Data Types in C

Goals of C

Designers wanted C to:	But also:
Support system programming	Support application programming
Be low-level	Be portable
Be easy for people to handle	Be easy for computers to handle

- Conflicting goals on multiple dimensions!
- Result: different design decisions than Java

Primitive Data Types

- **integer** data types
- **floating-point** data types
- **pointer** data types
- **no character** data type (use small integer types instead)
- **no** character **string** data type (use arrays of small ints instead)
- **no logical or boolean** data types (use integers instead)

For "under the hood" details,
look back at the
"number systems" lecture
from last week

Integer Data Types

Integer types of various sizes: **`signed char`**, **`short`**, **`int`**, **`long`**

- **`char`** is 1 byte
  - Number of bits per byte is unspecified!
    (but in the 21st century, pretty safe to assume it's 8)
- Sizes of other integer types not fully specified but *constrained:*
  - **`int`** was intended to be "natural word size"
  - 2 ≤ sizeof(**`short`**) ≤ sizeof(**`int`**) ≤ sizeof(**`long`**)

On ArmLab:

- Natural word size: 8 bytes ("64-bit machine")
- **`char`**: 1 byte
- **`short`**: 2 bytes
- **`int`**: 4 bytes (compatibility with widespread 32-bit code)
- **`long`**: 8 bytes

What decisions did the designers of Java make?

Integer Literals

- Decimal: 123
- Octal: 0173 = 123
- Hexadecimal: 0x7B = 123
- Use "L" suffix to indicate **`long`** literal
- No suffix to indicate **`short`** literal; instead must use cast

Examples

- **`int:      123, 0173, 0x7B`**
- **`long:     123L, 0173L, 0x7BL`**
- **`short:    (short)123, (short)0173, (short)0x7B`**

Unsigned Integer Data Types

unsigned types: **`unsigned char`**, **`unsigned short`**, **`unsigned int`**, and **`unsigned long`**

- Holds only non-negative integers
- Conversion rules for mixed-type expressions
  (Generally, mixing signed and unsigned converts to unsigned)
- See King book Section 7.4 for details

Unsigned Integer Literals

Default is signed

- Use "U" suffix to indicate unsigned literal

Examples

- **`unsigned int`**:
  - **`123U`**, **`0173U`**, **`0x7BU`**
  - **`123, 0173, 0x7B`** will work just fine in practice; technically there is an implicit cast from signed to unsigned, but in these cases it shouldn't make a difference.
- **`unsigned long`**:
  - **`123UL`**, **`0173UL`**, **`0x7BUL`**
- **`unsigned short`**:
  - **`(unsigned short)123`**, **`(unsigned short)0173`**, **`(unsigned short)0x7B`**

“Character” Data Type

The C `char` type

- `char` is designed to hold an ASCII character
  - And should be used when you’re dealing with characters: character-manipulation functions we’ve seen (such as `toupper`) take and return `char`
- `char` might be signed (-128..127) or unsigned (0..255)
  - But since 0 ≤ ASCII ≤ 127 it doesn’t really matter
- If you want a 1-byte type for *calculation,* you might (should?) specify `signed char` or `unsigned char`

Character Literals

Single quote syntax: `'a'`

Use backslash (the **escape character**) to express special characters

- Examples (with numeric equivalents in ASCII):

`'a'`	the a character (97, 01100001_B, 61_H)
`'\141'`	the a character, octal form
`'\x61'`	the a character, hexadecimal form
`'b'`	the b character (98, 01100010_B, 62_H)
`'A'`	the A character (65, 01000001_B, 41_H)
`'B'`	the B character (66, 01000010_B, 42_H)
`'\0'`	the null character (0, 00000000_B, 0_H)
`'0'`	the zero character (48, 00110000_B, 30_H)
`'1'`	the one character (49, 00110001_B, 31_H)
`'\n'`	the newline character (10, 00001010_B, A_H)
`'\t'`	the horizontal tab character (9, 00001001_B, 9_H)
`'\\'`	the backslash character (92, 01011100_B, $5C_H$)
`'\''`	the single quote character (96, 01100000_B, 60_H)

Strings and String Literals

Issue: How should C represent strings and string literals?

Rationale:

- Natural to represent a string as a sequence of contiguous chars
- How to know where char sequence ends?
  - Store length together with char sequence?
  - Store special “sentinel” char after char sequence?

Strings and String Literals

Decisions

- Adopt a convention
  - String is a sequence of contiguous chars
  - String is terminated with null char (‘\0’)
- Use double-quote syntax (e.g., **`"hello"`**) to represent a string literal
- Provide no other language features for handling strings
  - Delegate string handling to standard library functions

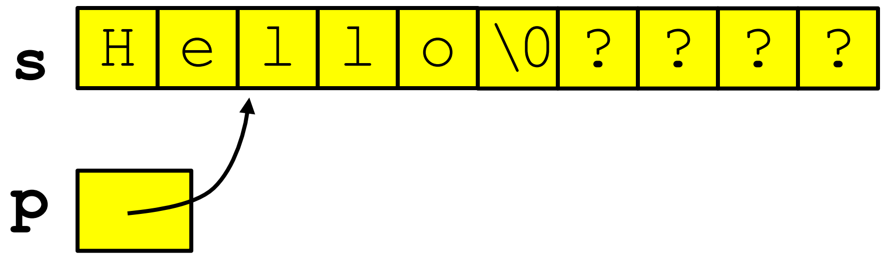
Examples

- **`'a'`** is a **`char`** literal
- **`"abcd"`** is a string literal
- **`"a"`** is a string literal

How many bytes?

What decisions did the designers of Java make?

Arrays of characters




```
char s[10] = {'H','e','l','l','o',0};
```

(or, equivalently)

```
char s[10] = "Hello";
```

p is a **pointer**: it contains the *address* of another variable

```
char *p = s+2;
```

```
printf("Je%s!", p);
```

prints **Jello!**

Unicode

Back in 1970s, English was the only language in the world[citation needed], so we all used this alphabet:

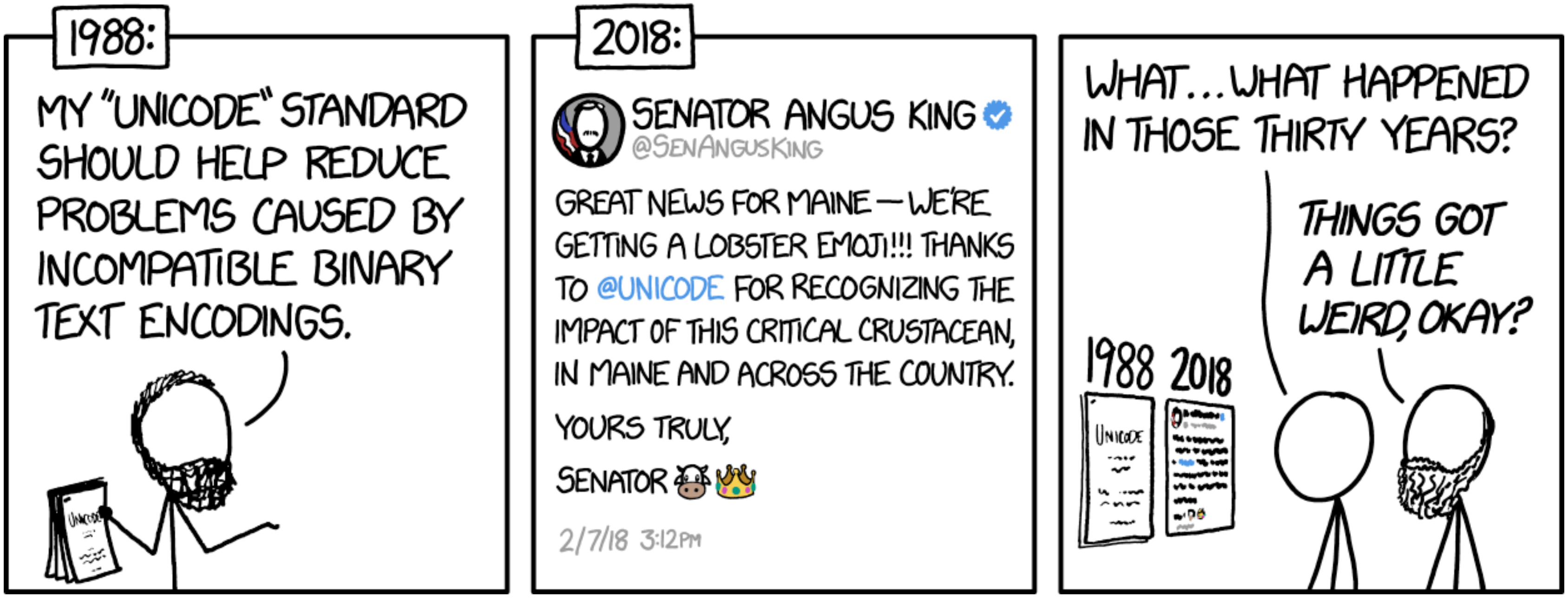
20	21 !	22 "	23 #	24 $	25 %	26 &	27 '	28 (	29)	2A *	2B +	2C ,	2D -	2E .	2F /
30 0	31 1	32 2	33 3	34 4	35 5	36 6	37 7	38 8	39 9	3A :	3B ;	3C <	3D =	3E >	3F ?
40 @	41 A	42 B	43 C	44 D	45 E	46 F	47 G	48 H	49 I	4A J	4B K	4C L	4D M	4E N	4F O
50 P	51 Q	52 R	53 S	54 T	55 U	56 V	57 W	58 X	59 Y	5A Z	5B [	5C \	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 ~	

ASCII: American Standard Code for Information Interchange

In the 21st century, it turns out that there are other people and languages out there, so we need:

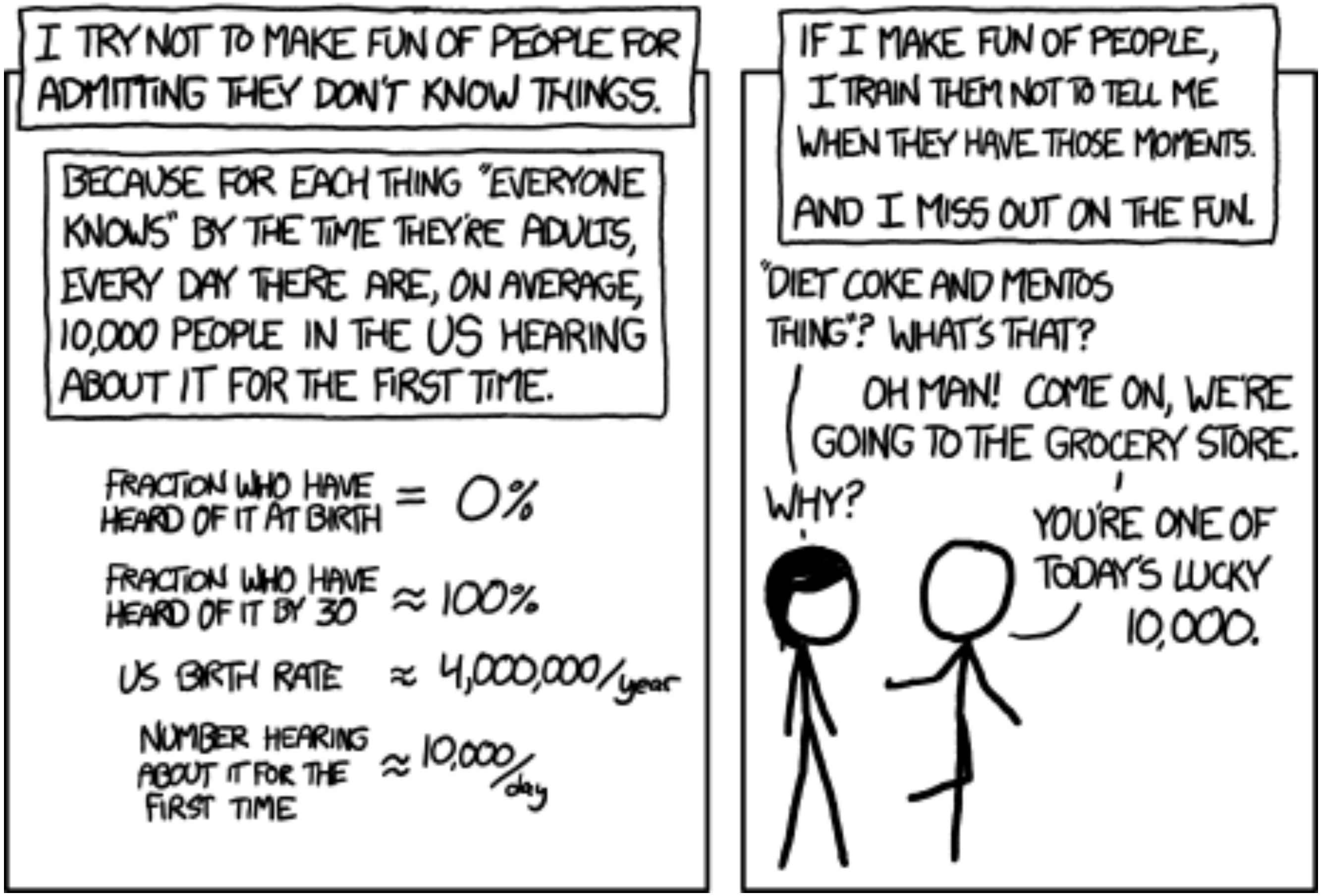
Modern Unicode

When Java was designed, Unicode fit into 16 bits, so **`char`** in Java was 16 bits long. Then this happened:



https://xkcd.com/1953/

Cultural Aside (comic -= 900)



https://xkcd.com/1053/

Unicode and UTF-8

Lots of characters in today's Unicode

- 100,000+ defined, capacity for > 1 million

Can't modify size of **`char`** in C

Solution: variable-length encoding (UTF-8)

- Standard ASCII characters use 1 byte
- Most Latin-based alphabets use 2 bytes
- Chinese, Japanese, Korean characters use 3 bytes
- Historic scripts, mathematical symbols, and emoji use 4 bytes
- This won't be on the exam!

Logical Data Types

No separate logical or Boolean data type

Represent logical data using type **`char`** or **`int`**

- Or any integer type
- Or any primitive type!

Conventions:

- Statements (**`if`**, **`while`**, etc.) use $0 \Rightarrow$ FALSE, $\neq 0 \Rightarrow$ TRUE
- Relational operators (**`<`**, **`>`**, etc.) and logical operators (**`!`**, **`&&`**, **`||`**) produce the result 0 or 1

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 Question

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

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

A. 0

B. 1

C. 2

D. 3

E. 4

Logical Data Type Dangers

The lack of a logical data type hampers compiler's ability to detect some errors

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

What happens in Java?

What happens in C?

Floating-Point Data Types

C specifies:

- Three floating-point data types:
  `float`, **`double`**, and **`long double`**
- Sizes unspecified, but constrained:
  sizeof(**`float`**) ≤ sizeof(**`double`**) ≤ sizeof(**`long double`**)

On ArmLab (and on pretty much any 21st-century computer using the IEEE standard)

- **`float`**: 4 bytes
- **`double`**: 8 bytes

On ArmLab (but varying a lot across architecures)

- **`long double`**: 16 bytes

Floating-Point Literals

How to write a floating-point number?

- Either fixed-point or “scientific” notation
- Any literal that contains decimal point or "**`E`**" is floating-point
- The default floating-point type is **`double`**
- Append "**`F`**" to indicate **`float`**
- Append "**`L`**" to indicate **`long double`**

Examples

- **`double`**: **`123.456`**, **`1E-2`**, **`-1.23456E4`**
- **`float`**: **`123.456F`**, **`1E-2F`**, **`-1.23456E4F`**
- **`long double`**: **`123.456L`**, **`1E-2L`**, **`-1.23456E4L`**

Data Types Summary: C vs. Java

Java only

- **`boolean`**, **`byte`**

C only

- **`unsigned char`**, **`unsigned short`**, **`unsigned int`**, **`unsigned long`**, **`long double`**

Sizes

- **Java**: Sizes of all types are specified, and *portable*
- **C**: Sizes of all types except **`char`** are system-dependent

Type char

- **Java**: **`char`** is 2 bytes (to hold all 1995-era Unicode values)
- **C**: **`char`** is 1 byte (to hold all ASCII in non-negative **`signed char`**)