Princeton University

Computer Science 217: Introduction to Programming Systems

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
- **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)

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 CourseLab

- 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`**

- Conversion rules for mixed-type expressions
  (Generally, mixing signed and unsigned converts 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`** can 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 or unsigned, 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

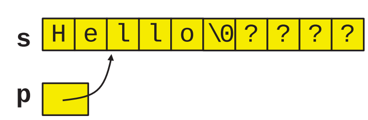
Examples

- **`'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";

char *p = s+2;

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

prints **`Jello!`**

Unicode

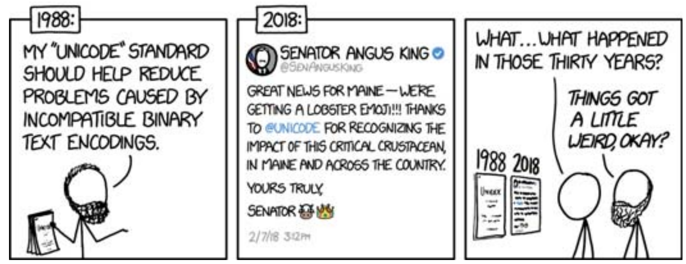
Back in 1970s, English was the only language in the world[citation needed], so we only needed this alphabet:

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/

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 ⇒ FALSE, ≠0 ⇒ 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 with certainty

```
…
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 CourseLab (and on pretty much any 21st-century computer using the IEEE standard)

- **`float`**: 4 bytes
- **`double`**: 8 bytes
- **`long double`**: 16 bytes (but only 10 bytes used on x86-64)

Floating-Point Literals

- 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`**

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