker Question

Q: Is the **if** statement really necessary?

A. Yes, necessary
for correctness.

B. Not necessary,
but I’d leave it in.

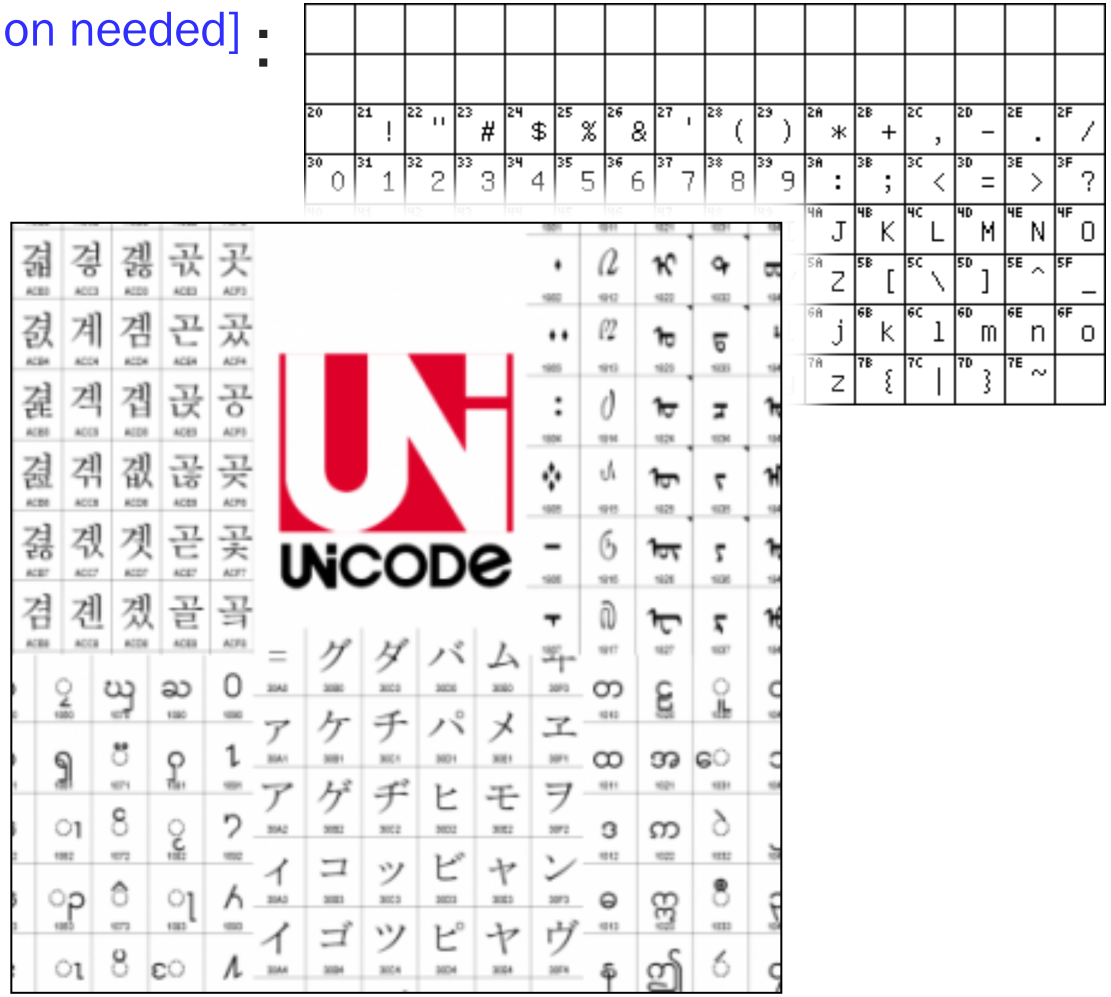
C. Not necessary,
and I’d get rid of it.

```
#include <stdio.h>
#include <ctype.h>
int main(void)
{
   int c;
   while ((c = getchar()) != EOF) {
      if (islower(c))
         c = toupper(c);
      putchar(c);
   }
   return 0;
}
```

Aside: Unicode

Back in 1970s, English was the only language in the world[citation needed]

so we all used this alphabet [citation needed] :



ASCII:

American Standard Code
for Information Interchange

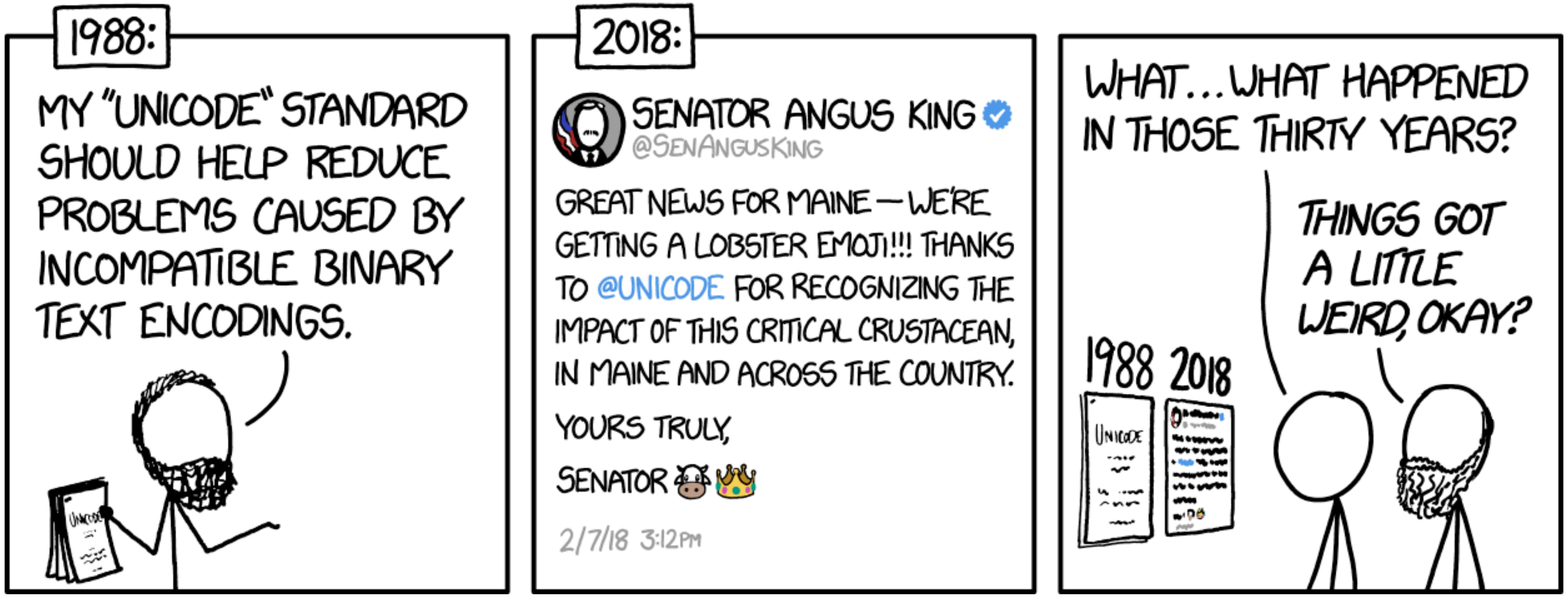
In the 21st century, it turns out there are other languages!

Modern Unicode

When C was designed, characters fit into 8 (really 7) bits, so C's chars are 8 bits long.

When Java was designed, Unicode fit into 16 bits, so Java's chars are 16 bits long.

Then this happened:


1988:
MY "UNICODE" STANDARD SHOULD HELP REDUCE PROBLEMS CAUSED BY INCOMPATIBLE BINARY TEXT ENCODINGS.
UNICODE
2018:
SENATOR ANGUS KING
@SENANGUSKING
GREAT NEWS FOR MAINE—WE'RE GETTING A LOBSTER EMOJI!!! THANKS TO @UNICODE FOR RECOGNIZING THE IMPACT OF THIS CRITICAL CRUSTACEAN, IN MAINE AND ACROSS THE COUNTRY.
YOURS TRULY,
SENATOR 🐮👑
2/7/18 3:12PM
WHAT...WHAT HAPPENED IN THOSE THIRTY YEARS?
THINGS GOT A LITTLE WEIRD, OKAY?
1988 2018
UNICODE

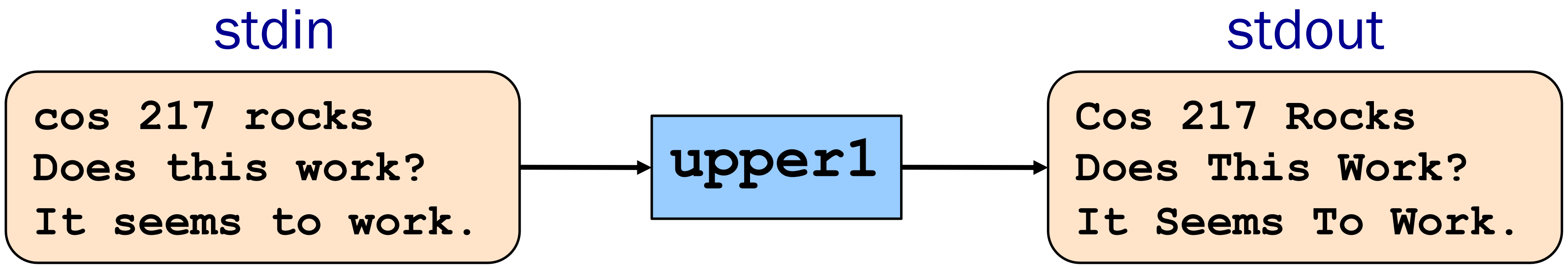
https://xkcd.com/1953/

Result: modern systems use *variable length* (UTF-8/16/32) encoding for Unicode.

Recall: The `upper1` Program

Functionality

- Read all chars from stdin
- Capitalize the first letter of each word
  - “cos 217 rocks” ⇒ “Cos 217 Rocks”
- Write result to stdout



stdin

```
cos 217 rocks
Does this work?
It seems to work.
```

stdout

```
Cos 217 Rocks
Does This Work?
It Seems To Work.
```

What we need: maintain extra information, namely “in a word” vs “*not* in a word”

- Need systematic way of reasoning about what to do with that information

upper1 Version 3

```
#include <stdio.h>
#include <ctype.h>
enum Statetype {NORMAL, INWORD};

enum Statetype handleNormalState(int c)
{
   enum Statetype state;
   if (isalpha(c)) {
      putchar(toupper(c));
      state = INWORD;
   } else {
      putchar(c);
      state = NORMAL;
   }
   return state;
}

enum Statetype handleInwordState(int c)
{
   enum Statetype state;
   if (!isalpha(c)) {
      putchar(c);
      state = NORMAL;
   } else {
      putchar(c);
      state = INWORD;
   }
   return state;
}
```

```
int main(void)
{
   int c;
   enum Statetype state = NORMAL;
   while ((c = getchar()) != EOF) {
      switch (state) {
         case NORMAL:
            state = handleNormalState(c);
            break;
         case INWORD:
            state = handleInwordState(c);
            break;
      }
   }
   return 0;
}
```

That's an A-, at best.
No comments!

upper1 Toward Final Version

Problem:

- The program works, but…
- No comments

Solution:

- Add (at least) function-level comments

Function Comments

Function comment should describe
what the function does (from the caller's viewpoint)

- Data coming into the function
    - Parameters, input streams
- Data going out from the function
    - Return value, output streams, (call-by-reference parameters)

Function comment should **not** describe
how the function works

Function Comment Examples

Bad main() function comment

```
Read a character from stdin using getchar.
Depending upon the current DFA state, pass the
character to an appropriate state-handling
function. The value returned by the state-
handling function is the next DFA state. Repeat
until end-of-file. Return 0.
```

Describes **how the function works**

Good main() function comment

```
Read text from stdin. Convert the first character
of each "word" to uppercase, where a word is a
sequence of non-whitespace. Write the result
to stdout. Return 0.
```

Describes **what the function does**
(from caller’s viewpoint)

upper1 Final Comments

```
/* defines constants representing each state in the DFA */
enum Statetype {NORMAL, INWORD};
```

```
/* Implement the NORMAL state of the DFA. c is the current
   DFA character. Write c or its uppercase equivalent to
   stdout, as specified by the DFA. Return the next state. */

enum Statetype handleNormalState(int c) {
```

```
/* Implement the INWORD state of the DFA. c is the current
   DFA character. Write c to stdout, as specified by the DFA.
   Return the next state. */

enum Statetype handleInwordState(int c) {
```

```
/* Read text from stdin. Convert the first character of each
   "word" to uppercase, where a word is a sequence of
   letters. Write the result to stdout. Return 0. */

int main(void) {
   /* Use a DFA approach.  state indicates the DFA state. */
   enum Statetype state = NORMAL;
```

Agenda

Simple C Programs

- charcount
    - character I/O
- upper (ctype library)
    - portability concerns
    - char details
- upper1 (switch statements, enums, functions)
    - internal documentation (i.e., comments)

Language Design: Two big differences from Java

- Variable declarations
- Logical operators

Declaring Variables

C requires variable declarations.

Motivation:

- Declaring variables allows compiler to check “spelling”
- Declaring variables allows compiler to allocate memory more efficiently
- Declaring variables’ types produces fewer surprises at runtime
- Declaring variables requires more from the programmer
  - Extra verbiage
  - Type foresight
  - “Do what I mean, not what I say”

Declaring Variables

C requires variable declarations.

- Declaration statement specifies type of variable (and other attributes too)

Examples:

```
int i;
int i, j;
int i = 5;
const int i = 5; /* value of i cannot change */
static int i; /* covered later in course */
extern int i; /* covered later in course */
```

Declaring Variables

C requires variable declarations.

- Declaration statement specifies type of variable (and other attributes too)
- Unlike Java, declaration statements in C89 must appear before any other kind of statement in compound statement

```
{
   int i;
   /* Non-declaration
      stmts that use i. */
   …
   int j;
   /* Non-declaration
      stmts that use j. */
   …
}
```

Illegal in C89

```
{
   int i;
   int j;
   /* Non-declaration
      stmts that use i. */
   …
   /* Non-declaration
      stmts that use j. */
   …
}
```

Legal in C89

Agenda

Simple C Programs

- upper (character data and I/O, ctype library)
  - portability concerns
- upper1 (switch statements, enums, functions)
  - DFA program design

Two big differences from Java

- Variable declarations
- Logical operators

Logical Data Types

- No separate logical or Boolean data type
- Represent logical data using type char or int
  - Or any primitive type! 😱
- Conventions:
  - Statements (if, while, etc.) use 0 ⇒ FALSE, ≠0 ⇒ TRUE
  - Relational operators (<, >, etc.) and logical operators (!, &&, ||) produce the result 0 or 1

@lunarts

Logical Data Type Shortcuts

Using integers to represent logical data permits shortcuts

```
…
int i;
…
if (i)  /* same as (i != 0) */
    statement1;
else
    statement2;
…
```

It also permits some really bad code…

```
i = (1 != 2) + (3 > 4);
```

iClicker? More like iBrainteaser!

Q: What is **`int i`** set to in the following code?

```
i = (i < (i < 0)) + (i >= (i > 0)) + ((i-i) < (i == i));
```

A. Depends on the initial value of i

B. 0

C. 1

D. 2

E. 3

D.

If i is negative, this will be 1 + 0 + 1

If i is non-negative, this will be 0 + 1 + 1

Logical Data Type Dangers

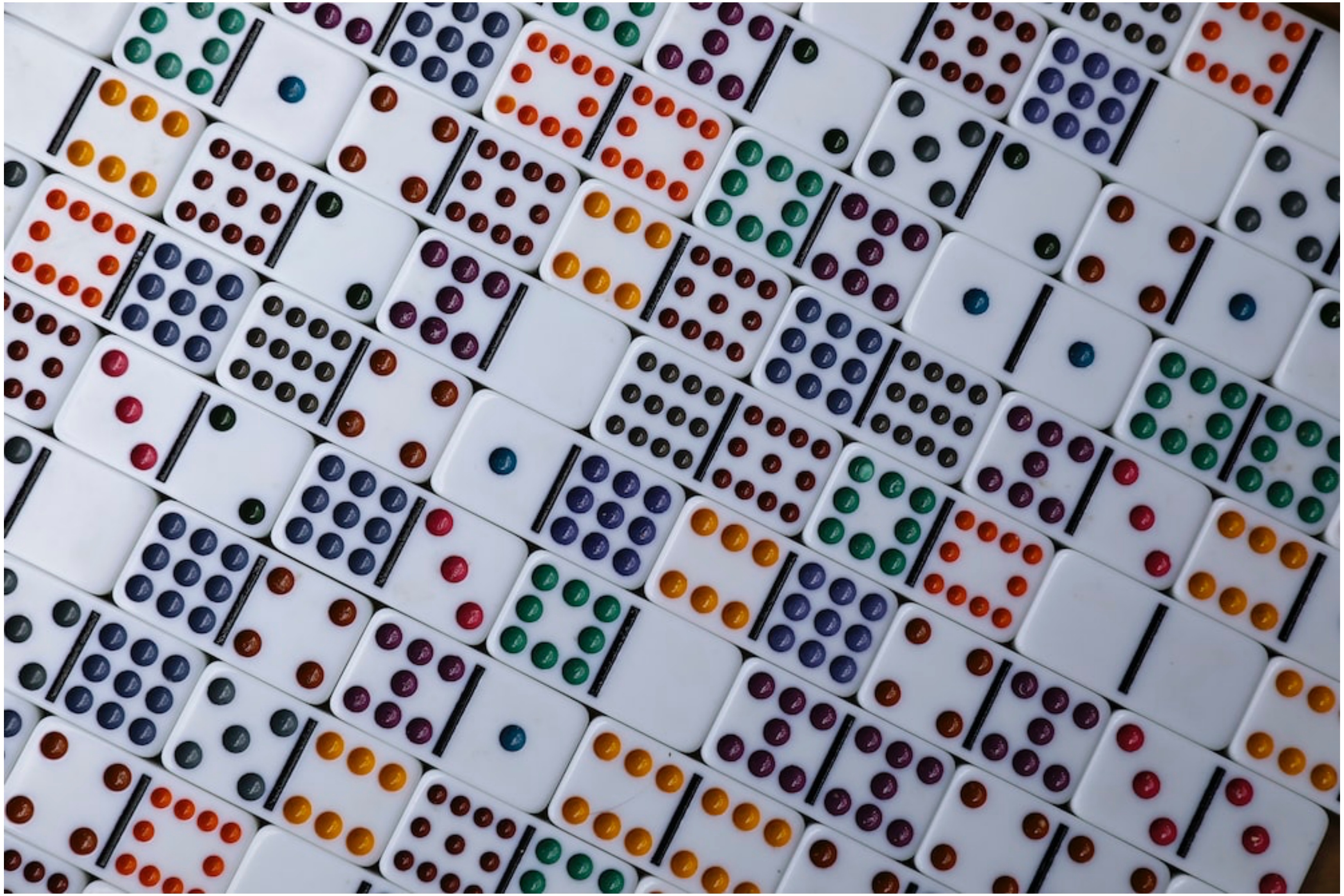
Beware: the following code will cause loss of sleep

```
…
int i;
…
i = 0;
…
if (i = 5)
   statement1;
…
```

What happens in Java?

What happens in C?

Next time … numbers! (Bigger than 127.)



Mick Haupt